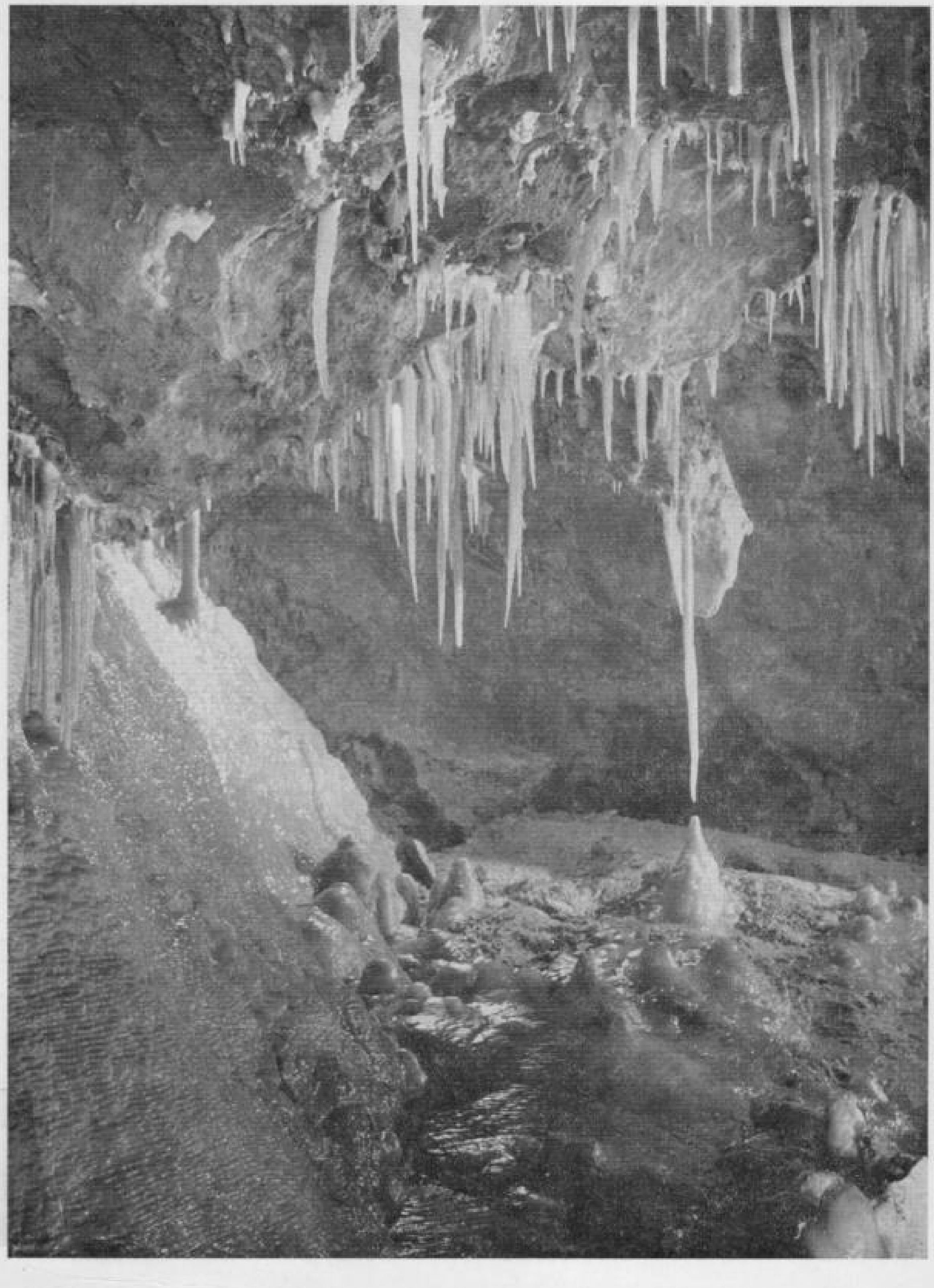
September 1977

Proceedings of the 7th International Speleological Congress, Sheffield England 7th International Speleological Congress proceedings, Sheffield, England Seventh International Speleological Congress proceedings, Sheffield, England

International Speological Congress. Organizing Committee

PROCEEDINGS OF THE
7th INTERNATIONAL SPELEOLOGICAL CONGRESS
SHEFFIELD, ENGLAND
SEPTEMBER, 1977



PROCEEDINGS OF THE 7th INTERNATIONAL SPELEOLOGICAL CONGRESS SHEFFIELD 1977

Cover picture Treak Cliff Cavern, Castleton, Derbyshire, England
By T.D. Ford

Further copies may be obtained from the British Cave Research Association Sales Officer, Bryan Ellis, 30 Main Road, Westonzoyland, Bridgwater, Somerset, TA7 0EB, England.

THE BRITISH CAVE RESEARCH ASSOCIATION

The primary objectives of the Association are to encourage and assist cave research and caving technology in the widest possible sense, and to publish the results. Open meetings are held in various parts of Britain for the presentation of lectures, seminars, discussions and symposia.

The publications of BCRA are a Bulletin and a Transactions both issued free to paid-up members.

The BCRA BULLETIN is a lively publication for up to date news items of interest to speleologists around the World. It contains news of meetings, conferences etc as well as book reviews, and short scientific and technical notes. Four issues per year.

The BCRA TRANSACTIONS contains papers read at meetings or symposia on all aspects of cave science, from descriptions of caves with surveys, technical articles on equipment,to hydrological, archeological and biological research. Articles may be submitted for publication without being read at a meeting. One of the World's premier speleological scientific publications, it is normally issued four times a year.

Membership is by subscription payable on January 1st each year. Ordinary Members £6 per annum. Corporate members (Institutions, Libraries etc) £7 per annum. Enquiries and applications to the BCRA Secretary, D.M. Judson, Bethel Green, Calderbrook Road, Littleborough, Lancashire OL15 9ND.

Back numbers of the BULLETIN and the TRANSACTIONS can be obtained from the BCRA Sales Officer, Bryan Ellis, 30 Main Road, Westonzoyland, Bridgwater, Somerset, TA7 0EB, England.

The BCRA has also sponsored a number of books on speleological matters in conjunction with commercial publishers:

"Limestones and Caves of Northwest England" by A.C. Waltham, and others
"Limestones and Caves of the Mendip hills" by D.I. Smith, D.P. Drew and others
"Limestones and Caves of the Peak District" by T.D. Ford and others
"The Science of Speleology" edited by T.D. Ford and C.H.D. Cullingford
"Manual of Caving Techniques" edited by C.H.D. Cullingford
"Surveying Caves" by B.M. Ellis and others

These books are available from the BCRA Sales Officer, Bryan Ellis, 30 Main Road, Westonzoyland, Bridgwater, Somerset TA7 0EB, England.

Preface

In welcoming the delegates the Organizing Committee of the Seventh International Speleological Congress are pleased to present the papers submitted for publication. Some 220 papers were submitted and over 80% were accepted, those rejected only being turned down after scrutiny by at least two of the editorial committee.

It is the first time in seven congresses that papers have been published before the actual congress and this ideal has only been attained by a change in policy. Papers were restricted to 1200 words in length and it was intended that there should not be more than one page of illustrations with any paper. For reasons of economy the intention was that the papers should be of a summary nature presenting the results of current research, excluding much local detail and long tables of data. Many contributors do not seem to have understood these simple criteria, clearly set out in the Circulars, and some drastic editing has been necessary. The Committee recommend that this practice of Summary papers only and pre-publication should be followed in future Congresses, as is the practice in many of the congresses of other sciences today.

The Editor wishes to apologize if the standard of editing has not been as high as it should have been, partly because a broken arm prevented his using the editorial pencil at all during a peak period of receipt of papers, and partly because some of the manuscripts required extensive revision to make them intelligible to others. Of the overseas papers submitted, many non-English-speaking authors had taken the trouble to translate their papers, though perhaps more advice could have been sought from colleagues thoroughly familiar with the English language.

Although abstracts in two languages were requested in the Circulars, many papers were submitted without abstracts at all, and a few went to the other extreme of abstracts three or four times the permitted length of 100 words. For reasons of economy and standardization it was decided to include only abstracts in English for those papers published in other languages.

The illustrations submitted were of very variable quality of draughting and materials. Everything from clean black drawings on strong white paper to muddy photocopies and poor quality tracing paper was submitted. Letters requesting improved diagram drawing mostly went unanswered. Inevitably the quality is reflected in the reproductions in this volume.

Assignation to Sections within the Congress structure has largely been arbitrary, as many authors did not indicate a section, and some balance was necessary between the numbers of papers in the different sections. Furthermore some papers could equally have been placed in two or more sections. In view of the difficulties of assignation of papers they are presented herein in alphabetical order of the first author's names, and a classified contents list follows this preface.

The Editor wishes to thank his numerous sub-editors for their willing co-operation, and his proof-readers, Mrs Sue Cunningham, Mrs Betty Ford and Mrs A. Boustead for their care in searching out mistakes. Finally this volume could not have appeared without the co-operation of the printers, Messrs Hawthornes of Nottingham Ltd., particularly Andy Whyatt and Len Richards.

PROCEEDING OF THE 7th INTERNATIONAL SPELEOLOGICAL CONGRESS

SHEFFIELD, ENGLAND

Sept. 1977

CONTENTS

2. KARST MORPHOLOGY

3. SPELEOGENESIS

5. CAVE CHEMISTRY AND PHYSICS

6. SPELEOBIOLOGY

7. ARCHEOLOGY & PALAEONTOLOGY

8. DOCUMENTATION

9. TECHNIQUES AND EQUIPMENT

Published by and obtainable from
The British Cave Research Association

Bryan Ellis,
7 School Lane,
Combwich,
Bridgwater,
Somerset. TA5 2QS.

RESULTS OF THE EXPERIMENTAL STUDIES OF THE CRACK SURFACE SOLUBILITY OF CARBONATE ROCKS OF VARIOUS MICROSTRUCTURES

E.M. Abashidze
ul. Titsidna Tabidze 41,
Tbilisi 30, U.S.S.R.

The prediction of the effects of the increase in fracture width as a result of dissolving the carbonate rocks below the water table in a definite period of time is a matter of great importance in hydrotechnical construction.

Carbonate microstructures include organogenic-debris or detrital, pseudoolite, crypto- and microcrystalline glauconite- sandy, siliceous, dolomitic limestones and limestone dolomites, of cryptocrystalline, porphyroblastic and mosaic structure. Marble and marble-like limestones of crypto- and microcrystalline structure are also met.

In 1963 and 1972 we studied the solubility of the structures in short 5-10 cm high and 3-6 cm wide blocks and a crack 3m long in dolomite limestone with porphyroblastic texture.

A brief description of the test methods in both short and long cracks was given in the Proceedings of the Conference on Karsts held in Perm in 1963 and the VIth International Congress of Speleology at Olomouc.

According to the experiments the amount of carbonate removed depended upon the amount of percolating and velocity of the water in the crack.

Mathematical expressions of the dissolving process in short and long cracks were found by the methods of square mean deviations and mathematical statistics.

Data on the solution in cracks in dolomite limestones of porphyroblastic texture 0.1, 0.2, 0.3, 0.4, 0.5m long (i.e. the data on dissolving those parts of a 3m crack) are given in this paper on the basis of the experiments with a 3m crack.

After comparison of the process in short and long cracks we came to the following conclusion:

In short cracks marble differs by greater velocity of solution.

The rate of solution of the remaining rocks decreased as in Table 1.

The above given data warns us to take them into consideration in hydrotechnical constructions. This fact is important in the prediction of crack widening. During 25 years of continuous water filtration through incipient cracks (with the initial openings 0.01-0.025cm wide and the water velocity 0.02-1cm/sec) under the experimental conditions will increase from 0.4 to 4.0 cm and more.

TABLE 1.

Type of limestone	*Rock Structure*	*Formula for dissolving velocity*
	Solubility in short cracks (6x10 and 3x5 cm)	
1. Marble	Microcrystalline	$m=2x10^{-7}+1.02x10^{-3} x y^{2.39}$
2. Dolomite	Porphyroblastic	$m=2x10^{-7}+1.9x10^{-5} x y^{1.6}$
3. Cryptocrystalline	Cryptocrystalline	$m=2x10^{-7}+1.88x10^{-5} x y^{1.48}$
4. Dolomite	Pseudoolite porphyroblastic	$m=2x10^{-7}+1.5x10^{-5} x y^{1.54}$
5. Dolomite	Cryptocrystalline and porphyroblastic	$m=2x10^{-7}+1.37x10^{-5} x y^{1.35}$
6. Glauconite	Cryptocrystalline	$m=2x10^{-7}+1.05x10^{-5} x y^{1.32}$
7. Organogenic	Organogenic detritus	$m=2x10^{-7}+1.09x10^{-5} x y^{1.29}$
8. Pseudoolite	Pseudoolite	$m=2x10^{-7}+1.01x10^{-5} x y^{1.25}$

Solubility in long cracks

		Crack length cm	
Dolomite	Porphyroblastic		
	– do –	10	$m=2.0x10^{-7}+1.01x10^{-3} x y^{6.5}$
	– do –	20	$m=2.0x10^{-7}+1.01x10^{-3} x y^{5.1}$
	– do –	30	$m=2.0x10^{-7}+1.02x10^{-3} x y^{5.2}$
	– do –	40	$m=2.0x10^{-7}+1.02x10^{-3} x y^{6.8}$
	– do –	50	$m=2.0x10^{-7}+1.02x10^{-3} x y^{5.0}$

m – dissolving velocity
y – water velocity

SACRED CAVES IN STRANDZA MOUNTAIN, S.E. BULGARIA

Georgi Antonov
NEK, Sofia, Bulgaria

Strandža (Istrandža – Vildiz Dağlari) is a low mountain range some 200 km long running parallel to the southwest coast of the Black Sea. The greater and highest part (up to 1031 m) is situated in Turkish territory while its northwest foothills lie in Bulgarian territory. Much of the mountain is covered with a karst evolved in marble and dolomitic limestone. Although it is mentioned at quite an early date (The Vitanovskata cave, Slaveikov, 1891, p. 441) until 1975 this region remained the last "blank spot" of Bulgarian speleology.

The Scientific Expedition's Club (NEK) organised an expedition for a detailed study of the caves and potholes of the region in 1975 and 1976. Over 60 caves and potholes were found and studied, many of them containing interesting archeological finds.

Over 20 caves are known in Bulgaria besides those in Strandža which provide sufficient evidence to be considered by the local population as sacred. (See Map fig. 2).

In all of them there was either a spring, a small lake, water dropping from the ceiling or oozing along the wall, all considered to have curative qualities.

Visited on certain Christian festivals these caves were the location of rituals performed in or in front of the caves where votive offerings, coin, spoons, food, other objects, clothes, threads of different colours etc. were left.

What surprised us was the discovery during the expedition over a relatively small territory of several sacred caves where the cult was still followed or alive in the memory of the older generation or was already partially or entirely forgotten. (Part of the folklore material was gathered by M. Stefanova & K. Ivanov).

Among these caves are:

"SVETA MARINA" in the locality of LYCUDI, located east of Slivarevo (Kadara) in a rock overhanging a beautiful tributary of the Rezovska river, it is in fact a spacious niche capable of holding 40 people, and lit by the entrance and the small "window" opposite it. Water frequently drips from the ceiling, oozing abundantly down the curtain between the entrance and the window, filling the rimstone pools from which people drank. The villagers of Sliverarevo, Kosti, and Gramatikovo, as well as from the town of Malko Tarnovo, would meet on the eve of the Christian feast of the Holy Martyr St. Marina (Georgieva, 1972, p.160), the local priest conducting a service. The followers of the cult would light candles and drink water in accordance with the belief that it would promote good health, while those who were ill would try to let the drops, dripping from the ceiling fall on the location of their ailment. The spring was considered to provide successful treatment for eye complaints. Votive offerings were left at the cave, such as coins (left in rimstone pools), towels or clothes in front of the entrance. After the service the participants would cross over to the terraces cut out in the other bank. The elder participants spent the night on the nearby terrace, while the younger ones danced a "horo" dance all night on the wider terraces.

About 30 years ago the festival was still popular and was even attended by muslims – Turks. At present the cave is only visited by elderly people who go there for treatment; no service is held, however, it is evident that the belief in the magical properties of the spring is still alive for during our visit in the Autumn of 1975 we found votive offerings on a small tree at the entrance of the cave, obviously having been left here quite recently: handkerchiefs, towels, two shirts and even an expensive silk slip. Some of the objects still had the nylon envelopes and the price tags.

Fig. 1. The cave "Hambarceto" near the village Brasljan. The position of the skulls of wild boar (Sus scrofa) at the end of the cave.

Fig. 1. SACRED CAVES: 1 - "ST. MARINKA", Ostrata cuka. 2 - "ST. MARINA", Lykudi. 3 - "ST. TROICA", Gramatikovo. 4 - "HAMBARCETO", Brasljan. 5 - "ST. TROICA", Ceglaik. 6 - "ST. JOAN", Ineada. 7 - "ROSIN KAMAK", Rusokastro. 8 - "ST. PETAR", Ustrem. 9 - "IPANDI", Mihalic. 10 - "ZMEJOVI DUPKI", Sliven. 11 - "NIRIC", Kotel. 12 - "KIPILOV-SKATA", Kipilevo. 13 - "CARNA", Galabovo. 14 - "GOLJAMATA", Madara. 15 - "ST. MARINA", Poroiste. 16 - "GLAVA PANEGA", Zlatna Panega. 17 - "OVNARKATA", Karlukovo. 18 - "ZIVATA VODA", Bosnek. 19 "DUHLATA", Bosnek. 20 - "LJULJAKOVIJA VARTOP", Dragoman. 21 - "TEMNATA DUPKA", Kalotina. 22 - "TZARKVETO", Breze. 23 - "ST. TERAPON", Tran. 24 - "SVETATA VODA", Ginci. 25 - "BESOVISKA PEC", Oresec.

II. *"SVETA MARINKA" in the locality OSTRATA ČUKA,* situated southeast of Stoilovo, represents a small descending fissure 12 metres long and between 1.5-2.5 metres wide. Three natural steps appear to have been hewn out of the rock. The end consists of a narrow passage amidst rimstone curtains, reminiscent of an altar with a small shelf on one side where candles were set, amidst rimstone pools, filled with water oozing from the wall.

An annual ritual, similar in character with that of Sveta Marina, Lycudi was observed here about 30 years ago with an identical belief in the curative qualities of the spring.

An annual feast of Sveta Marina, still alive in the memory of most old people from Stoilovo and Malko Tarnovo was also observed here; however, certain differences attracted our attention: the service was conducted not in the cave, but outside, in a small chapel (now in ruins) some 70 m away from the cave, while a ritual, so far unknown to us, was performed *in* the cave itself. Married women used to sweep out the cave and burn incense. All unmarried youths were allowed to enter and when it was announced that they had left the cave (a few would hide in the cave), the unmarried maidens would enter. On their entering the youths would blow out the maidens' candles and, as it was put by the narrator, the maidens were "pinched", in the dark, i.e. the pinching was considered as an understatement, for these acts were contrary to the high moral views held by the Strandza population, and would not be tolerated on other occasions. If a maiden came out holding a youth by the hand she was considered to have been engaged, therefore avoiding the traditional official engagement ceremony. This did not apply to the remaining participants and the frivolities in the cave brought brought no other consequences. An old folk song recorded at Stoilovo during the expedition confirms the description of the ritual in the cave and its authenticity.

We are therefore justified in asking whether this is not a reminiscence of a certain archaic orgiastic cult with a limited promiscuous character, linked with the caves; should that be the case we can claim that they are venerated by the ancestors of the inhabitants of Strandza in ancient Thrace down to the present day.

III. *"SVETA TROITZA" cave (the Holy Trinity),* north of GRAMATIKOVO. Its entrance is in the centre of the monastery, the church of the Holy Trinity. It is a small cave with two parts, one of which has steps made of stones, brought in from outside the cave. The church above the cave has undergone alterations (the last in 1875) when flat Roman bricks were used in the structure. Mouths of medieval amphorae were found around the church. Services are still held in the church which is the centre of a gathering, a *sabor* on the day of the Holy Trinity, when peasants light candles and float lights on the water. However, here the peasants believe that the drips from the ceiling fall only on a person, free of sins.

IV. *HAMBARČETO, south of Brašlian (SARMAŠIK)* is a two storey labyrinth close to the remains of a dolmen and an ancient necropolis which has not been excavated. No feast or magical acts are recalled here. In spite of this, the fact that four skulls of a boar (*sus scrofa*) each with a calcareous surface were found at its dry inaccessible end justifies our inclusion of it among the sacred caves in Strandza, in view of:

- The skulls, without the lower jaw, were carefully arranged (fig. 1) one next to the other in an inaccessible place, which can be reached after a difficult crawl. No other bones were found.
- This is the first collective find of bones of *Sus scrofa* in Bulgarian caves. In the remaining 7 cases (Nikolov, 1976) separate specimens were found.
- The back of one of the skulls reveals a surface showing the result of a blow from a sharp object, most probably a metal axe.
- The cave is dry at present and has been known to have been dry in the memory of the oldest inhabitants which explains the absence of any sort of sacred veneration, connected with water; the calcarous surface on the skulls points to a considerable age (a sample has been sent for C-14 dating).

It is evident that the skulls belong to boars killed by hunters and brought in at a time when the cave was damp so that sacrifices or other ritual acts could be performed (The wild boar, an attribute of Arthemis, was venerated by the ancient Thracians as a favoured game and sacrificial animal. (Marazov, 1975, p.40)).
We have evidence of the existence of other sacred caves in Turkish territory in proximity to the studied region.

1. Old people recall that on the feast of the Holy Trinity a large gathering used to be held near a cave or under an overhanging rock on the south bank of the Rezovska river, near the village of Ceglaic. A song similar to the song about Sveta Marina in the vicinity of Ostrata Čuka, is also recalled.

2. On the map drawn up for the Russian-Turkish war of 1828-1829, by the Russian Military Depot in St. Petersburg (1853) the only cave given is that of "Sveti Ioan" (St. John) at Inneada at the Black Sea. This must have been a cave popular with its sacred rituals.

Conclusions

Caves which were venerated in antiquity and in some instances up to the present day, have been found in many places in the Balkan peninsula, Asia Minor and the Aegean Islands. However while the author of the only systematic study on the subject — Dr. Paul Faure's work on Crete, believes that the cave cults were interrupted and it was only after a lapse of 1000 years that at certain places caves attracted a Christian population because of their sacred nature. (Faure, 1967, p. 148). We believe that the folklore of Strandža has rituals linked with caves with interesting remains of a Thracian heritage, appearing in the present day in such an ancient ritual as the *nestinari dance* (fire dance, performed barefoot) (Arnaudov 1971, p. 17-161, Angelova, 1955).

An analysis of the limited factual material on the Strandža caves allows the following conclusions to be drawn:-

1. The ceremonies were essentially fertility cults, linked with the summer, they are connected with the popular celebration of rites connected with gathering the first harvest. In the case of the cave of Sveti Ioan, we believe that the feast of St. John was celebrated not on the day of St. John, during the winter, but in summer, on the day of St. Enio, v. analosous with the Russian Iank Kupala.

2. We have grounds for considering that the present day patrons and rituals (with the exception of that of St. John) as the successors of pagan worship of a female deity for popular belief places the Holy Trinity as a female saint with a variety of functions: curative (both caves of St. Marina, the Holy Trinity, Caglaic and probably the Holy Trinity, Gramatikovo), a deity of marriage (St. Marinka, Ostrata Čuka and the Holy Trinity, Ceglaic) and a deity of hunting or protector of the crops (the sacrifices in Hambarčeto). All these facts support the hypothesis that the inhabitants of the mountains of southeast Bulgaria identified St. Marina in the veneration of the Thraco-Phrygian goddess Bendis (Georgieva, 1972, p. 164-168), a veneration which passed on in Greece as the cult of Arthemis-Persephone (Core).

3. Possibly the absence of sacred caves in the Rhodopes is evidence of considerable differences in their religious beliefs of the Odrysae (the inhabitantas of Strandža) and the Bessi and the Dii (the inhabitants of the Rhodopes) in ancient Thrace.

4. Perhaps a study of caves in the high parts of Vildiz Daglari, together with folklore studies could provide interesting data on the religion of the Thracians.

References

Angelova, R. 1955. *"Igra po ogan"*, Sofia, (with a summary in Russian and French).
Arnaudov, M. 1971 and 1972. *"Studii varhu balgarskite obredi i legendi"*, Sofia, vol. I, and vol. II.
Beskov, V.I. 1971. "Ipandi" — in *"Turist 2"*, Sofia, No. 1, p. 24.

Bogorov, I.V.(Andreov) 1846. "Opisanie na selo Kotel" — in: *"Balgarskij orel"*, Leipzig, vol. I, no. 1, p. 2.
Buresch, I.V. 1952. "Izvorite na reka Zlatna Panega v drevnostta" — in: *"Priroda"*, Sofia, No. 3, p. 52-61.
1970. "Skazanija za pesterite v Balgarija" — in: *"Turist"*, Sofia, No. 86, p. 8-9, No. 7, p. 12-13, no. 8, p. 26-27.
Deliradev, P. 1953. *"Prinos kam istoriceskata geografija na Trakija"*, Sofia, vol. I - II.
Djakovic, V. 1905. "Pesterata Carna pri selo Novosel" — in: *"Periodicesko spisanie"*, Sofia, vol. LVI, p.241.
Dzambazov, N. 1956. *"Pesterite v Balgaria"*, Sofia.
Faure, P. 1963. "Cultes de sommets et cultes de cavernes en Crète" — in: *Bulletin de Correspondence Hellènique"*, Athene-Paris, v.2.
1967. "Nouvelles recherches sur troi sortes de santuaires crétois", in: *BCH*, Athéne-Paris, vol. I.
1969. "Sur troi sortes de sanctuaies crétois" — in: *BCH*, Athéné — Paris, vol. I.
Georgieva, I.V. 1972. "Edin starinen kult v Rodopite, Standza i mezdurecieto na Struma i Mesta" — in: *"Rodopski sbornik"*, Sofia, (with a summary in French and Russian).
Jirecek, K. 1899. *"Knjazestvo Balgarija"*, vol. II, "Patuvanija po Balgarija", Plovdiv.
Marazov, I.V. 1975. "Sjuzetat 'lov na gligan' v kolana ot s. Lovec" — in: *"Arheologia"*, Sofia, No. 2 (with a summary in Russian and French).
Metodiev, A. 1974. *"Cepan i tri usi"*, Sofia.
Mihailov, G. 1972. *"Trakite"*, Sofia, (with a summary in Russian and French).
Mikov, V. 1928. "Pesteri v Belogradcisko" — *"Balgarski turist"*, Sofia, p. 43-44.
Nejkovski, P. & Stoitzev, V. 1975. *"Ponor planina"*, — Sofia.
Nikolov, I.V. 1976. "Paleontolgicni nahodki v nasite pesteri" — in: *Papers of the II National Speleolgocial Conference*, (in print).
Skorpil, K. & H. 1900. *"Krazski javlenija"*, Plovdiv.
Slavejknov, P.R. 1891. "Razni belezki" — in: *"Sbornik za naradni umotvorenija"*, Sofia, vol. VI, p.440-442.
Todorov, P. Ju. (Penko) 1894. "Draski", *Veliko Tarnovo*, p. 9-11.
Tranteev, P. 1965. *"Pešteri — turističeski obekti"*, Sofia.
Tranteev, P. 1966. *"Karlukovskijat prolom"*, Sofia.
Velkov, Iv. 1933. "Stari selišta i gradišta juzno ot Sakar planina" — in: *"Godišnik na Narodnija muzej"*, Sofia, vol. V, p. 183-184.

RADIOMETRIC DATING OF SPELEOTHEMS AND CAVERN DEVELOPMENT IN THE MENDIP HILLS, ENGLAND

T. C. Atkinson,
School of Environmental Sciences,
University of East Anglia,
Norwich, England.

R.S. Harmon,
Department of Geology,
Michigan State University,
East Lansing,
Michigan, U.S.A.

P. L. Smart,
Department of Geography,
University of Bristol,
Bristol, England.

The Mendip Hills are a karstic upland of anticlinal geological structure, located 25 km south of Bristol, England (Fig. 1). The tops of the hills form a plateau at 250-260 m.a.s.l., mainly underlain by the cavernous Carboniferous Limestone. In the cores of the anticlines outcrops of Devonian sandstone form low hills reaching to 60 m above the plateau. The surrounding lowlands are separated from the plateau by steep flanking slopes into which deep gorges have been cut by streams which now sink underground. At the present day the drainage of the hills is entirely subterranean, emerging from springs at the foot of the flanking slopes. The geomorphology of the area has been described by Tratman (1963), Ford and Stanton (1968) and Donovan (1969). In addition detailed studies have been made of five major engulfment caves and two complex systems of fossil effluent caves (Ford 1963, 1964); Atkinson (1967); Smart and Stanton (1974).

Geomorphic History of G.B. Cave

G.B. Cave is a cave of engulfment located at NGR ST 477562 (Fig. 1). An up-to-date survey has been published by Savage (1969) (Fig. 2). The geomorphic history has been previously described by Ford (1964) who summarised the development of the cave as occurring in six phases. After an initial phreatic erosion of small tubes and rift-like passages the cave was drained with the water table stabilizing at about 135 m.a.s.l. The Ladder Dig and Bat Passage continued to function as phreatic passages close to the water table, while the vadose parts of the cave were greatly enlarged in Phase 2. Next Ford envisaged two phases (3 and 5) in which widespread clastic fills were deposited and capped in places with spreads of thick flowstone. Each episode of flowstone deposition was followed by clearance of deposits and active stream erosion (phases 4 and 6), the latter of these being thought by Ford to have occurred during the Holocene. At the start of Phase 4, the water table fell to a level at about 120 m.a.s.l. The modern level is not known but must lie below 120 m.a.s.l. which is the altitude of the deepest parts of the known cave. In the nearby Longwood Swallet, the modern water table lies below 70 m.a.s.l. Atkinson (1967). Both caves drain to the Cheddar spring at 26 m.a.s.l. (Atkinson, 1976 in press).

We have re-examined the stratigraphy of the deposits in the G.B. Cave, including those in newly discovered sections in Bat Passage and at the top of the Gorge (Fig. 2). While our studies confirm Ford's earlier work to a great extent, we have evidence of a period fairly early in the cave's history during which very thick (up to 3 m) flowstone layers were deposited in many of the inlet passages. This episode preceded Ford's Phase 3. The stratigraphic evidence is supported by radiometric dates on speleothems (see below). Furthermore, we have recorded exposures in the Gorge and some of the complex entrance passages (Fig. 2) which suggest that there may have been another phase of infilling and flowstone deposition before Ford's

Phase 3 but after the thick flowstone just described (see Note to Table 1). This evidence is not conclusive, however, and we await further radiometric dates to resolve the matter.

The detailed cave stratigraphy is too complex to be discussed here and will be published elsewhere. Table 1 shows our interpretation of the deposits, and a correlation with Ford's erosional history. Note that we associate vadose stream-laid deposits in Bat Passage with a water table at 120 m.a.s.l. (our Phase 5) while the 135 m.a.s.l. is associated with the earlier clastic fills and flowstones seen in the upper part of the cave (Phase 3).

Fig 1 Geology, topography and major caves of the central Mendip Hills
1 Devonian Sandstone 2 Carboniferous Lower Limestone Shale
3 Carboniferous Limestone. 4 Permo-Triassic calcareous breccias
5 Later rocks

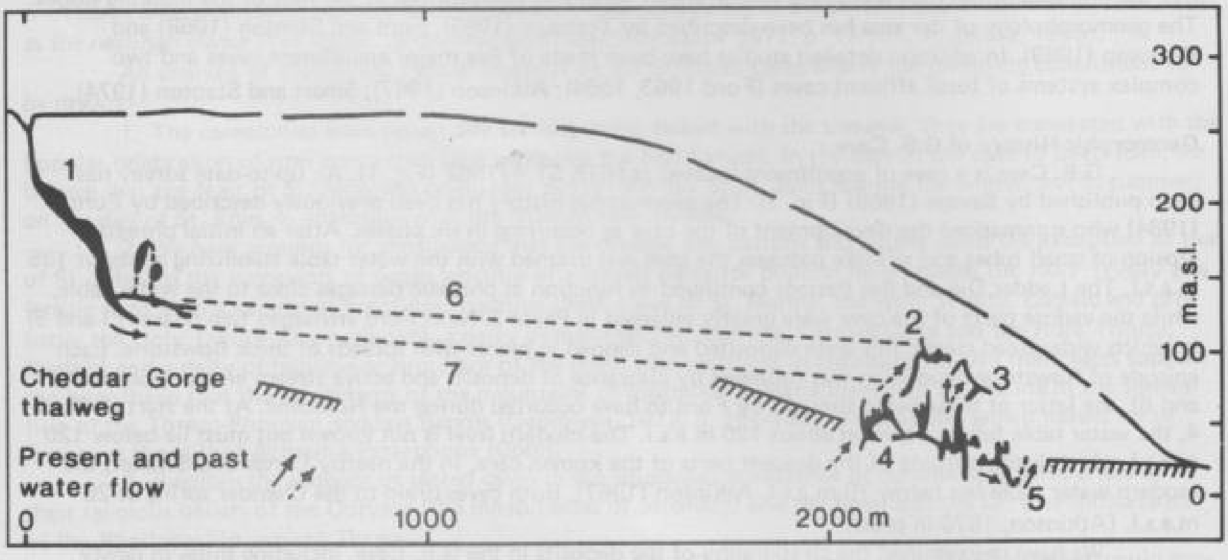


Fig 3 Suggested correlations between G. B. Cave and fossil effluent caves at Cheddar.
1 G. B. Cave. 2 Great Oones Hole. 3 Long Hole. 4 Gough's Cave.
5 Active conduit. 6 Water Table during G. B. Phase 3.
7 Water table during G. B. Phases 4 and 5.

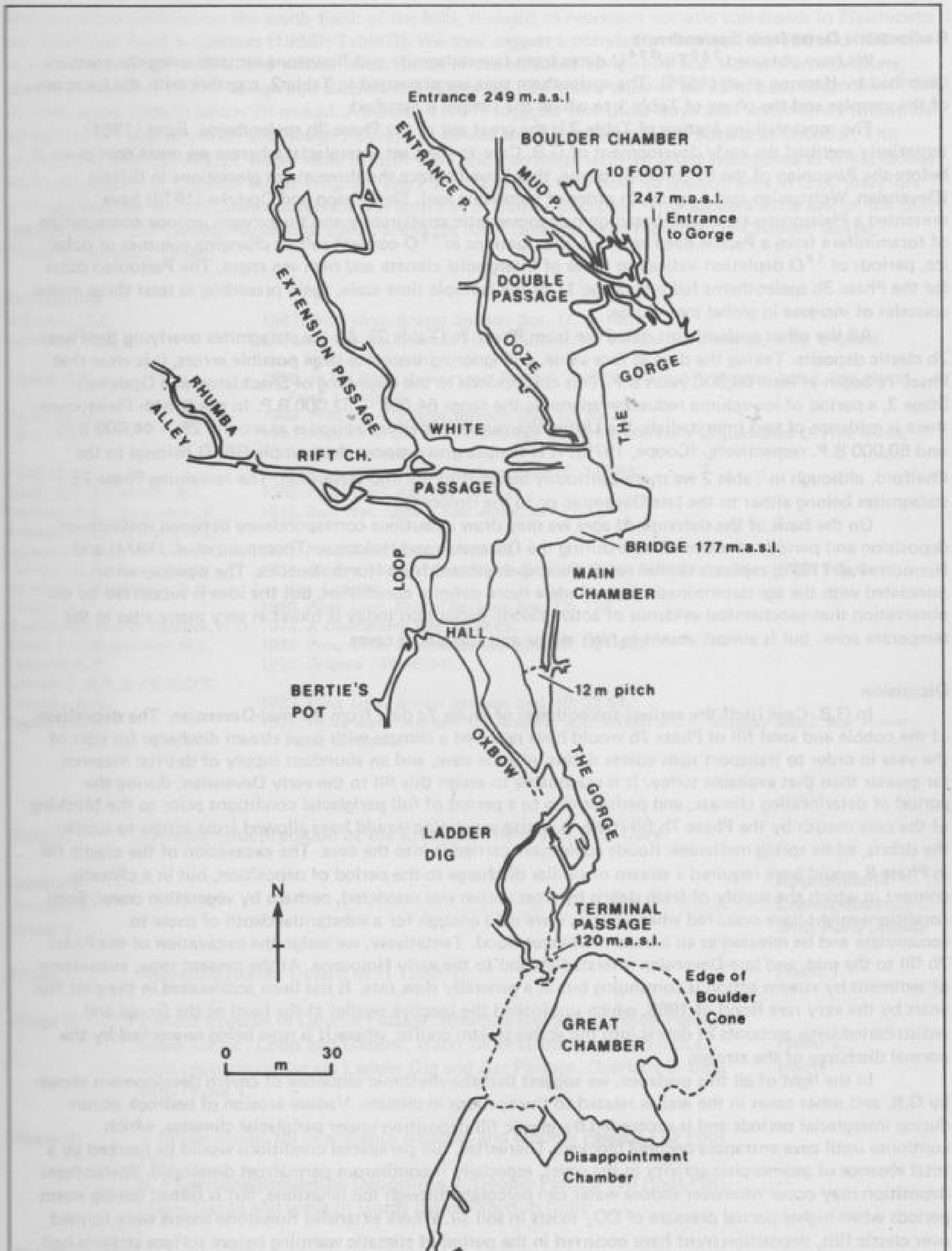


Fig. 2 Plan of G.B. Cave (after Savage, 1969)

Radiometric Dates from Speleothems

We have obtained $^{230}Th/^{234}U$ dates from five stalagmite and flowstone samples using the method described by Harmon *et al.* (1975). The speleothem ages are presented in Table 2, together with the locations of the samples and the phase of Table 1 to which the sample is ascribed.

The most striking feature of Table 2 is the great age of the Phase 3b speleothems. Ford (1964) tentatively ascribed the early development of G.B. Cave to the Last Interglacial whereas we must now place it before the Pastonian of the British Pleistocene, that is well before the three major glaciations in Britain (Devensian, Wolstonian and Anglian, in order of increasing age). Shackleton and Opdyke (1973) have presented a Pleistocene time-scale based on palaeomagnetic stratigraphy and the oxygen isotope composition of foraminifera from a Pacific deep sea core. Fluctuations in ^{18}O content reflect changing volumes of polar ice, periods of ^{18}O depletion indicating times of interglacial climate and high sea stand. The Pastonian dates for the Phase 3b speleothems fall into Stage 11 of the isotopic time scale, again preceding at least three major episodes of increase in global ice volume.

All the other speleothems dated are from Phase 7c (Table 2). All are stalagmites overlying the Phase 7b clastic deposits. Taking the data at face value, and ignoring the quite large possible errors, it is clear that Phase 7c began at least 60,000 years B.P. This corresponds to the beginning of Shackleton and Opdyke's Stage 3, a period of ice volume reduction spanning the range 64,000 – 32,000 B.P. In the British Pleistocene there is evidence of two interstadials, the Upton Warren and Chelford episodes at around 25 – 44,000 B.P. and 60,000 B.P. respectively. (Coope, 1975). It is tempting to suppose that sample GB1D belongs to the Chelford, although in Table 2 we more cautiously assign it to the mid-Devensian. The remaining Phase 7c stalagmites belong either to the late Devensian or to the Holocene.

On the basis of the determined ages we may draw a cautious correspondence between speleothem deposition and periods of warm climate during the Devensian and Holocene. Thompson *et al.* (1974) and Harmon *et al.* (1975) report a similar result from speleothems from North America. The possible errors associated with the age determinations preclude a more definite conclusion, but the idea is supported by our observation that geochemical evidence of active calcite deposition today is found at very many sites in the temperate zone, but is almost absent in high alpine and sub-glacial caves.

Discussion

In G.B. Cave itself the earliest speleothems of Phase 7c date from the mid-Devensian. The deposition of the cobble and sand fill of Phase 7b would have required a climate with large stream discharge for part of the year in order to transport such coarse debris into the cave, and an abundant supply of detrital material, far greater than that available today. It is reasonable to assign this fill to the early Devensian, during the period of deteriorating climate, and perhaps also to a period of full periglacial conditions prior to the blocking of the cave mouth by the Phase 7b fill itself. A sparse vegetation would have allowed frost action to supply the debris, while spring meltwater floods could have carried it into the cave. The excavation of the clastic fill in Phase 8 would have required a stream of similar discharge to the period of deposition, but in a climatic context in which the supply of fresh debris by frost action was restricted, perhaps by vegetation cover. Such conditions might have occurred when winters were cold enough for a substantial depth of snow to accumulate and be released as an annual meltwater flood. Tentatively, we assign the excavation of the Phase 7b fill to the mid- and late-Devensian interstadials and to the early Holocene. At the present time, excavation of sediment by stream action is continuing but at a generally slow rate. It has been accelerated in the past few years by the very rare flood of 1968, which unblocked the inactive swallet at the head of the Gorge and redistributed large amounts of debris into the active stream course, where it is now being re-worked by the normal discharge of the stream.

In the light of all this evidence, we suggest that the rhythmic sequence of cavern development shown by G.B. and other caves in the area is related to fluctuations in climate. Vadose erosion of bedrock occurs during interglacial periods and is succeeded by clastic fill deposition under periglacial climates, which continues until cave entrances become blocked. Thereafter, full periglacial conditions would be marked by a total absence of geomorphic activity in the caves, especially if continuous permafrost developed. Speleothem deposition may occur whenever vadose water can percolate through the limestone, but is fastest during warm periods when higher partial pressure of CO_2 exists in soil air. Where extensive flowstone sheets were formed over clastic fills, deposition must have occurred in the period of climatic warming before surface streams had sapped and removed the deposits blocking cave entrances, or alternatively have been confined to sites protected from the action of the excavating stream. Excavation of coarse clastic fills probably occurs during interstadials and late-periglacial periods. It is worth noting that the Mendip Hills were in an ice-front position during at least one of the major ice-advances of the Pleistocene (Hawkins & Kellaway, 1971), so that the contrasts in geomorphic activity during periods of different climate are likely to be at a maximum.

As noted above, the Phase 3b speleothems in G.B. date from the relatively warm Pastonian stage. There are at least three cold stages between the Pastonian and Devensian, namely the Beestonian, Anglian and Wolstonian. During the last two ice was widespread in Britain. Only one episode (Phase 5) of clastic fill can be identified with certainty in G.B. Cave during this interval, and so it is impossible to decide to which cold period it belongs. Further dating work is required.

In terms of regional chronology, Ford and Stanton (1968) have put forward a tentative erosional history based upon correlations of water table levels between engulfment caves and successively older and higher levels of former resurgences in the fossil effluent caves at Cheddar and Wookey Hole. Resurgence levels are in turn correlated with knick points indicating successive episodes in the deepening of the dry gorges, and

with erosional benches on the south flank of the hills, thought to represent eustatic still-stands in Pleistocene sea levels (see Ford & Stanton (1968), Table 3). We now suggest a correlation between the 120 and 135 m.a.s.l. water tables in G.B. and similar levels found in the adjacent Longwood and Manor Farm Swallets, (Smart & Stanton, 1974). Longwood Swallet also displays a past water table at 90-93 m.a.s.l. while the modern water table is below 70 m.a.s.l. Atkinson (1967) suggests that these three past water levels should be correlated respectively with the Gough's Cave, Long Hole and Great Oones Hole outlets at Cheddar. This implies that the 135 m.a.s.l. water table in G.B. Cave also correlates with an active resurgence at Great Oones Hole, 92 m.a.s.l. in Cheddar Gorge (Fig. 3). The Pastonian dates for Phase 3b speleothems in G.B. therefore indicate that the Great Oones resurgence was active at or before that time. This appears to be one of the older resurgences in the Cheddar system of caves, although fossil caves do exist higher up in Cheddar Gorge, (Ford & Stanton, 1968).

References

Atkinson, T.C. 1967. *Proc. Univ. Bristol Spelaeo. Soc. 11:* 161-85.
Atkinson, T.C. Diffuse Flow and Conduit Flow in Limestone Terrain in the Mendip Hills, England. *J. Hydrol.* (in press).
Coope, G.R. 1975. In *Ice Ages: Ancient and Modern.* A.E. Wright and F. Moseley (eds.). Seel House Press, Liverpool.
Donovan, D.T. 1969. *Proc. Univ. Bristol Spelaeo. Soc. 12:* 63-74.
Ford, D.C. 1963. *Aspects of the Geomorphology of the Mendip Hills.* Unpublished D. Phil. thesis, Bodleian Library, Oxford.
Ford, D.C. 1964. *Proc. Univ. Bristol Spelaeo. Soc. 10:* 149-88.
Ford, D.C. & Stanton, W.I. 1968. *Proc. Geol. Ass. 79:* 401-27.
Harmon, R.S., Thompson, P., Schwarcz, H.P. & Ford, D.C. 1975. *Bull. Nat. Speleo. Soc. Amer. 37:* 21-33.
Hawkins, A.B. & Kellaway, G.A. 1971. *Proc. Geol. Ass. 82:* 267-92.
Mitchell, G.F., Penny, L.F., Shotton, F.W. & West, R.G. 1974. *A correlation of Quaternary Deposits in the British Isles, Spec. Rept. (4), Geol. Soc. London.*
Savage, D. 1969. *Proc. Univ. Bristol Spelaeo. Soc. 12:* 126.
Shackleton, N.J. & Opdyke, N.D. 1973. *J. Quaternary Res. 3:* 39-55.
Smart, P.L. & Stanton, W.I. 1974. *Proc. Univ. Bristol Spelaeo. Soc. 13:* 391-402.
Thompson, P., Schwarcz, H.P. & Ford, D.C. 1974. *Science 184:* 893-5.
Tratman, E.K. 1963. *Proc. Univ. Bristol Spelaeo. Soc. 10:* 22-57.
Zagwijn, W.H. 1975. In *Ice Ages: Ancient and Modern*, A.E. Wright and F. Moseley (eds.), Seel House Press, Liverpool.

Table 1: **Authors' Interpretation of the Erosional History of G.B. Cave**

Authors' Erosional History		Approximate Correspondence with Ford (1964)
Phase 1:	**Phreatic Erosion.** Details as in Table 1.	Phase 1.
Phase 2:	**Vadose Erosion** in Double Passage, Rhumba Alley, Extension Passage, upper Gorge, Loop and Oxbow. Water table stabilises at 135 m.a.s.l. with phreatic outlet via Ladder Dig and Bat Passage. Overlaps in time with Phase 1.	Phase 2. (part)
Phase 3:	a. **Minor clastic fill** in entrance passages and Double Passage (10 Foot Pot) b. **Flowstone/Stalagmite Deposition** in Double Passage (10 Foot Pot), upper Gorge and walls of Gorge below Whitsun Folly.	—
*** See below		
Phase 4:	**Vadose Erosion** in Stream Passage, Ooze and Mud Passage, Extension Passage, White Passage, Rift Passage and Oxbow. Main entrenchment of Gorge and probably Bat Passage. Water table at 120 m.a.s.l.	Phase 2. (part)
Phase 5:	a. **Clastic deposition** in Gorge, Ladder Dig and Bat Passage, and probably also in Extension Passage, Loop and Bertie's Pot. b. **Flowstone/Stalagmite Deposition** in Upper Grotto, Double Passage, Gorge, Ladder Dig, Bat Passage.	Phase 3.
Phase 6:	**Vadose Erosion** in Hall, Oxbow, Lower Gorge, Terminal Passage. Minor excavation of clastic and flowstone deposits in Ladder Dig and Bat Passage. Water table below 120 m.a.s.l.	Phase 4

Phase 7: a. **Massive rockfall:** Great Chamber and Hall dejection cones. — Phase 5
b. **Clastic deposition:** minor fill in Ladder Dig, Lower Grotto, Mud Passage, and major fill in Gorge. Main sinkhole at head of Gorge blocked.
c. **Stalagmite/Flowstone Deposition:** in Gorge, Ladder Dig, Bat Passage and elsewhere.

Phase 8: a. **Vadose erosion:** excavation of phase 7 fill by stream entering from present swallet through Boulder Chamber. Erosion in Stream Passage. — Phase 6
b. **Local Stalagmite deposition** continues, mainly over residual Phase 7 deposits.

***** Note:** Deposits of stream-laid fill and flowstone occurring high on the walls of the Gorge may form a separate Phase between Phases 3 and 4 with subsequent excavation during Phase 4.

Table 2: $^{230}Th/^{234}U$ **Ages of Speleothems and Pleistocene Stages**

Sample	Location	Phase	Age (10^3 yrs B.P.)	Oxygen Isotope[1] Stage	Pleistocene/Holocene Stage
GB 9B	Top of 1.5 m flowstone, 10 Foot Pot	3b	359 + 00 - 85	10/11 Boundary	Pastonian[2]
GB 17	Flowstone, roof slot near top of Gorge	3b	390 + 00 - 70	11	Pastonian[2]
GB 1A	Stalagmite overlying Phase 7 fill, Gorge/White Passage junction. Outer shell	7	11 ± 6	1	Late Devensian[3] or Holocene
GB 1B	Same Stalagmite as GB1A, inner shell	7	8 ± 1		
GB 1E	Stalagmite, upper terrace at Bridge in Gorge	7	13 ± 3	1/2 Boundary	Late Devensian[3]
GB 1D	Stalagmite from Balcony, overlying Phase 7 fill in Gorge	7	63 ± 19	3/4 Boundary	Mid Devensian[3]

[1] Shackleton and Opdyke (1973). [2] Zagwijn (1975); Mitchell *et al* (1974). [3] Coope (1975).

RELATIONS ENTRE LA DYNAMIQUE DES EAUX DU KARST ET LES PROCESSUS DE KARSTIFICATION

Michel Bakalowicz
Laboratoire souterrain du C.N.R.S.
F.09410 Moulis, France.

Many hypothetical mechanisms for limestone attack have been advanced to explain the seeming opposition between surface denudation and cave development into karstic aquifers. However these mechanisms seem to operate only locally and are not sufficient for creating conduit systems.

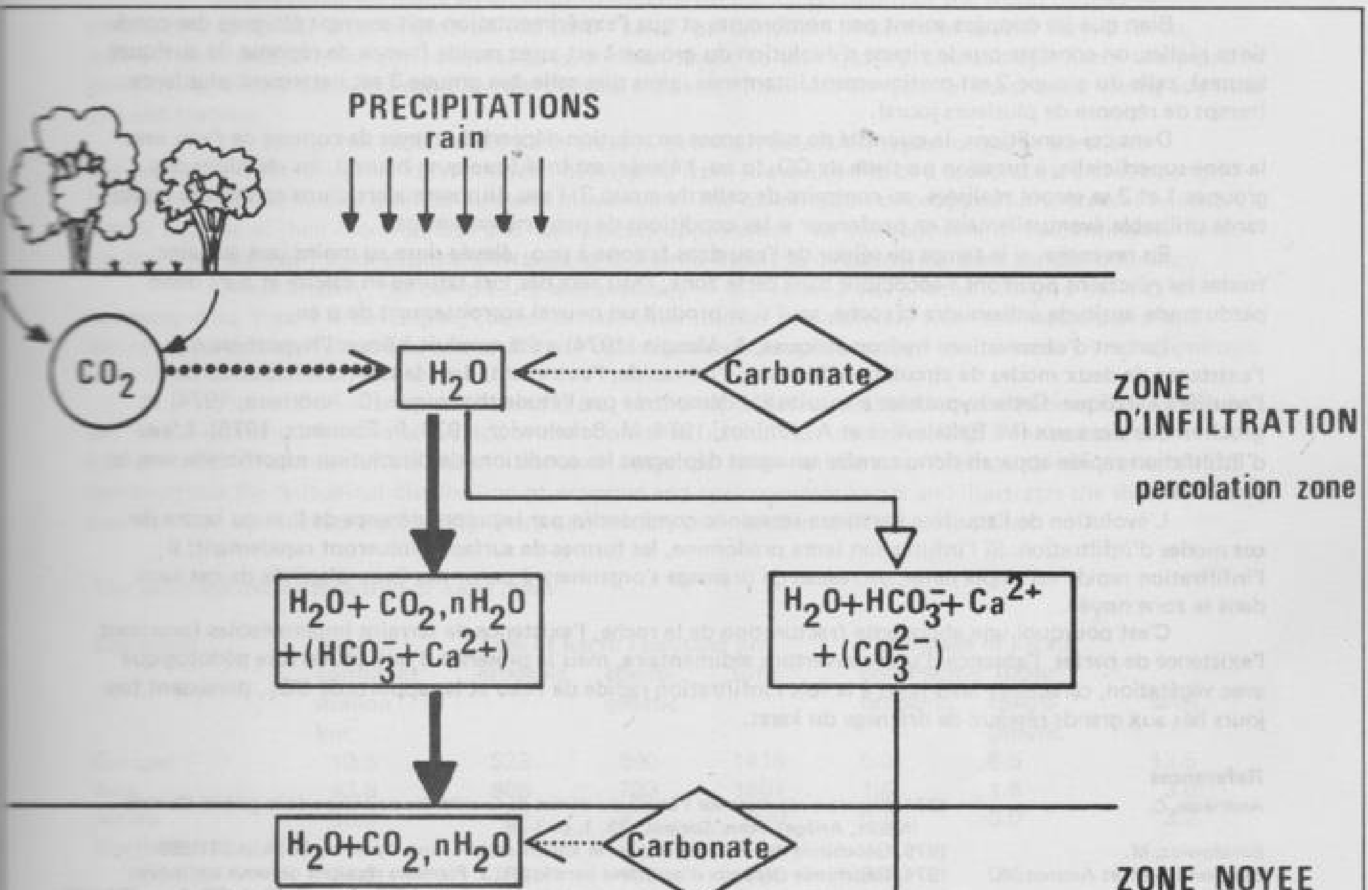
New information about water circulating in karstic terranes contributes to the understanding of both *water dynamics* in the percolation zone and *evolution rate* of physical and chemical reactions in the CO_2-H_2O — carbonate system. Relations between these two induce solubility in waterlogged karst.

Les nombreaux travaux effectués sur la chimie des carbonates ont mis clairement en évidence le rôle de l'anhydride carbonique dans les processus de karstification (cf notamment les travaux de H. Roques). Ils montrent tout particulièrement l'importance du CO_2 d'origine biologique produit à la surface du karst et devant lequel le CO_2 atmosphérique apparait en quantité négligeable. Il s'en suit que l'eau de pluie qui s'infiltre acquiert un maximum d'aggressivité vis-à-vis des carbonates dans les premiers mètres de roche traversés. Tous les karstologues (*in* M.M. Sweeting, 1972; M.D. Bleahu, 1974) affirment en conséquence que la dissolution maximale de la roche carbonatée intervient à proximité de la surface. Or, toutes les observations concourent à montrer que la en karstification se manifeste notablement au niveau de la zone noyée en aboutissant à l'organisation d'un réseau de drainage qui conduit les eaux souterraines vers les émergences.

Cette contradiction apparente, soulignée par A.D. Howard (1964) et J' Thrailkill (1968) a incité les karstologues à rechercher les mécanismes pouvant permettre une reprise de la dissolution dans la profondeur du karst. C'est ainsi que de très nombreuses hypothèses ont été émises. V. Caumartin et P. Renault (1958) suggèrent

l'intervention de microorganismes. F. Trombe (1952), puis J.J. Miserez (1973) font jouer un rôle non négligeable à l'eau se condensant sur les parois des cavités. Pour A.D. Howard (1964), la matière organique entraînée par les eaux pourrait être oxydée par des microorganismes, ce qui fournirait du CO_2. Le même auteur envisage aussi l'oxydation de minéraux sulfureux, ce qui augmente le produit de solubilité du calcium. P. Renault (1964) puis J. Thrailkill (1968) invoquent un refroidissement de l'eau au cours de son infiltration. Mais tous ces mécanismes paraissent n'intervenir que localement et seulement dans la zone d'infiltration.

Au niveau de la zone noyée, le passage de l'écoulement d'un régime laminaire à un régime turbulent peut provoquer une reprise de la dissolution (W.B. White et J. Longyear, 1964), de même que le mélange d'eaux saturées en calcite (A. Bögli, 1964). Bien que conformes aux lois de la physique ou de la chimie, ces processus ne semblent pas se réaliser couramment, car les conditions nécessaires à leur réalisation ne sont en général pas observées, (cf. par exemple les remarques de J. Thrailkill, 1968, et J.J. Miserez, 1973, à propos de la théorie de la corrosion par mélange des eaux).



Il semble plutôt que l'organisation d'un réseau de drainage dans un aquifère karstique, phénomène tout à fait général aux roches carbonatées, ne puisse procéder que d'un mécanisme unique et général, et non d'un ensemble de mécanismes dont les conditions de fonctionnement ne sont pas toujours remplies, à la fois dans le temps et dans l'espace.

D'après H. Roques (1969), c'est surtout la variation de la pression partielle de CO_2 qui est responsable des phénomènes de dissolution et de précipitation de la calcite. Lors de la dissolution, la vitesse d'evolution de la chaîne des équilibres des différents réactants intervenant dans les phases gazeuse, liquide et solide de système $CO_2 - H_2O - CaCO_3$ est déterminée par les vitesses d'évolution propres à chaque groupe de réactions:

1) transfert du CO_2 à l'interface gaz-liquide,
2) réactions chimiques dans la phase liquide,
3) transfert de carbonate à l'interface liquide-solide.

Bien que les données soient peu nombreuses et que l'expérimentation soit souvent éloignée des conditions réelles, on constate que la vitesse d'évolution du groupe 1 est assez rapide (temps de réponse de quelques heures), celle du groupe 2 est pratiquement intantanée, alors que celle due groupe 3 est nettement plus lente (temps de réponse de plusieurs jours).

Dans ces conditions, la quantité de substances en solution dépend du temps de contact de l'eau avec la zone superficielle, à pression partielle de CO_2 ($p\ co_2$) élevée, est bref (quelques heures), les réactions des groupes 1 et 2 se seront réalisées, au contraire de celle du group 3; l'eau disposera alors d'une agressivité importante utilisable éventuellement en profoneur si les conditions de pco_2 ne varient pas.

En revanche, si le temps de séjour de l'eau dans la zone à pco_2 élevée dure au moins une semaine, toutes les réactions pourront s'accomplir dans cette zone; l'eau sera dès lors saturée en calcite et aura donc perdu toute aptitude à dissoudre la roche, sauf si se produit un nouvel accroissement de $p\ co_2$.

Partant d'observations hydrométriques, A. Mangin (1974) a été conduit à poser l'hypothèse de l'existence de deux modes de circulation des eaux, l'un rapide, l'autre lent, dans la zone d'infiltration de l'aquifère karstique. Cette hypothèse a ensuite été démontrée par l'étude thermique (C. Andrieux, 1974) et géochimique des eaux (M. Bakalowicz et A. Aminot, 1974; M. Bakalowicz, 1975; P. Eberentz, 1975). L'eau d'infiltration rapide apparait donc comme un agent déplaçant les conditions de dissolution superficielle vers la profondeur.

L'évolution de l'aquifère karstique sera donc commandée par la prépondérance de l'un ou lautre de ces modes d'infiltration. Si l'infiltration lente prédomine, les formes de surface évolueront rapidement; si l'infiltration rapide est importante, un réseau de drainage s'organisera à partir des lieux d'arrivée de ces eaux dans la zone noyée.

C'est pourquoi une abondante fracturation de la roche, l'existence de terrains imperméables favorisant l'existence de pertes, l'absence d'une couverture sédimentaire, mais la présence d'une couverture pédologique avec végétation, caractères favorisant à la fois l'infiltration rapide de l'eau et les apports de CO_2, paraissent toujours liés aux grands réseaux de drainage du karst.

References

Andrieux, C. 1974. Premiers résultats sur l'étude du climat de la salle des peintures de la galerie Clastres (Niaux, Ariège). *Ann. Speleol.*, 29, 1, p. 3-25.

Bakalowicz, M. 1975. Géochimie des eaux karstiques et karstification. *Ann. Spéléol.*, 30, 4, p.581-589.

Bakalowicz, M. et Aminot, A. 1974. Géochimie des eaux d'aquifères karstiques. 3. Premiers résultats obtenus sur le système karstique de Baget durant le cycle hydrologique 1973. *Ann. Spéléol.*, 29, 4, p. 484-493.

Bleahu, M.D. 1974. *Morfologia carstică.* Ed. Stiintifică, Bucarest, 590 p.

Bögli, A. 1964. Corrosion par mélange des eaux. *Intern. J. Speleol.*, 1, 1-2, p. 61-70.

Caumartin, V. et Renault, P. 1958. La corrosion biochimique dans un réseau karstique et la génèse du mondmilch. *Notes Biospéol.*, 13, p'87-109.

Eberentz, P. 1975. *Apports des méthodes isotopiques à la connaissance de l'aquifère karstique.* Thèse Doc. Spécialité, Géologie Dynamique, Paris, 70p.

Howard, A.D. 1964. Processes of limestone cave development. *Intern. J. Speleol.*, 1, 1-2, p'47-60.

Mangin, A. 1974. Contribution à l'étude hydrodynamique des aquifères karstiques. *Ann. Spéléol.*, 29, 3, p. 283-332; 29, 4, p. 495-601; 30, 1, p. 21-124.

Miserez, J.J. 1973. *Géochimie des eaux du karst jurassien.* Thèse de Doct. ès Sciences, Univ. Neuchâtel, 313 p.

Renault, P. 1964. Remarques sur la signification des expériences en géodynamique karstique. *Intern. J. Spéléol.*, 1, 1-2, p. 109-152.

Roques, H. 1964. Contribution à l'étude statique et cinétique des systèmes $CO_2 - H_2O$ – carbonates. *Ann. Spéléol.*, 19, 2, p. 255-484.

1969. Problèmes de transfert de masse posés par l'évolution des eaux souterraines. *Ann. Spéléol.*, 24, 3, p. 455-494.

Sweeting, M.M. 1972. *Karst landforms.* MacMillan Press, London, 362 p.

Thrailkill, J. 1968. Chemical and hydrologic factors in the excavation of limestone caves. *Geol. Soc. Am. Bull.*, 79, p. 19-46.

Trombe, F. 1952. *Traité de Spéléologie.* Payot, Paris, 376 p.

White, W.B. et Longyear, J. 1964. Some limitations on speleogenetic speculation imposed by the hydraulic groundwater flow in limestone. *Bull. N.S.S.*, 26, 2, p. 68-69.

THE GEOGRAPHICAL DISTRIBUTION OF KARST AREAS

D. Balázs,
H-1366 Budapest
Postafiók 12
Hungary

The geographical distribution of karst areas is determined by the planetary distribution of carbonate rocks. The proportion of carbonate rocks is about 22 per cent, but they occupy as much as 27 per cent of the surface (about 40 million km^2) as counted by G.A. Maksimovich (1947). These figures seem to be overestimates if both the naked karst areas and the buried lowland carbonate areas are included as, for instance, in case of the Moscow basin.

In this paper we make an attempt to summarize the karst regions of the world instead of considering carbonate areas in general. The term "karst" presumes the presence of special karstic forms, dolines, caves and/or other corrosion features, without regard to their quality, size and age. From this point of view, this summary considers not only the classical holokarsts, but also all types of karst areas having any kind of karst features.

The author has grouped the karst areas in two main structural types: orogenic karst and epeirogenetic karst. Orogenic karst has been developing from the sediments of a geosyncline and is strongly folded, faulted and finally uplifted by earth movements. The delimitation of orogenic karst areas is relatively simple because of their mountainous and high plateau appearance. The epeirogenetic or epicontinental karsts are flat areas emerged from shallow shelf seas; it is often difficult to circumscribe their surface boundary.

Unfortunately, the complexity and accuracy of this summary is limited owing to the lack of necessary data. Karsts in developing countries have been studied incompletely from the karstological and speleological point of view. The karsts of these countries have been determined in this paper by using geologic maps and personal information.

The total karst areas of the world are, according to data available at present, about 5.3 million km^2, i.e. 4 per cent of the total surface of the continents, excluding Antarctica. Fig. 1 shows a simple interpretation of the size of the global karst areas in comparison with the assembled continent masses. Fig. 2 demonstrates the latitudinal distribution of orogenic and epeirogenetic karsts and illustrates the share of the continents in karst areas. Data of Fig. 2 are numerically presented in the following table.

The geographical distribution of karst areas

Continent	Area of continent million km^2	Area of karst/Thousand km^2 orogenic	epeiro-genetic	total	Percentage of karsts/ continent = 100% orogenic	epeiro-genetic	total
Europe	10.5	528	890	1418	5.0	8.5	13.5
Asia	43.9	808	793	1601	1.8	1.8	3.6
Africa	30.3	67	923	990	0.2	3.0	3.2
North and Central America	24.2	760	100	860	3.1	0.4	3.5
South America	17.9	90	–	90	0.5	–	0.5
Australia and the Pacific	8.5	132	250	382	1.6	2.9	4.5
Total without Antarctica	135.3	2385	2956	5341	1.8	2.2	4.0

The data show that Europe is the "most karstic" continent in respect of both orogenic karst (Alpida) and epeirogenetic karst (the vast carbonate plain of Russia). The largest amounts of karst areas are found in the following countries: France (about 40% of the total area), Yugoslavia (33%), Albania (30%), Bulgaria (23%), Austria (17%).

The most extensive karst regions of Asia are located in South China (about 500 000 km^2, 5% of the country's area. The "most karstic" Asian country is Turkey (150 000 km^2 karst areas, 19%). Asia holds the highest elevated karstic rocks and caves in the Himalayan Mountains.

In Africa orogenic karsts are found only in the Atlas and Cape Mts., but tabular karsts occupy vast areas (Cyrenaica Miocene plateau, 270 000 km^2; Somali Peninsula Eocene limestone, 230 000 km^2 and Jurassic 250 000 km^2).

In North America most of the large karst regions belong to the Appalachian Karst Belt. The areas of the United States have a limestone karst proportion of about 8% and the other soluble rocks occupy 7%. In Central America the Caribbean region is very rich in carbonate rocks (Jamaica 66%, Cuba 50%) and their morphology is one of the most variable and scenic karsts in the world. South America is the poorest continent for carbonate rocks with the exception of Venezuela, where the existing karst areas have been studied intensively.

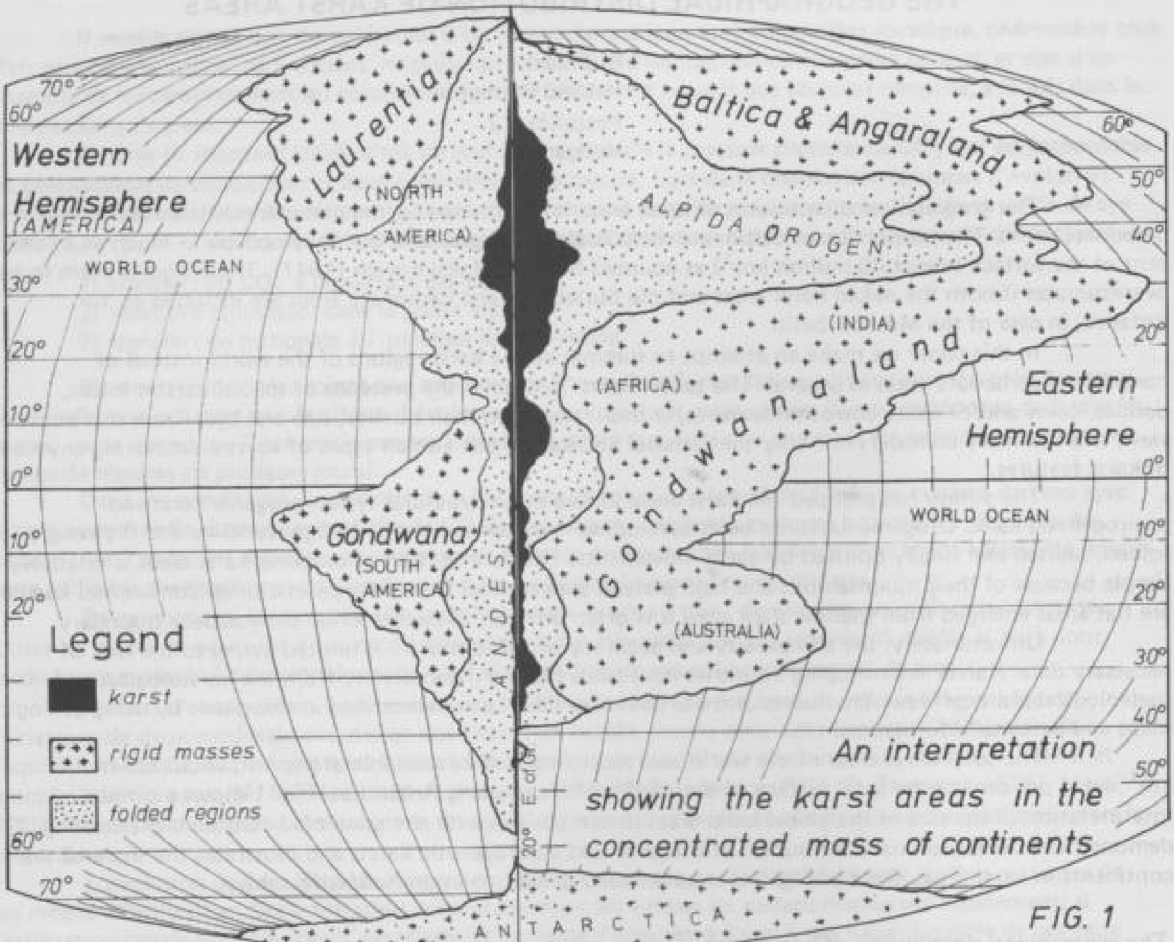

Western
Hemisphere
(AMERICA)
WORLD OCEAN
Laurentia
(NORTH AMERICA)
Baltica & Angaraland
ALPIDA OROGEN
(INDIA)
(AFRICA)
Gondwanaland
Eastern
Hemisphere
WORLD OCEAN
Gondwana
(SOUTH AMERICA)
(AUSTRALIA)
ANDES
ANTARCTICA
Legend
karst
rigid masses
folded regions
An interpretation
showing the karst areas in the
concentrated mass of continents
70°
60°
50°
40°
30°
20°
10°
0°

FIG. 1


LATITUDINAL
DISTRIBUTION
OF KARST AREAS
OROGENIC KARST
EPEIROGENETIC KARST
1000 km²/5°
Cyrenaica
South
China
Russian
Plain
Somali
Peninsula
Nullarbor
Plain
latitude°
N 70°
40° S
orogenic karst
epeirogenetic karst
EUROPE
ASIA
AFRICA
NORTH
C.
SOUTH AMERICA
AUSTRALIA & PACIFIC

FIG. 2

In Australia the semi-arid Nullarbor Plain is the largest karst region (195 000 km^2), and among the data of the Pacific the karst regions of Papua New Guinea are significant (80 000 km^2).

Most of the karst areas are distributed in the Northern hemisphere (4700 000 km^2, 4.7% of the Northern continents) and only 12% of the world's areas are in the Southern hemisphere (642 000 km^2, 1.8% of the Southern lands).

The share of so-called tropical karst is relatively small in this summary. The well developed cone and tower karsts occupy about 430 000 km^2 (8% of the total karst area) of which that of South China is taken into account with 200 000 km^2. Although the areas of tropical karsts are limited, their forms are the most varied on the earth in consequence of the special genetic circumstances such as undisturbed long period of karstification, abundant precipitation etc.

This paper is only a preliminary work made by the author to compile a world-catalogue of karst areas. Therefore data should change according to new investigations and improved information in the future. The author requests the kind help of karst experts of different countries for completing this compilation.

THE OPTIMAL GEO-CLIMATIC PROVINCES OF KARSTIFICATION

by D. Balázs H-1366 Budapest, Postafiók 12, Hungary

The development of karst areas requires two fundamental factors: the presence of soluble rocks on or near the earth surface and a climate suitable to karstification. As a consequence, their coexistence determines the planetary distribution of karst areas. Naturally, the karst process also needs the time factor and is influenced by other natural circumstances, but we discuss only the first two basic factors here.

The main carbonate belts of the earth

The primary factor is the material: the soluble rocks; no karst can exist without them. About 90% of the rocks suitable to karstification are carbonates (limestone, dolomite), so we further use the term of carbonate rocks. Sedimentation of carbonate rocks may occur in two standard ways: (1) by accumulation of sediments containing calcium-magnesium carbonate in geosynclinal deep-water sediments, (2) by deposition of carbonates on a continental shelf or a submerged rigid platform as shallow-water sediments.

The geosynclinal carbonate rocks uplifted by orogenic movements are fundamental material for classical holokarst, the orogenic type of karst. The geosynclinal carbonate rocks are usually thick, pure limestone, i.e. very suitable to karst corrosion, but sometimes strong folding, faulting and overthrust formations complicate their structure. Geomorphologically orogenic karst presents classical karst features such as dolines, caves etc.

Much orogenic karst is found in the Tethys geosyncline raised up by the Alpine orogenic movements in different phases, i.e. Eurasian Karst Belt, (see Fig. 1). Here is concentrated about 50% of the well developed orogenic karst areas of the world. The other large Tertiary orogenic belt is the Cordilleras-Rockies and Andes on the West coast of the Americas, but these are deficient in carbonate rocks in consequence of their genetic structures.

Important karst areas are located in the Hercynian fold belt of Carboniferous-Permian age, especially in North America (Appalachian) and in Western Europe (West Iberian Mts., Central Massif, Voges, Pennines and Ardennes). The Middle European region of Hercynian folding (the Bohemian and Moravian Heights, Sudetes etc.) and the Ural Mts. are relatively poor in carbonate rocks. Sporadic karst regions are found in the Caledonian folding area (Cambrian Mts., Mo-i-Rana etc.).

The other structural type of carbonate areas is the epeirogenetic karst ("epicontinental karst", a term used by M. Herak, 1972). It consists of shelf carbonate rocks uplifted by epeirogenesis. Most of this karst type is in semi-arid zones and therefore the karst features are not impressive, except those which form tropical islands or peninsulas having enough precipitation for special karst development as in the Caribbean and Indonesian Archipelagoes. This latter is placed among the neighbouring carbonate belts of orogenic origin, as can be seen in Fig. 1, since there is no reason to differentiate one from another in respect of the existence of carbonate rocks.

Properly two large carbonate belts can be circumscribed, one in the areas of North and Central America and the other in Eurasia along the Tertiary orogenic belt (Fig. 1).

Humid zones

Since the 1930s numerous papers have been published on the importance of climate in the karstic process. The karst areas were typified as tropical, temperate and cold (subpolar) karst zones according to their latitudinal distribution. This zonality is due to temperature, but the influence of temperature in karstic development is a very complex, indirect and disputable factor. Possibly the permafrost boundary is the only reasonable climatic dividing line in the karst evolution.

The most important climatic factor of karstification is precipitation. Its quantity and quality has direct influence on the intensity of karst development, and the annual runoff is a basic parameter for the karstic denudation.

The humid areas of the earth do not form any continuous latitudinal zones, though the equatorial latitudes are generally wet and hot, deserts are found around 30°. The annual world-mean precipitation is about 850 mm, therefore we can say that an annual precipitation over 1000 mm is relatively favourable for

karstic corrosion in the tropics and temperate zones. The actual karstification is very low in warm regions where the precipitation is less than 250 mm and evaporation is high as in deserts and semi-deserts. Most areas of the earth belong to the intermediate zone.

It is possible to circumscribe three major and a few smaller regions where the actual conditions of rainfall are optimal (more than 1000 mm per year) for karstic development (Fig. 1).

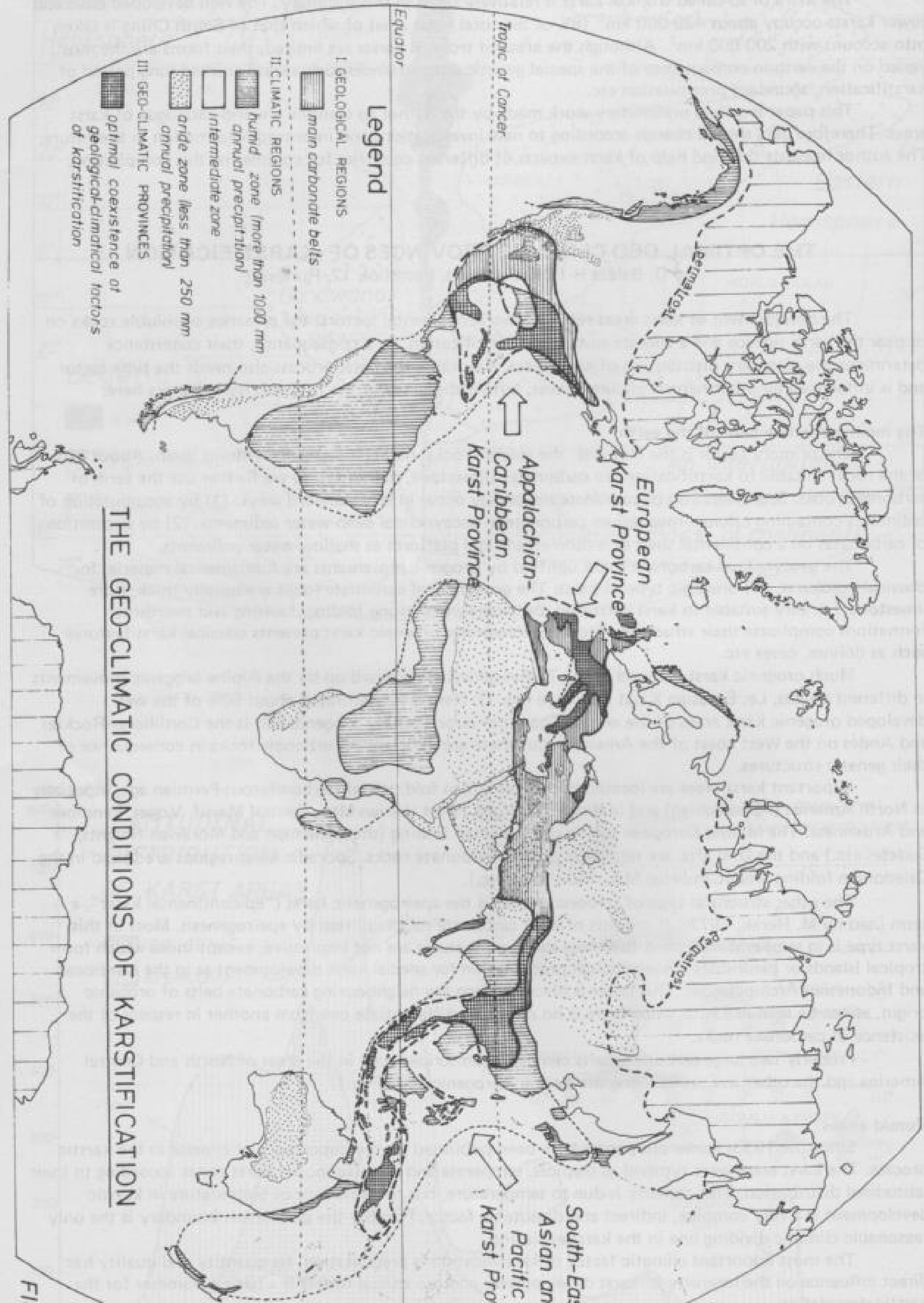


FIG. 1

Optimal geo-climatic provinces of karst

Drawing the outlines of the carbonate belts and those of the humid regions in the same map, we can find some coincidence of the basic factors. These areas are called "optimal geo-climatic provinces" of karstification. As Fig. 1 shows, three large provinces where these favourable conditions at present exist: (1) the Appalachian-Caribbean Karst Province (about 1.3 million km^2), (2) the European Karst Province (1.8 million km^2) and (3) the South-East Asian and Pacific Karst Province (at least 4 million km^2).

According to our calculations, the two main carbonate belts occupy about 14 million km^2 (inclusive of non-karst areas). The extent of the humid areas is approximately 35 million km^2. The total coincidence of the two factors are present only at an area of about 7 million km^2. There are, of course, other places where natural circumstances are similar to those mentioned above, but these form only isolated small regions. On the contrary, there are unfavourable conditions inside the large optimal geo-climatic provinces.

KARST DU MONGIOIE (Italie): UN EXEMPLE TYPIQUE DU KARST DE MONTAGNE

C. Balbiano d'Aramengo
Società Speleologica Italiana
Via Balbo 44, Torino.

V. Bergerone
Società Speleologica Italiana
Via Balbo 44, Torino
Speleo Club Saluzzo "Costa", CAI

F. Cossutta
Società Speleologica Italiana
Via Balbo 44, Torino
Gruppo Speleologico Biellese, CAI

The authors describe the geographical, geological and speleological characteristics of the Mongioie (Maritime Alps, Italy), a mountain showing very interesting features.

About 200 potholes have been discovered in 3,5 km^2; most of them represent a recent surface karst; other caves show phreatic or vadose features and were formed before the last glaciation; some of them were probably formed in the Tertiary Era and they have been decapitated by glacial erosion.

One cave (Abisso dei Gruppetti, 221 m. deep, 699 m. long) drains a little water, which joins the "Le Vene" cave, the main resurgence of the massif. Up to now no explorable connection has been found and it seems that the water is mainly absorbed in the massif through narrow fissures.

Le Mongioie, bien qu'il soit un massif encore peu connu par les spéléologues, contient des phénomènes karstiques très remarquables, surtout pour ceux qui aiment étudier le karst de montagne.

Il fait partie des Alpes Maritimes, étant compris entre les vallées du Tanaro, Corsaglia et Ellero. Les versants sur le Tanaro et la Corsaglia sont très raides et probablement ils ne contiennent pas des phénomènes karstiques importantes, bien qu'on n'ait jamais fait une vrai recherche de grottes. Au contraire le versant de la vallée de l'Ellero est plutôt doux et dans les 3,5 km^2 de calcaires qui affleurent on a déjà trouvé presque 200 grottes.

C'est dans cette zone qu'on a fait jusqu'à présent 5 campagnes de prospection et exploration: en 1969, 1970 et 1971 y a travaillé le G.S.P. de Turin; en 1975 et 1976 le S.C.S. CAI de Saluzzo et le G.S. Bi de Biella. Les campagnes 1969-70-71 avaient pour but principal de chercher beaucoup de grottes, avec l'espoir de trouver une liaison avec la source de Le Vene, qui était supposée être la source principale de ce massif. Dans les campagnes 1975-76, bien qu'on ait continué à chercher (et trouver) des nouvelles grottes, on a surtout cherché d'interpréter les caractéristiques du phénomène karstique, en utilisant les données géologiques (stratigraphie, tectonique), hydrologiques et spéléologiques qu'on avait.

A l'heure actuelle il y a encore des zones peu prospectées; on connait aussi des grottes dont l'exploration est pour le moment barrée par la neige qui ferme les trous et donc une partie des données que nous allons montrer est à considérer comme provisoire.

Geologie

La succession stratigraphique du Mongioie, d'après les études récentes de Vanossi (5) est la suivante:

- un substrat imperméable constitué par des porphyroides du Permien et des quartzites du Trias inférieur.
- calcaires dolomitiques du Trias moyen et supérieur.
- calcaires schisteux du Crétacé supérieur.
- pélites de l'Eocène (ces dernières sont celles que dans les vieilles cartes géologiques on appelait "flysch") qui recouvrent une partie des calcaires et qui sont presque imperméables.

Mais la roche qui affleure le plus souvent sur le versant ouest du Mongioie est le calcaire très blanc du Malm, où se trouvent presque toutes les grottes.

Bien que le Mongioie soit très tectonisé, la succession stratigraphique est en général bien conservée, parce que les couches ont rarement une pente supérieur à 30°. Au contraire le massif est intérsecté, par beaucoup de failles, la plupart des quelles a la direction NNE-SSO. Ces failles sont bien reconnaissables parce que le bloque occidentale est toujours plus élevé que l'orientale. C'est rare qu'on puisse calculer la valeur du réjet, puisque les failles mettent en contact des roches même age (Malm), mais probablement il s'agit d'un valeur considérable, puisque il n'a pas été annullée par l'action du glacier qui descendait du sud au nord mais aussi de l'est à l'ouest, et donc en quelque cas devait remonter les failles. Beaucoup de fois les miroirs de faille sont si parfaits et bien conservés, qu'il parait difficule penser que le glacier ne les ait pas de touches, et donc on

pourrait supposer l'existence d'une tectonique postwurmienne (il s'agit naturellement d'une hypothèse qui doit être vérifiée).

A propos du glacier, il faut dire que la morphologie générale du Mongioie est effectivement une morphologie glaciaire qui s'est bien conservée du Wurm jusqu'aujourd'hui parce que le ruissellement superficiel est pratiquement nul. Mais naturellement la morphologie de détail est karstique: lapiés, petites dolines et ouvalas sont bien représentés. Le lapiaz du Mongioie surtout a des caractéristiques vraiment spectaculaires qui justifieraient une étude particulière pour la grande quantité de types morphologiques qui y sont representés.

Les grottes

Et voyons maintenant quelles sont les caracteristiques spéléologiques du Mongioie. Jusqu'à présent on connait 190 grottes qui sont toutes dans le versant ouest, le seul qui a été prospecté plutôt bien. Les zones A, B, D, E ont une densité de grottes plus grande que les zones C, F, G, H. Cela est dû à des motifs contingents (ce sont les zones les plus prospectées et celles à moindre altitude, donc la neige laisse plus tôt l'entrée libre) mais aussi à des motifs liés à la localisation qui ne sont pas encore completement claires (il y a des larges étendues de roches non karstifiables, surtout pélites, et pour une bonne partie de l'année la temperature est au dessous de 0°C).

Le nombre de grottes est grande, mais la profondeur moyenne est petite. En effet voice les grottes regroupées selon la profondeur:

plus de 100 mètres	2
40 – 100 mètres:	4
10 – 40 mètres:	50
5 – 10 mètres:	134

Et aussi le développement est toujours petit, puisque la plupart des grottes est verticale:

plus de 500 mètres:	1 (Abisso dei Gruppetti)
100 – 500 mètres:	2
50 – 100 mètres:	6

Les autres ont un développement de moins que 50 mètres et, en général, moins que 10 mètres.

(Dans cette classification on a omis la grotte des Vene, c'est à dire la resurgence principale du massif qui est connue pour plus de 3 kilomètres, mais qui n'a pas fait l'objet d'étude dans ces campagnes).

Ces grottes ont étés classifiées du point de vue morphologique et génétique en les regroupant en deux grandes catégories:

1. Grottes de karst superficiel: 126
2. Grottes de karst profond: 40
   (Morphologie douteuse: 24)

Le premier groupe comprend les grottes de lapiaz et les puits à neige; il s'agit de grottes de petite dimension, généralement inférieures à 20 mètres et presque toujours verticales. Nous pensons que ces cavites se soient formées après le Wurm par l'action de la neige et de l'eau de pluie. Dans le même groupe nous avons aussi compté beaucoup de formes d'origine exclusivement tectonique mais qui semblent plutôt récentes.

Les grottes de karst profond comprennent des puits cascade et des conduits phréatiques ou vadoses qui, avec deux seules exceptions (pour le moment), dans le Mongioie sont toujours fossiles.

Nous pensons que les grottes du deuxième groupe, formées avant le Wurm et quelqu' unes probablement aussi dans le Pliocène, se soient creusées quand la surface du Mongioie était beaucoup plus élévée que maintenant et se soient décapitées par l'érosion glaciaire.

Naturellement cette classification a beaucoup d'incertitude et d'approximation; il y a des formes qui sont difficiles à interpréter et des autres qui ont des caractéristiques de grottes anciennes et récentes à la même fois, mais quand même on peut avoir une idée du type de karst du Mongioie.

Le circulation souterraine

Les deux groups de grottes ont une action très faible sur le drainage souterrain de l'eau, c'est à dire qu'ils contribuent très peu à l'alimentation de la source des Vene.

Nous avons parlé de deux exceptions: en effet les grottes A3 et A20 ont une circulation permanente, même si le débit est très faible; la grotte A20 (gouffre des Gruppetti) est dans le Mongioie la grotte la plus profonde (221 mètres), la plus développée (699 mètres) et jus qu'aujourd'hui la mieux étudiée; elle a été creusée en régime phréatique (et beaucoup de galeries en constituent des remarquables exemples) mais sur la morphologie primaire s'impose maintenant une morphologie vadose due à l'eau qui actuellement va de l'extérieur jusqu' au collectuer; il s'agit quand même de petites quantitées (1 – 2 litres/sec en période normale).

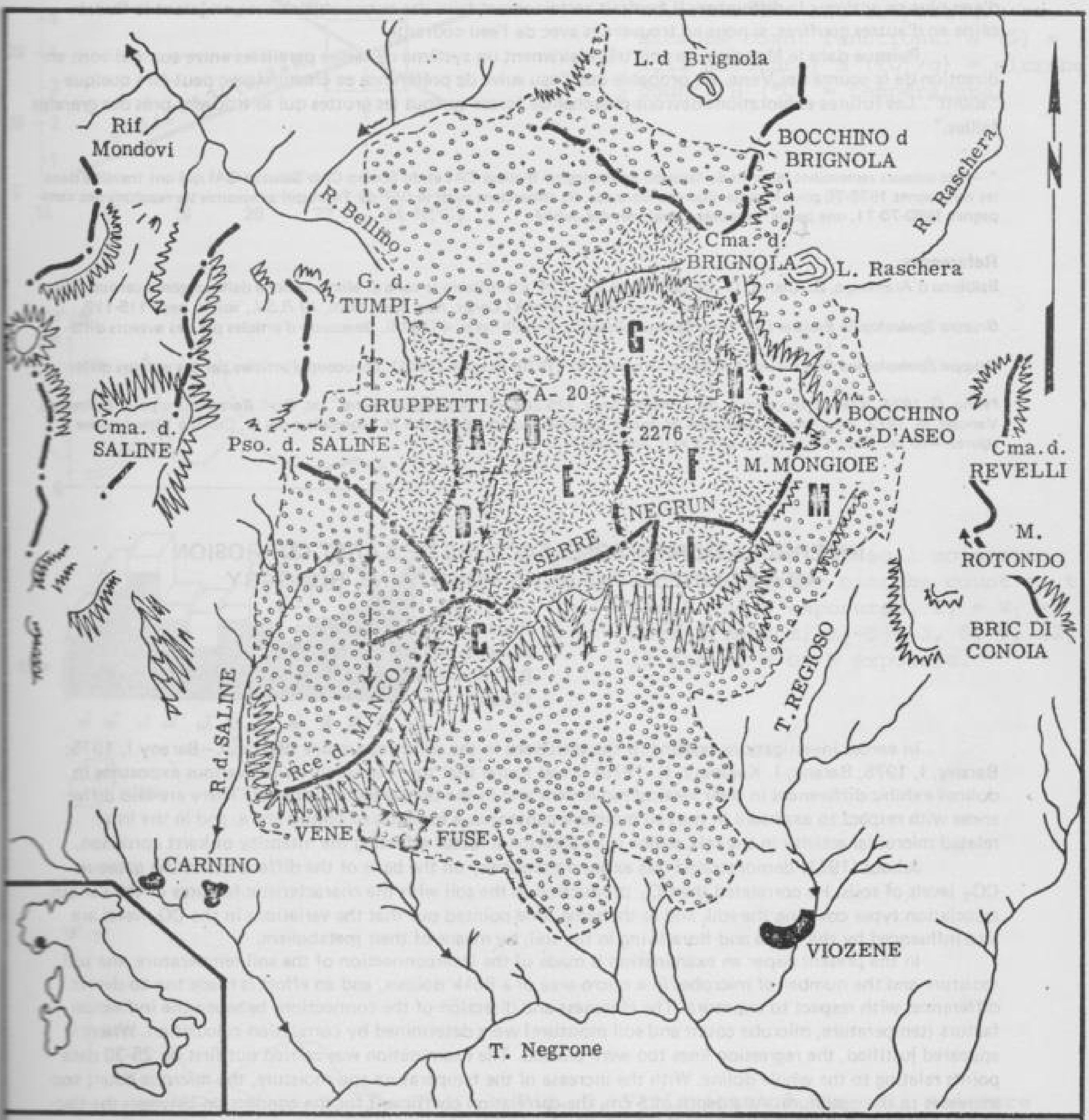
En conclusion, nous avons vu que, sur une extension de 3,5 km^2, il ne y a pas de ruissellement superficiel, iln'y a beaucoup de grottes qui représentent un karst jeune de surface et iln'y a aussi des grottes phréatiques qui avaient constitué une vie de drainage importante, mais qui actuellement sont fossiles. Il faut donc resoudre ce problème: comment est-ce-que l'eau de pluie et de neige rejoint le collecteur souterrain? Il s'agit d'une absorption très diffure, due au fait que le calcaire du Malm très blanc et très pure, est bien soluble, avec peu de residu et se laisse creuser par de petites quantités d'eau qui vont sous terre par de petits trous inaccessibles à l'exploration.

Sur le Mongioie il y a aussi des affleurements de Bélite, une roche peu perméable qui facilite la formation du ruissellement en surface, mais le contact pelite-Malm est tectonique et presque toujours au thal-

weg, où naturellement il y a de l'alluvion, et donc aussi dans ce cas les voies de drainage ne sont pas explorables.

Si on n'a pas encore trouvé un gouffre qui lie le Mongioie à la source des Vene, et pas même un gouffre de grande profondeur avec de l'eau, les explorateurs ne sont pas sans espoir: certaines zones du Mongioie ont été peu prospectées et surtout on attend à une année de secheresse dans laquelle on puisse trouver ouverts les gouffres qui normalement sont bouchés par la neige même dans le mois d'août.

Pour le moment, puisque on ne connait pas quelles sont le voies de drainage hypogé, il faut faire des hypothèses: deux expériences à la fluoréscéine nous assurent que l'eau absorbée par le versant ouest du Mongi-



oie ressort dans la vallée du Tanaro à la source de "Le Vene", constituée par deux sources distinguées. Les expériences de coloration nous ont donné des résultats dont on croit utile à parler en détail.

Dans la première expérience la fluoréscéine a étée dans la grotte " I Tumpi" qui est la grotte à moindre altitude dans tout le massif; l'eau colorée est sortie seulement par une des sources des Vene (expérience du G.S.P., 1970), tandis que dans la deuxième expérience (1975) la fluoréscéine, jetée dans le gouffre des Gruppetti, est sortie par toutes les deux sources, mais dans une aprés deux jours et dans l'autre après 4-5 jours. Cela nous conduit à imaginer un reseau plutôt complex, avec une diffluence très loin de la source et avec des apports d'eau plus en aval que la diffluence. Il faudrait certainement faire des autres expériences, en jetant la fluoréscéine en d'autres gouffres, si nous en trouverons avec de l'eau courante.

Puisque dans le Mongioie on voit très clairement un système de failles parallèles entre eux qui vont en direction de la source des Vene, est probable que l'eau suive de préférence ce chemin, avec peut-être quelque "shunt". Les futures explorations devront chercher de forcer surtout les grottes qui se trouvent prés des grandes failles.*

* — Les auteurs remercient les amis du Gruppo Speleologico Biellese CAI et du Speleo Club Saluzzo CAI qui ont travaillé dans les campagnes 1975-76 pour la collection des données. Ils remercient aussi le GSP de Turin qui a transmis les resultats des campagnes 1969-70-71, une partie desquels n'avait pas été publié.

References

Balbiano d'Aramengo, C., Clerici, C., De Laurentiis, P., 1974' Identificata la zona di alimentazione della sorgente carsica delle Vene in val Tanaro. *Atti XI Congr. Naz. Spel. Mem. XI R.S.I.*, vol. II, page 115-119.

Gruppo Speleologico Biellese CAI' Orso Speleo Biellese n. 3(1975) et n. 4 (1976). Beaucoup d'articles par des auteurs différents.

Gruppo Speleologico Piemontese CAI Uget: Grotte n. 42 (1970) et n. 45 (1971). Beaucoup d'articles par des auteurs différents.

Peano, G. 1974. Il fenomeno carsico nel Cuneese, pagg. 225-267. *En "Montagne nostre" Ist. Graf. Bertello, Borgo S. Dalmazzo.*

Vanossi, M. 1972' Rilevamento geologico ed analisi strutturale delle dorsali del M. Mongioie e del M. Cimone (Brianzonese ligure). *Atti Ist. Geol. Univ. Pavia*, vol. XXIII, page. 29-71.

INTERRELATION OF SOME FACTORS OF KARST CORROSION IN A DOLINE IN THE BUKK MOUNTAINS, HUNGARY

Ilona Barany and G. Mezosi
Jozsef Attila University,
P.O. Box 428, Szeged,
Hungary.

In earlier investigations relating to the variations in the soil temperature (Boros, J.—Barany I, 1975; Barany, I, 1975; Barany, I. Kajdocsy, K. 1976) it was found that the heat levels on the various exposures in dolines exhibit differences in their vertical movement and in the temperature extremes. There are also differences with respect to exposure in the soil moisture content as a function of temperature, and in the interrelated microbial activity in the soil, which is an additional factor affecting the intensity of karst corrosion.

Jakucs (1971) demonstrated this exposure tendency on the basis of the differences in the gaseous CO_2 levels of soils. He correlated the CO_2 production in the soil with the characteristic features of the various association types covering the soil, and at the same time pointed out that the variations in the CO_2 level are also influenced by the fauna and flora living in the soil, by means of their metabolism.

In the present paper an examination is made of the interconnection of the soil temperature, the soil moisture and the number of microbes in a micro-area of a Bukk dolines, and an effort is made too to detect differences with respect to exposure. The closeness and direction of the connections between the individual factors (temperature, microbe count and soil moisture) were determined by correlation calculation. Where it appeared justified, the regression lines too were plotted. The examination was carried out first on 25-30 data points relating to the whole doline. With the increase of the temperature and moisture, the microbe count too increases to the optimum. At a depth of 5 cm, the correlation coefficient for the connection between the bacterium count and the temperature is $R = 0.46$. The connection between the temperature and the moisture is essentially weaker at this depth. At a depth of 30 cm, however, the correlation coefficient for the moisture and the bacterium count is the higher ($R = 0.42$), the connection with the temperature being very weak here. (Both correlation coefficients differ significantly from 0.) All this is related to the fact that the development of the bacterium population is affected in the soil layer close to the surface by temperatures exhibiting larger extremes, and at a depth of 30 cm by the less variable moisture content.

The regression curves (in our case straight lines) of the temperature vs. moisture and temperature vs. microbe count regression functions were drawn for a depth of 5 cm (Fig. 1). This indicates that the temperature optimum for which development of the bacterium population is most certain is found at 23.4°C. At this temperature the soil moisture content is ca. 20%, and the microbe count is 3.9×10^6 /g. The scatter was taken into an optimum range. This range can be given here with temperature values of 22.2-24.6°C, moisture contents of 14-25%, and microbe counts of $3 \times 10^6 - 5 \times 10^6$ /g. The appreciable decrease of the soil moisture at a higher temperature has an unfavourable effect on the development of the microbe count.

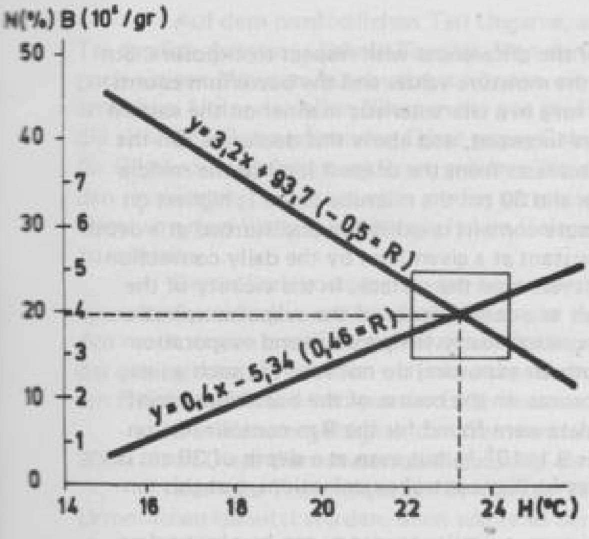


Fig. 1. Regression lines of the temperature vs. moisture and temperature vs. microbe count functions. N (%) = soil moisture; B (10^6/g) = microbe count; H (°C) = temperature.

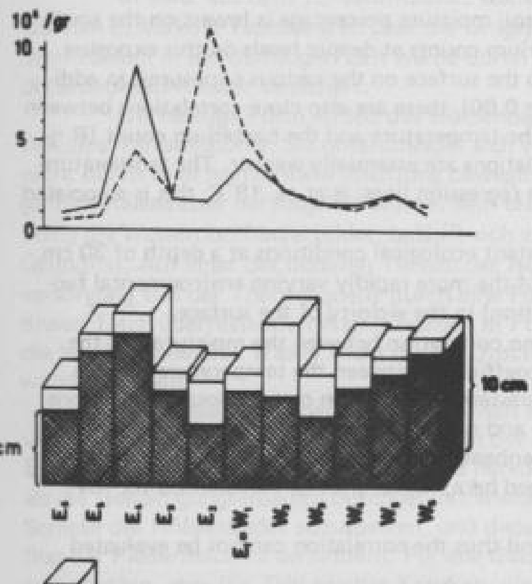


Fig. 2. Variations of the soil moisture and the aeroboc microbe count on t the E and W exposures. $E_1 = W_1$ = doline bottom; E_2-E_7: 3, 6, 9, 12, 15 and 18 m on W exposure.

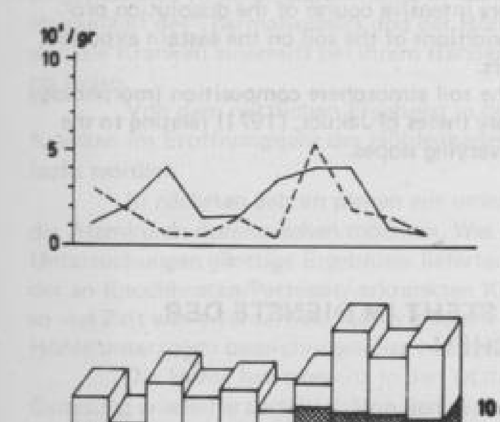


Fig. 3. Variations of the soil moisture and the aerobic microbe count on the S and N exposures. $S_1 = N_1$ = doline bottom; S_2-S_7 : 3, 6, 9, 12, 15 and 18 m on S exposure; N_2-N_4: 3, 6 and 9 m on N exposure.

Fewer data (in general 10) were available for analysis of the differences with respect to exposure, but the tendencies can be well demonstrated. Figures 2 and 3 show the moisture values and the bacterium counts on four different exposures. The moisture and bacterium count vary in a characteristic manner on the eastern exposure. From the 3 m to the 9 m contour line the soil moisture increases, and above this decreases. On the other exposures of the doline the moisture content of the soil decreases from the deepest level to the middle of the slope, and subsequently increases. At depths of both 5 cm and 30 cm the microbe count is highest on the eastern exposure. The exposure-different nature of the moisture content is exhibited undisturbed at a depth of 30 cm, since the soil moisture is prevented from becoming constant at a given level by the daily convection precipitation (in the midday and early afternnon hours), in the layers near the surface. In the vicinity of the surface the moisture also varies more rapidly than at deeper levels as a consequence of the evapotranspiration. The characteristic daily courses of the temperature and the evaporation (early temperature and evaporation maxima, in general with lower values than on the western or southern exposure) do not result in such an extensive drying-out of the soil as on the western or southern exposures. In the course of the bacterium count determination, in harmony with the soil moisture, outstanding data were found for the 9 m contour line on the eastern exposure. At a depth of 5 cm, the bacterium count is 9.1×10^6 /g, but even at a depth of 30 cm it is 4.3×10^6 /g. Determination of the bacterium count still requires further control examinations, but this tendency with regard to the exposure must be accepted.

In the interrelation of the bacterium count and the moisture, a similar tendency can be observed on the northern exposure, but here the quantitative proportions of the bacterium population are moderated by the lower nature of the temperature, and presumably by its daily course.

Both close to the surface and at a depth of 30 cm, the soil moisture percentage is lowest on the southern exposure, and this leads primarily to a decrease in the bacterium counts at deeper levels on this exposure.

When a study is made of the 5 cm soil layer adjacent to the surface on the various exposures, in addition to the correlation of the temperature and the moisture ($R = 0.60$), there are also close correlations between the moisture and the bacterium count ($R = 0.79$) and between the temperature and the bacterium count ($R = 0.74$) on the eastern exposure. At a depth of 30 cm, these correlations are essentially weaker. The temperature optimum of the population here, determined with the aid of the regression lines, is at ca. 18°C; this is associated at this depth with a soil moisture of ca.30%.

Although the microorganisms develop under more constant ecological conditions at a depth of 30 cm, the characteristics are nevertheless more favourable in the case of the more rapidly varying environmental factors (temperature, precipitation, different intensities of evaporation) in the vicinity of the surface.

In the 5 cm soil layer on the western exposure there is no correlation between the moisture and the bacterium count, but the value of $R = -0.74$ for the correlation coefficient between the temperature and the bacterium count indicates an interrelation equivalent to that on eastern exposure. In our previous publications it was pointed out that the soil is heated up more strongly here, and on proceeding upwards on the slopes the maxima are higher than on the other exposures; this leads to an enhanced drying-out of the soil, as a result of the increased evaporation. The heating-up is the most prolonged here, which gives an explanation for the lack of a moisture correlation.

Too few data are available for the southern exposure, and thus the correlation can not be evaluated mathematically.

It may be stated, therefore, that on the eastern exposure, the temperature and the moisture are in close correlation with the number of bacteria in the 5 cm soil layer next to the surface. On the southern and western exposures the bacterium count is in close correlation with the temperature.

In the soil layer adjacent to the surface the number of microorganisms is determined predominantly by the temperature, whereas at a depth of 30 cm their number depends primarily on the soil moisture content.

On the above basis, it becomes understandable that the more intensive course of the dissolution processes is favoured by the characteristic temperature and moisture conditions of the soil on the eastern exposure, and by the microbe population there, which depends on these factors.

These results are in agreement with experimental data on the soil atmosphere composition (morphology of karsts) obtained in the Bukk in 1968, and throw new light on these theses of Jakucs, (1971) relating to the morphogenetics of karst dolines with asymmetric ground-plans and varying slopes.

DAS HOHLENBAD IN MISKOLC-TAPOLCA STEHT IM DIENSTE DER THERAPIE DES MENSCHEN

Jenö Barsonyos
H 3501 Miskolc
pf: 361, Hungary

At Miskolc-Tapolca on the southern slope of Bükk-Mountains, Hungary, a spring of 2500-3000 l/min. wells up in one of the caves. The water is rich in calcium, magnesium and hydrocarbonate and it contains some fluorine, iodine, free carbonic acid and radium emanation. In the cave a bath of 250 m^2 water surface has been constructed where chronic diseases of the respiratory organs are successfully cured and at the same time complaints of neurogenic origin are also treated with favourable results. By further exploration of the galleries extension of the therapeutical area can be expected.

Auf dem nordöstlichen Teil Ungarns, am Rande der Bükk-Gebirge erstreckt sich in einem mahlerischen Tal der Erholungsort Miskolc-Tapolca. Von der Innenstadt Miskolc's ausgegangen, auf der gut ausßebauter Strasse nach einigen Minuten Autobusfahrt können wir diesen in besonders schöner Umgebung liegenden Erholungsort erreichen. Unter den alten Bäumen der gut gepflegten Parkanlage sind schöne Spazierwege ausgebildet, wodurch die sich nach Ruhe sehnenden Gäste genug Gelegenheit haben, angenehme Spaziergänge machen. Darüber hinaus, für Gäste, die sich bereit erklären, grössere Wanderungen zu unternehmen, bietet sich die Möglichkeit an, auf den markierten Touristenwegen zu den verschiedenen Ausflugsorten zu gelangen. Den Badeaufenthalt liebenden Gäste von dem Wetter unabhängig haben Gelegenheit, von den Frei-, Thermal-, Wannenbäder und Badeteich zu wählen.

Dieser Badekomplex ist von besonderer Bedeutung: es ist einzigartig in Europa, in eine natürliche Felsgrotte gebettetes Warmwasserbad, das als ein Komplex, mit dem Thermalbad und dem Badeteich verbunden ist. Am rande des im westlichem Teil der Parkanlage des Badekomplexes befindlichen Kalksteingebirge – entlang der geologischen Bruchlinie – direkt nebeneinander kaltes Karstwasser und warmes Thermalwasser in sehr grossen Reichlichkeit brechen aus der Erde hervor.

Die Wasserergiebigkeit der Warmwasserquelle von der Temperatur 31° C beträgt pro Minute 2500-3000 Liter. Diese Warmwasserquelle besorgt den ganzen Komplex mit Badewasser.

Von den Thermalquellen in Miskolc-Tapolca sei es mit Recht zu vermuten, dass diese bereits von den Urmenschen benutzt würden, denn während der Ausgrabungen in einem Schlot des Höhlenbades fand man einen Hinterhauptknochen einer Frau, und nebeneinander liegend einen Kirschzahn sowie zahlreiche abgesplitterten Steinwerkzeuge.

In einer aus dem 13. Jahrhundert stammenden Aufzeichnung kann man lesen, dass die Höhlen-Quellen in Miskolc-Tapolca weit über die Umgebung als ein berühmter Kurort bekannt seien. Die Betreuung der Kranken in der damaligen Zeit würde durch die Klosterbrüder des in der Nachbarschaft gelegenen Benediktinerorden-Kloster versichert.

Die heutige Form erhielt das Höhlenbad in den Jahren 1958-1959. Das Höhlenbad selbst ist eigentlich eine Terassenhöhle. Sie unterscheidet sich von anderen Höhlen underer Heimat darin, dass dise Höhle nicht durch as in horizontaler Richtung bewegliches kaltes Karstwasser, sondern durch die von unten entsteigenden Heisswasser herausgelöst wurde. Sein bisher aufgeschlossene und in Betrieb gesetzte Gebiet was gleichzeitig die Wasseroberfläche bildet, beläuft sich etwa 250 m^2, mit dem etwas korrigierten, aber originellen Grundriss. Auf einer der höheren Terasse der Höhle wurde ein künstlicher Teich ausgebildet, dessen Wasserversorgung von der Thermalquelle durch eine Pumpe mit der Leistung von 1000 Liter/Minut erfolgt. Die diesen Teich überflissenden Wasser werden in Form von Wasserfällen an das untere Niveau gelangen, wobei die herabströmenden Wasser nicht nur als Duschbad, sondern auch als eine natürliche Massage können angewendet werden.

Das Wasser der Thermalquelle enthält Kalcium-Magnesium-Hidrocarbonat, etwas Jod, Brom, Fluor, und auch freie Kohlensäuere. Das Wasser in der Höhle hat einen Radiumemanationsgehalt von 0,61 Mache-Einheit, der Radiumemanationsgehalt des hervorschiessendes Gases aber 3,57 Mache-Einheit. Im Jahre 1961, als die Gewältigungsarbeiten durchgeführt wurden gelang es uns, auch die bisher verborgen gebliebenenen Schlote des Höhlenbades abzusperren, und dadurch die Ausströmung der heilkräftigen Luft und den Einflug der Fledermaus zu verhindern. Für alle Gäste, die die Eintrittskarte gekauft haben, ist das Höhlenbad zu benutzen, aber die Zahl solcher Kranken, die zu den Lasten der Krankenversicherung zu Höhle eingewiesen sind, beträgt järlich um etwa 40.000, wobei der Zeck dieser Einweisung ist die Therapie der Kreislaufstörungen, der Blutgefäss-Erkrankungen und der verschiedenartigen Erkrankungen des Nervensystems.

Wegen dem Radiumemanationsgehalt, nicht nur das Höhlenwasser, sondern auch deren Luft heilkraftig ist und hat sich bei der Behandlung der Erkrankungen von Atemwege bereits vielfach bewährt. Die eingewiesenen Kranken stehen heute in keiner besonderen ärztlichen Behandlung, ihre Heilung ist rein der Heisamkeit des Thermalwassers und der Höhlenluft zu verdanken. Bezüglich der Benutzung der Höhle können sich die Kranken einerseits bei ihrem ständigen behandelnden Arzt und anderseits bei dem Badearzt einen rat holen.

Von dem nützlichen Ergebniss in der Therapie spricht die Tatsache, dass die Zahl der eingewiesenen Kranken im Eroffnungsjahr des Höhlenbades auf 9227 Personen betrug, und zur Zeit ist diese Zahl vervierfacht worden.

In nächsten Jahren planen wir unter anderen, die Erschliessung der trockenen Höhlenteile, wo wir die Atemkuren durchmachen möchten. Was die Atemkuren anbelangt, kann man sagen, dass die bisheringen Untersuchungen günstige Ergebnisse lieferten. Sollte man sogar einen Fall erwähnen, dass sich die Symptome der an Keuchhusten/Pertussis/ erkrankten Kinder rapid linderten und bis zur völligen Genesung bloss halb so viel Zeit war erforderlich, falls wie solche erkrankten Kinder sich gegenüberstellten, die einer Kur in der Höhle unterzogen bezeichungsweise nicht unterzogen worden.

Die Höhle hatte bereits in den letzten Jahren bei mehrtausend Menschen dazu beigetragen, ihre Genesung wiederherzustellen. Von den geplanten Erschliessungen erwartet man die Erhöhung der zur Zeit beschränkten Kapazität.

PRELIMINARY RESULTS OF THE APPLICATION OF QUATERNARY GEOLOGICAL METHODS OF SPELEOGENETIC STUDIES OF A BELGIAN CAVE

Bruno Bastin
Laboratoire de Palynologie
Universite de Louvain, 4,
Place Crois-du-Sud B.1348.
Louvain-la-Neuve.

Christian Dupuis
Laboratoire de Mineralogie-
Petrographie, Faculte polytechnique
de Mons, 9 rue de Houdain, B.7000.
Mons.

Yves Quinip
Laboratoire de Mineralogie-Petrograph
Petrographie, Faculte polytechnique
de Mons, 9 rue de Houdain, B.7000.
Mons.

Karst frequently contains sediments which are contemporary and/or subsequent to hypogean circulation. Such deposits offer two main interests:

1. They show more or less past hydrodynamics of the karst.
2. They form protected records of the regional gemorphological evolution.

Up to now, three types of studies have been devoted to karst fills:

1. detailed studies of prehistoric horizons located near the mouths of the caves and disconnected from karstic evolution,
2. geological or paleontogolical studies of fossil karst fillings (bauxites, phosphorites, etc . . .),
3. superficial investigations of deposits situated far from the entrances.

Considering the above, our purpose is to realize :

1. a multi-field research, using the various techniques of Quaternary geology : stratigraphic analysis, sedimentology, geochemistry, paleontology, mineralogy of concretions, thermoluminescence, etc. . .
2. a study of sediments in relation to the karstic context to elucidate their genesis in the dynamics of subterranean networks (sinks, emergences, etc . . .) in relation to the morphology (gallery, well, room . . .) and the micromorphology (scallops, cupolas, flutes, overdeepenings, etc. . .).

Below are the results of the application to a section in the sediments of the main gallery in the cave of Eprave. We have more especially dealt with the stratigraphic, palynologic and sedimentologic (preliminary study of clays and granulometry) of the deposits.

The Main Context of the Cave of Eprave (Loome Basin)

The cave in the limestones of the upper Givetian (Devonian) situated in the downstream side of the complex network of on-Jemelle-Rochefort-Eprave (Delbrouck, 1970). It is a subterranean meander resection (Quinif, 1977). Opening 16 meters above the river and about 100 meters from one of the active emergences of the network, a Vauclusian resurgence at least 45 meters deep (Premier Colloque, 1972), it is composed of galleries crossing in form of a maze (fig. 1).

The cave is an ancient vauclusian resurgence. The galleries are regular and well calibrated, especially the main drain which leads from the entry to the maze. Rock benches, cupolas and smooth walls are the visible "microforms". On the other hand no scallops potholes, overdeepenings ("microforms" of free surface fluvia flow) or other microforms can be seen.

The Studied Section

1. *Situation* (fig.1)

The studied section is located in the ancient main drain between the maze and the resurgence. Figures 1c and 1d show that all or part of the studied sediments might have been under the piezometric surface or, at least under water, when the cave was active.

2. *Stratigraphic and preliminary sedimentologic data* (fig.2.)

The study of the section leads us to distinguish two quite different assemblies, the first includes the beds 1 to 4, the second the beds P1 to P4.

The first, sandy at the base, becomes progressively thinner at the top. It contains, especially in its lower part, particular carbonated and ferromanganic concretions and there are abundant tiny modules and remains of pedologic origin (1).

The second assemblage scoured out the first. It is composed of some clay beds with loamy pebbles with stalagmitic floors between; a thick stalagmite crust caps these beds and seals a gully. The floors show interruption of detrital sedimentation and dewatered phases (micro-rimstones) Bones are included in the reworked elements in the clays (vertebra, teeth and human remains, goat, hare). Their nature and their fossilization degree allow us to assign to the second assemblage a Holocene age (2). The clays attract our attention by the presence of interstratified montmorillonite among argillaceous minerals. We presume that the small clay ball levels at the top of beds 2 and 4, indicate sedimentation interruption, or even a dewatered phase. Indeed, a similar facies can often be seen on the top of the fills of numerous galleries in Belgium. The minor unconformity between beds 3 and 4, as well as the gully at level 5, are not so easy to explain at present, but are discussed later.

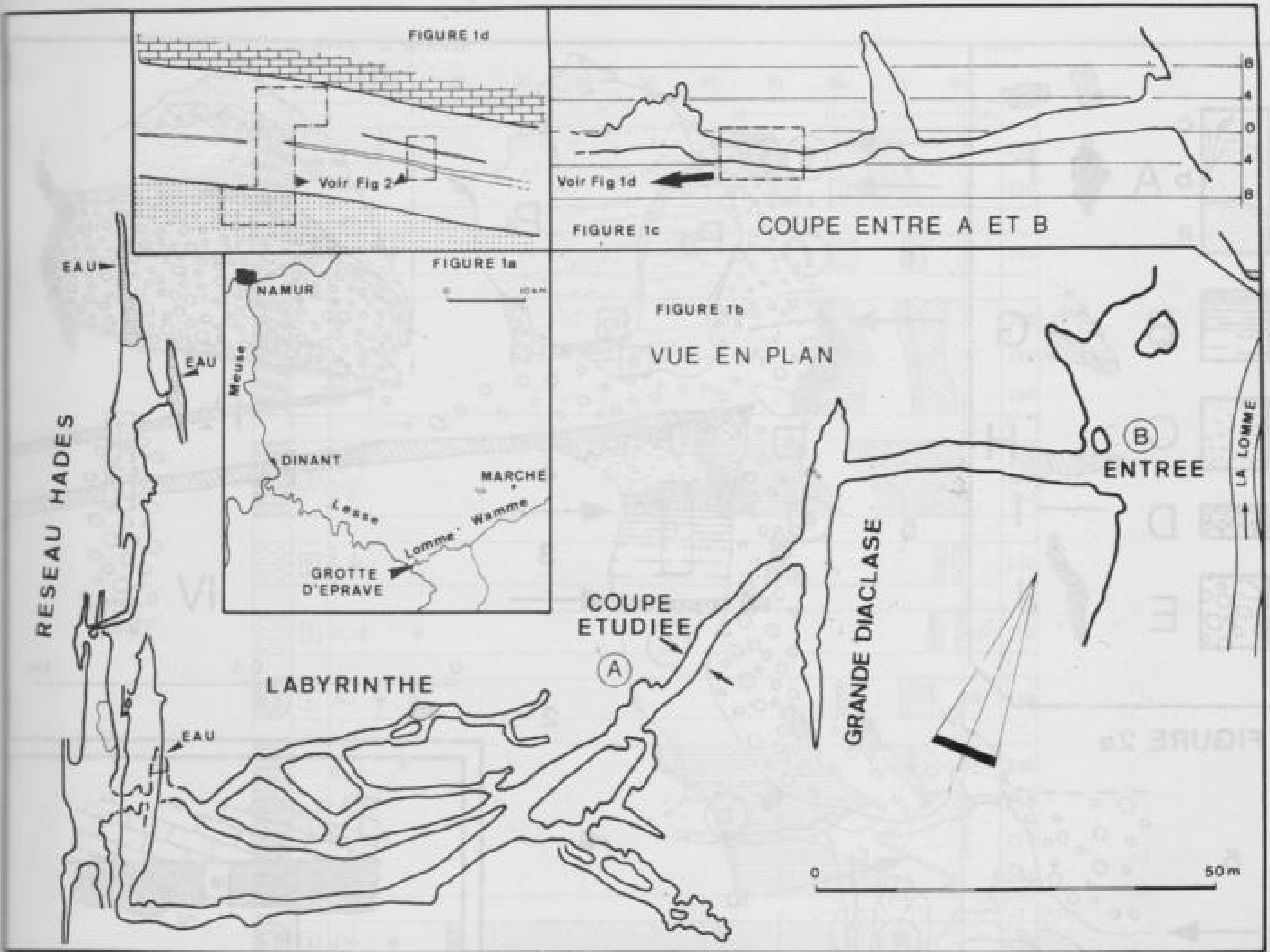


Fig. 1. Location of the studied site.

1a. Situation of the Eprave cave.
1b. Map of the cave with situation of the studied section.
1c. Section of the main gallery.
1d. Situation of the section in the main gallery showing the stalagmitic floors and fill. 1a, 1b, 1c, after P. Vandersleyen (1972).

Palynology. (Fig. 3)

a. *Introduction*

In order to date the succession of deposits by palynology, the beds have been sampled in detail (fig.2.) In the laboratory pollen was concentrated by a flotation process (B. Bastin, 1971). (1, 2).

b. *Pollen contents of the samples*

Varying from one sample to the other, the abundance and the variety of pollen grains is considerably less important in the sediments and the concretions than in the floors and stalagmitic crusts. In the latter preservation of pollen grains is much better. So, we think that the pollen spectra of the stalagmitic floors and crusts are more representative of the vegetation populating the catchment basin of the cave than the spectra obtained in the sediments and the concretions.

c. *Commentary on pollen spectra*

Three types of qute different pollen spectra have been obtained:-

— The pollen spectra obtained in bed 1 (fig 2) are characteristic of a high tree cover (average 94%) and by the predominance of Pinus (86%) over other trees among which only Corylus (2%) and Picea (0.5%) are present. Among herbs, only the Poeceae (2.5%) and the Filicales (1.5%) have a significant percentage. The high corrosion of pollen grains suggests that Pinus is overrepresented in these spectra, Pinus pollen, being the easiest to recognize even in a much corroded condition. We think that those pollen spectra are the reflection of an open vegetation, probably a steepe strewn with pines.

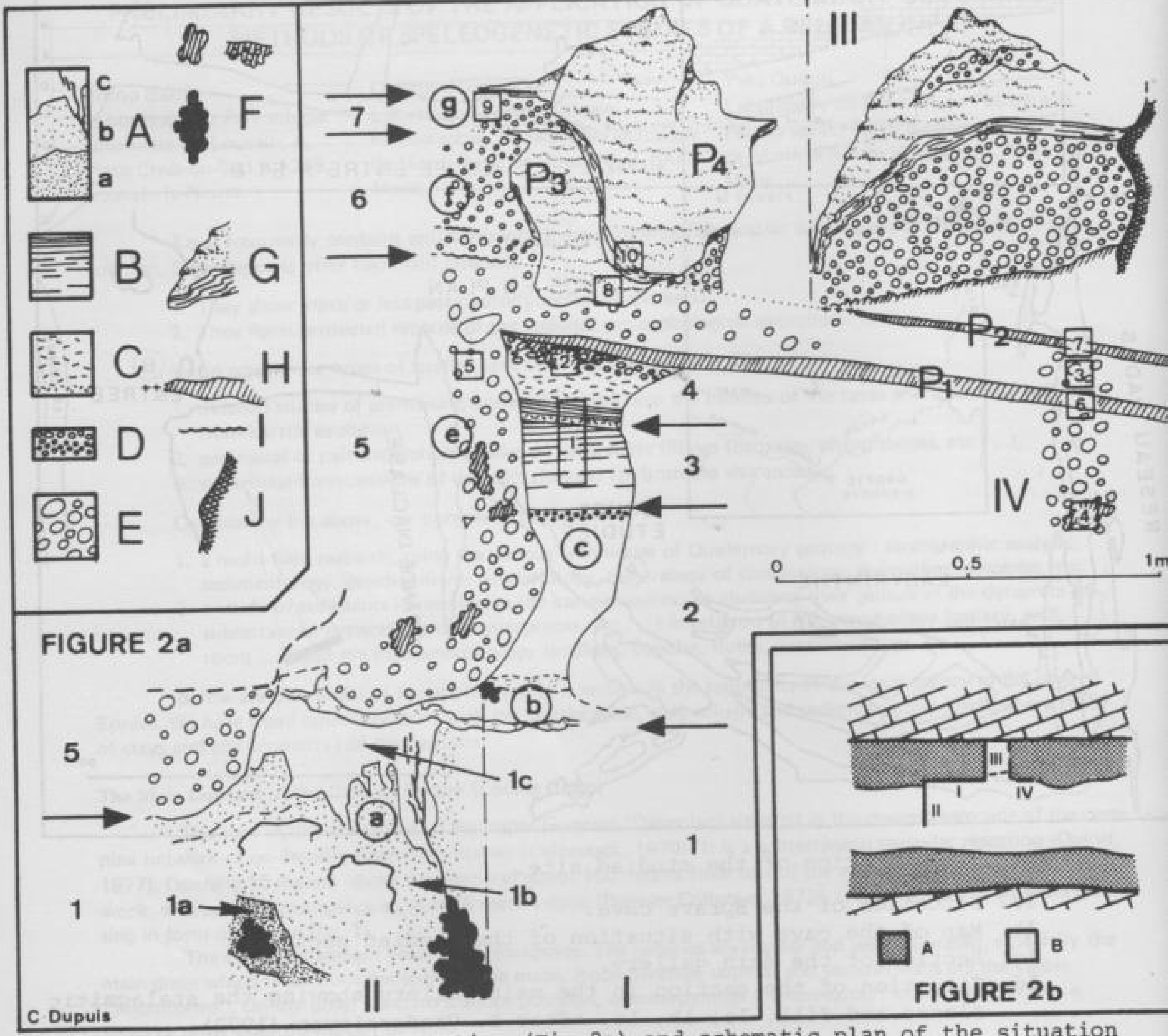


Fig. 2. Details of the section (Fig.2a) and schematic plan of the situation of the sections in the gallery (Fig. 2b).

Fig. 2a.

A = Loamy sand to argillaceous loam with manganese dentrite-covered cracks.
B = Stratified loamy clay.
C = Stratified more or less loamy clay.
D = Small argillaceous balls.
E = Clay with loamy pebbles.
F = Diverse concretions : in black, ferromanganic and carbonate : in hatching; principally clacitic.
G = Stalagmitic crusts.
H = Stalagmitic floors.
I = Hilly surface covered by a black coating and lengthening P2.
J = Bedrock.

The studied sedimentologic samples, from a to g, are indicated by a circle; the pollen samples, from 1 to 10, by a rectangle.

Fig. 2b.

A = Sediment in situ against the walls.
B = Section cut in the deposits.

Remark: The stalagmitic crust sealing the deposits are partly represented in re

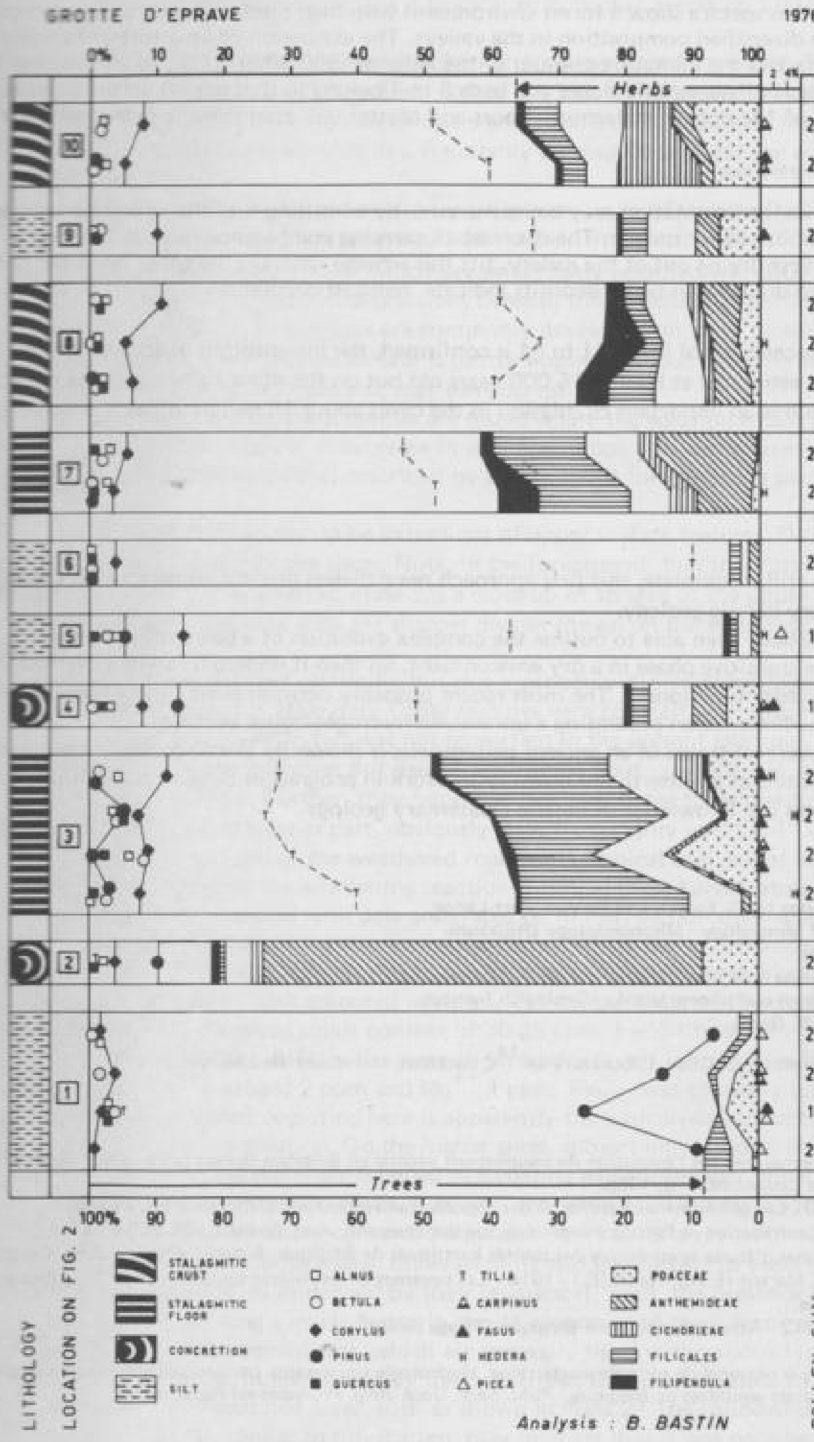


Fig. 3. Pollen spectra.

- In the second pollen spectrum, there is less than 20% of trees among which Pinus once more predominates (10.5%), the herbs are predominantly Anthemideae (65.5%) Poeceae (8.5%). We suppose this pollen spectrum to be the reflection of steepe-like vegetation almost without trees. So we suggest that the emplacement of beds 3 and 4 was in a cold climatic period belonging, at least, to the last glaciation (Weichsel).

- Pollen spectra 3 to 10 are principally characterized by a high tree cover (average 71%) and by a clear predominance of Tilia (52.5%). Among other trees, Corylus (7%) Alnus (2.5%) and Betula (2%) are present throughout Pinus (2%) and Quercus (1%) regularly present, whereas Hedera (1%), Fagus (0.3%) and Carpinus ().2%) appear from time to time. Among herbs, the Filicales (10%) the Poeceae (4%), the Anthemideae (4%) and Filipendula (2%) are present nearly everywhere, the Cichorieae (2.5%) are regularly present, and about twenty other herbs appear from time to time.

The pollen spectra show a forest environment with high predominance of lime on the plateau, with a more diversified composition in the valleys. The expansion of lime forests in western Europe characterizes the climatic optimum of the Atlantic (500-3000 B.C.) , so we consider that the emplacement of stalagmitic floors and beds 5 to 7 belong to that period, in the expectation that the results of 14c data of stalagmitic floors and crusts[3] will confirms the paleontologic date.

Preliminary. interpretations

The observed sedimentation may be interpreted by admitting that the circulation progressively leaves the main drain to utilize lower springs. The decrease of carrying competence recorded by beds 1 and 2, which seems to lead to a first drying out of the gallery, fits this scheme well. On the other hand the gallery probably loses its roll of main drain when bed 3 deposits indicate reduced circulation.

If the Holocene age of levels P1 to P4 is confirmed, the interruption of sedimentation between the assemblages can be estimated at least as 15,000 years old but on the other hand a delicate hydrogeological problem if this requires an important circulation in the caves about 16 meters above the Lomme level.

Conclusions

Although still incomplete, this first approach nevertheless opens new perspectives both in the speleogenesis field and Quaternary karstic geology.

Indeed we have been able to outline the complex evolution of a paleo-drain first in the waterlogged zone, then during a transitive phase in a dry environment. So then it undergoes some violent detrital discharges (as "morphological delta functions"). The most recent probably occured during the Atlantic phase after a very long interruption sedimentation presenting a unresolved hydrogeological problem.

The discovery of traces of an ancient pedogenesis is shown by the discovery of ferrogmanganic and carbonated concretions of a hitherto unknown type. Work in progress in Belgian caves should in the future contribute to extend our knowledge of karstic Quaternary geology.

NOTES

1. Study in progress by G. Stoops and B. Van Vliet-Lanoe, Laboratory of Mineralogy - Micropedology (Rijiksuniversiteit, Gent)
2. The bone remains have been determined by A. Gauthier to whom we address our sincere thanks (Geologich Institut, Rijisuniversiteit, Gent).
3. Study in progress by E. Gilot, Laboratory of ^{14}C datation, Université de Louvain.

BIBLIOGRAPHY

Bastin (B.) - 1971 - Recherches sur l'évolution du peuplement végétal en Belgique durant la glaciation de Würm. *Acta geographica Lovaniensia,* 9, 136p.

Delbrouck (R.) - 1970 - Les phenomènes karstiques des règions Han-Rochefort. L'Electron Ed. Bruxelles.

Quinif (Y.) - 1973 - Contribution à l'étude morphologique des coupoles. *Ann. Speleol., 28,* 565-573.

Quinif (Y.) - 1977 - Essai d'étude synthétique des cavités karstiques de Belgique. A parâ dans *Rev. Belg. Geogr.*

Van Den Broeck (E.), Marten (E.A.), Rahir (E.) - 1910 - Les cavernes et les rivières souterraines de la Belgique. Lamertin Ed. Bruxelles.

Vandersleyen (P.) - 1972 - Atlas des grottes de Belgique (Tirage limité).

1972 - Premier colloque national de plongée souterraine. Hydrologie souterraine par prospection directe : contribution à l'étude des karsts aquifères de Belgique. *Publ. Serv. Geol. Belg. Professional Paper, n° 8.*

ON THE OCCURRENCE AND ORIGIN OF KARREN ON GRANODIORITE IN PUERTO RICO

Barry F. Beck
Earth Sciences Dept.
Georgia Southwestern College
Americus, Georgia, 31709, U.S.A.

Carlos Cram
Div. Rec. Min., Dir. Geol.
Min. Minas Hidrocarburos
Caracas, Venezuela

Karst is generally associated with soluble rocks. However, silikatkarren (karren features on silicate rocks) have long been known (*e.g.,* Branner, 1913). Recently, major drainage features typical of integrated solution processes have been reported on silicate rocks in Venezuela (White, *et al.,* 1966; Szczerban and Urbani, 1974). On this basis, silikatkarren should be included as true karst features (Otvos, 1976). Excellent examples of silikatkarren are developed on the San Lorenzo granodiorite in southeastern Puerto Rico.

The average granodiorite composition in the area studied is: 48.2% plagioclase (44.8% anorthite), 21.2% quartz, 12.0% potassium feldspar, 6.6% hornblende, 7.3% biotite, and 2.9% chlorite, with minor

accessories. The surface of the batholith is generally covered by a thick saprolite (*ca.* 60 m) with numerous large residual boulders resting on it. The climate here is tropical with rainfall averaging 1700 mm and temperature 22°C.

One particularly concentrated area of diverse silikatkarren was selected for study, 13 km south of San Lorenzo on Highway #181 and approximately 1 km east of the highway. Here numerous boulders rest on a broad alluvial plain. Generally they have irregular, almost crenulated, heavily vegetated upper surfaces, with sides marked by closely spaced, deep grooves or flutes. Randomly located throughout the area are absolutely smooth, featureless boulders.

Vegetation varying from mosses and lichens and small grasses up to "Elephant Ears" (pl. 1) and mature trees colonizes the tops of the boulders or any suitable surface irregularity. The root mass and the plant debris form a sponge-like mat holding water which becomes highly acidified with CO_2 and organic acids. Field measurements on the black, fetid water in depressions beneath this organic mat yielded pH's as low as 4.8 with temperatures as high as 28°C. Kamenitzas are commonly developed on these more level surfaces wherever vegetation exists. Where the vegetated surface is gently sloping, sinuous troughs roughly 50 cm wide and 30 cm deep, with rounded divides and bottoms, may develop (pl. 3).

Deep vertical flutes separated by sharp divides are found where the solution basins or troughs overflow the edge of a boulder. They appear to decrease in area downslope like wandkarren. The sequence of forms developed here appears analagous to that described by Bögli (1960) for limestone partially covered with humus.

However, some flutes do not appear to be extensions of upper surface features. On Plate 2, note that some smaller flutes appear to originate on the slope. Note, in the foreground, that the flutes obviously decrease in size downslope, finally disappearing. Plate 3 is a close-up of an area of the upper surface of this boulder. Contrast the rounded divides here with the sharper divides shown on the steep slopes of Plates 1 and 2.

The flutes are not always oriented vertically, but this is probably due to downslope rotation (Wall and Wilford, 1966, for similar features in Malaysia). Other features here contrast with those in Malaysia. Joint control is obvious there (*ibid.*, p. 463), but was not important in the present example. Also, Wall and Wilford noted that their flutes became narrower but deeper downslope (*ibid.*, p. 463) and it is obvious from Plate 2 that this is not always true here. Further, they hypothesized their flutes to be due to acid rainfall (*ibid.*, p. 466), whereas these flutes, at least in part, obviously stem from highly acid "soil" water.

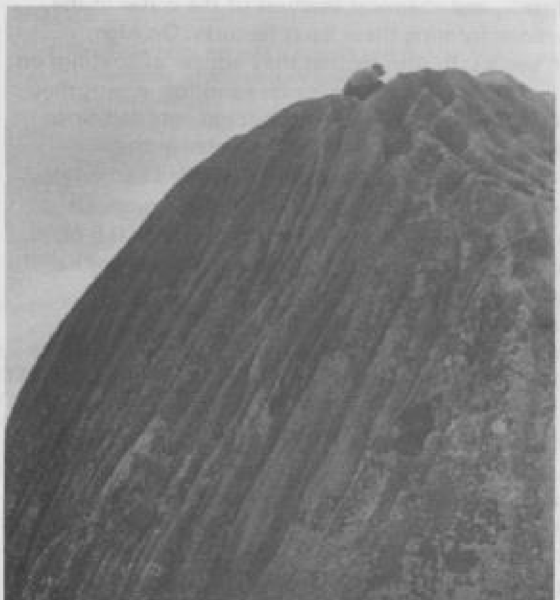
Field observations, thin-sections of the weathered rock, and chemical analyses of the water in the kamenitzas were combined to delineate the weathering reactions forming these karst features. On high, unvegetated areas the granodiorite is dotted with pale green specks. In thin-section they appear as coatings on the plagioclase grains. These are not seen in the depressions or flutes. Where mafic rich xenoliths occur, they stand out as resistant high spots. The insoluble residue in the kamenitzas is whole rock fragments and finer mineral grains which are almost totally dark coloured minerals. The conductivity of the water in the kamenitzas corresponds to a total dissolved solids content of 30-35 ppm. Field titrations yielded carbonate hardness values of 14-15 ppm as $CaCO_3$. Alkalinities were all bicarbonate and ranged from 5-22 ppm. Ca^{++} and Na^{+} each averaged 3 ppm; K^{+} averaged 2 ppm and Mg^{++} 1 ppm. $Fe_{tot.}$ was generally less than 0.5 ppm.

The major weathering reaction occurring here is apparently the hydrolysis and carbonation of plagioclase, releasing Ca^{++} and Na^{+} in solution. On the higher areas, subject only to local wetting and subsequent drying, the clay mineral products are retained as a coating which probably impedes further reaction. In the bottoms of the kamenitzas and flutes, however, the water acidified by biogenic CO_2 attacks the feldspars much more rapidly and the more concentrated water flow carries away the reaction products, either in solution or as colloids. (The ferromegnesian minerals must also be reacting to yield the magnesium in solution, but apparently less intensely, as evidenced by their resistance). Thus, the presence of water enriched with biogenic CO_2 is postulated as being a major factor in the development of these features.

This obviously applies to the kamenitzas, which are generally filled with various types of organic debris, and it should also apply to the flutes formed by their overflow. But, does it relate to the smaller karren which do not appear to stem from vegetated areas, such as shown in Plate 2? The rounded character of the upper surface of this boulder (pl. 3), similar to rundkarren, may indicate that it was once heavily vegetated. This vegetative cover could have supplied CO_2 enriched runoff to all the slopes. The fact that these flutes disappear downward like wandkarren (pl. 2), and do not deepen like rinnenkarren, is further indication that they are related to runoff. By this same analogy, flutes which do deepen downslope, like those noted by Wall and Wilford (1966), are most probably related directly to rainfall, as they hypothesize. This may also explain the featureless boulders scattered among the karstified ones. Field examination and thin-section analysis did not detect any significant differences in jointing, texture, or mineralogy. The only apparent difference is the presence of vegetation on all the karstified boulders, and the total absence of vegetation (other than lichens) on the smooth, featureless boulders. This would support the hypothesis that biogenic CO_2 is a major factor in the formation of silikatkarren.

In conclusion it is postulated that the solution forms described in a granodiorite tertain are largely due to the chemical action of water in contact with a vegetative cover and acidified by biogenic CO_2 and organic acids. Further, it appears that the acidified water is preferentially attacking the plagioclase and that, on the bottom of kamenitzas or flutes, the weathering products are carried away in solution or as colloids.

Pl. 1: Heavily vegetated granodiorite boulder showing karren. Broad-leafed plants are known as "Elephant Ears".



Pl. 2: Granodiorite boulder with intense karren development. Note that the flutes in the foreground disappear downward like wandkarren.

Pl. 3: Upper, gently sloping, surface of same boulder shown in Pl. 2. Note the rounded character of this surface, analagous to rundkarren.

Acknowledgments

Field instrumentation, laboratory facilities, and writing time were supplied by the Geologic and Water Resources Division of the Georgia Department of Natural Resources. Field assistance was provided by Patricia Beck, Jody Atwood and Margarita Irizarry.

References

Bögli, Alfred — 1960. Solution of calcium carbonate and the formation of karren: *in Internationale Beiträge zur Karstmorphologie,* H. Lehmann editor, *Zeitschrift fur Geomorphologie,* Suppl. Band 2, p. 4-21.

Branner, J.C. — 1913. The fluting and pitting of granites in the tropics: *Proc. Am. Phil. Soc.,* v. LII, no. 209, p. 163-174.

Otvos, E.G., Jr. — 1976. "Pseudokarst" and "pseudokarst terrains": problems of terminology: *Geol. Soc. Amer. Bull.,* v. 87, p. 1021-1027.

Szczerban, E., & F. Urbani — 1974. *Carsos de Venezuela, Parte 4: Formas cársicas en areníscas précambrias del Territorio Federal Amazonas y Estado Bolivar:* Soc. Venezolana Espeleol. Bol., v.5, p. 27-54.

Wall, J.R.D., & G.E. Wilford — 1966. A comparison of small-scale solution features on micro-granodiorite and limestone in West Sarawak, Malaysia: *Zeit. Geomorph.,* NF 10, p. 462-468.

White, W.B., G.L. Jefferson, & J.F. Haman — 1966. Quartzite karst in southeastern Venezuela: *Int. Jour. Speleol.,* v. 2, p. 309-314.

THE SEDIMENTS OF CARLSWARK CAVERN, DERBYSHIRE

J.S. Beck
University of Leicester, Leicester, U.K.

The caves of North Derbyshire are notorious for their content of fluvio-glacial sediment which in many cases has filled abandoned passages to the roof. While in most cases this has limited the extent to which the phreatic complexes can be explored and surveyed, it has, in a few instances, been of great importance in deducing the developmental sequences of the passages.

Carlswark Cavern near Stoney Middleton has been known at least since the early 18th Century, and reports from that time suggested that it was a cave of very great extent, far greater than it is today. When the known cave was extended in 1959, it was assumed that the fill of the passages at the north western limit of the system was original cave sediment. A great deal of effort was expended in excavation, but no progress was made.

In 1973, the known cave was again extended, and the well decorated abandoned route known as 'Gimli's Dream' was entered. This stretch of cave had undergone several phases of infilling and re-working of the sediments; the sequence was excellently displayed in a chamber 50 m west of the Eyam Dale Shaft entrance (Fig. 1).

The passage roof is flat, and has become so by the process of breakdown of the roof of a phreatic tube below a prominent bedding plane (Fig. 1). The collapsed blocks are part of a prominent fossiliferous bed full of *Giganto productus* sp. The relative date of the breakdown was fixed by the fact that the collapsed blocks were surrounded and covered by several fining-upwards sequences of pebbles, gravel, sand, and silt (Fig. 2). That the collapse had in some cases occurred long before silting was shown by the scalloping of the blocks, which was oriented relative to the new positions of the blocks on the floor.

The whole sequence became covered by a thick layer of stalagmitic calcite (Fig. 3). The main section did not show any lower, thinner layers, but in passages further to the west, unmodified by cavern breakdown, there were several thin layers up to 5 cms apart.

A trench, up to 1.5 metres deep, was cut through the whole sequence by a vadose stream which must have flowed for a considerable period in order to cut through this thickness of flowstone; removal of the underlying silt would take place relatively fast (Fig. 4). A large amount of water must have been flowing then through the Merlin Streamway, for it never backs up far enough to flow through this stretch of cave now, even in very severe floods.

The blocks of limestone exposed on the floor of the trench bear evidence of fresh flowstone formation after the retreat of the secondary stream (Fig. 5). The rate of flowstone formation in abandoned mines of the area suggests that this small amount of calcite is of no very great antiquity, although it is thicker than any in mines up to 300 years old.

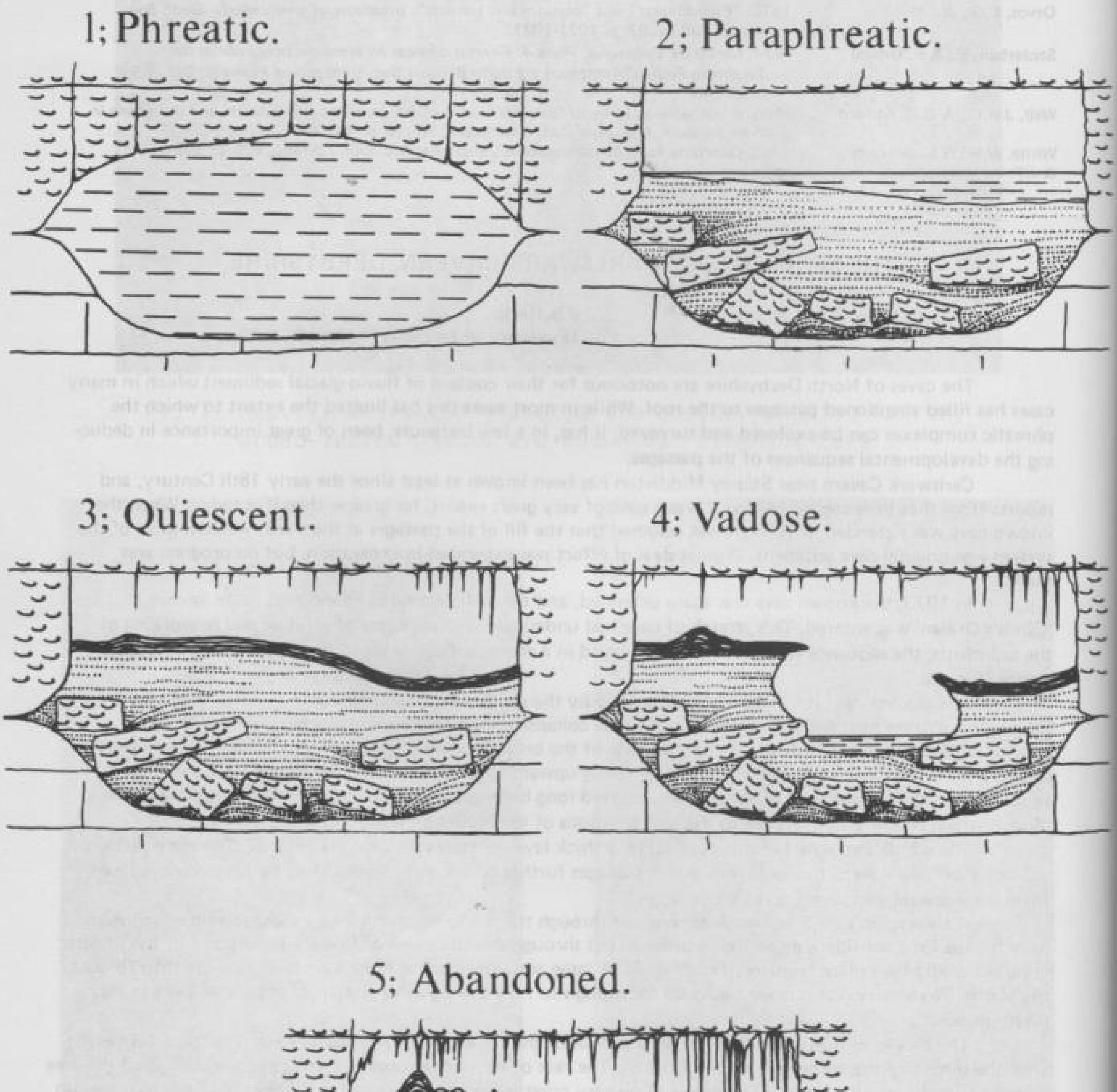
Further to the east, there is far less silting in Carlswark Cavern. The silt diminishes in quantity east of the Eyam Dale Shaft, the area of most extensive cavern breakdown. The process of silting commenced after the large chamber at the bottom of the shaft had become open to the valley side by holes now blocked, and after accumulation of the large amounts of scree which ran into the chamber from the hillside above, which gives a tentative relative date for the incision of Eyam Dale to its present depth.

The heavy silt deposits in the northwestern area of the cave deterred cavers from digging, and gave rise to dismissal of the old stories regarding the alleged extent of the cave. One north-west-trending passage, silted to the roof with loess-like sediment, was excavated during 1974/5 for 20 metres to a point where it intersected a chamber developed on a northwest-trending joint. The dig was abandoned soon afterwards.

Recent excavations to provide a drainage trench for flood water which enters from the west revealed that some of these passages were more than two metres high, and at the base of the silt, which was up to roof

level throughout, a piece of miners' timber was found. This proved beyond doubt that when the miners of the early eighteenth century were working in the cave, a complex network of phreatic passages varying in diameter from a few centimetres to nearly three metres extended to the west, and was free from silt. This discovery has changed our view of the hydrology of the cave, and recent accurate surveying has revealed that this late silting took place after miners' 'deads' had collapsed into the stream channel, active only in flood conditions.

The effort to discover the main stream passages of the area has redoubled, and it is hoped that restoration of the original water levels will remove the silt, and reveal the onward route.



Development phases in Gimli's Dream passage, Carlswark Cavern, Stoney Middleton, Derbyshire.

MORPHOLOGICAL AND GEOPHYSICAL SURVEYS ON SOME DOLINAS OF THE SOUTHERN MONTE BALDO (VENETIAN PRE-ALPS)

G. Benvenuiti
Istituto di Fisica Terrestre, Geodesia e Geografia Fisica dell'Università di Padova, Italia.

N. Sauro
Instituto di Fisica Terrestre, Geodesia e Geografia dell'Università di Padova, Italia.

A large area of the southern part of Monte Baldo, between 700 and 1650 m above sea level, is morphologically speaking, a "plateau" with respect to the surrounding areas which have high relief energy.

This area, not covered by the Pleistocene glaciers, is characterized by many karst landforms of the dolina type, with diameters varying from between 40 and 200 m. These dolinas are grouped in strips running N–S. The average slope of the surface along these strips with dolinas does not generally exceed 15°; in those areas with slopes of more than 20°, the dolinas are almost totally absent.

Inserted in a relief which still reveals well-preserved tectonic forms, these karst depressions have some peculiar aspects. The dolinas are often aligned according to the principal tectonic lines (N-S and NNE-SSW), thus showing the structural control exerted on them very clearly. In some areas (e.g. 2 km SW of Dosso di Naole), close "beehive" groupings of dilinas with roughly polygonal shapes can be found. Other are hydrographically arranged.

Several small dome-shaped hills rise among the various dolinas.

Some dolinas of the Creste di Naole between 1500 and 1650 m above sea level were particularly closely esamined. In this area, most of the dolinas show a flat, horizontal, and very extended bottom, and a remarkable difference between maximum and minimum depth (differences in level between the highest and lowest points of the watershed with respect to the bottom of the basin). The diameter of the flat bottom varies between 10 m and more than 60 m; depths range from more than 30 m down to a minimum of a few dozen centimetres (see Figs. 1 and 2).

In some samples excavated from the bottoms of the dolinas, we found a level made up of abundant silt (lacking in $CaCO_3$ and with neutral or acid PH), containing rather spiky calcareous fragments. Considering the local situation, the silt of this level cannot be interpreted either as a dissolution residue, nor as material deriving from erosion of the sides of the dolinas. It is very probably eolian loess. The calcareous fragments are derived from the slopes of the dolinas, probably by gelifraction processes. This eolian loess, together with the calcareous fragments, thus fossilized the dolinas covering and waterproofing them during one or more cold phases of the Pleistocene.

Geophysical methods were used in order to evaluate the thickness of these infillings responsible for the flat shape of the bottom of the dolinas.

Geophysical survey

In order to make a quantitative evaluation of the thickness and soil characteristics of the material making up the cover of the rocky bottom, a geoseismic investigation was carried out, using equipment particularly suitable for shallow surveys. (Bison Enhancement Seismograph). This type of investigation was preferred to the electrical method since it gives greater accuracy in determining the thicknesses of the material particularly when dealing with an electrostratigraphic succession with resistivities which increase downwards.

From the seven profiles shown in Figs. 1-2, it was possible to obtain a series od dromochrons, and thus make up the following scale of longitudinal velocities of the elastic waves (from top to bottom):

– *layer with velocity between 400 and 600 m/sec.* This was generally very thin – less than 3m. It can be identified partly with humus and partly with prevalent clayey deposits:, there is a relatively thick grass-soil layer which does not show up as a layer in itself but whose effect is to give a slower velocity in the more superficial complex;

– *layer with velocity between 700 and 1000 m/sec.* This leve, where present (or rather, where its minimum thickness is sufficient for it to show up on the dromochron), is between 3 and 6 m thick – locally perhaps more.

These velocity values may be indicative of a rough elastic horizon in which a clayey fraction is also present. Considering the local situation, this terrain with its relatively low velocity may correspond to the calcareous alteration fringe, made up of detritus and calcareous blocks of various sizes surrounded by clay.

– *layer with velocity between 2800 and 3300 m/sec.* We consider this layer the substratum, since the length of the bases we used turned out to be the deepest marker which the dromochron were able to show.

It is difficult to establish whether the solid limestones are to be identified with this fast layer, whose lower limits are near 3000 m/sec, or whether it can still be identified with a level of slightly fractured limestones with a very small clayey content.

On the other hand, the length of our array did not allow us to verify whether the thickness of this layer was very high (which would support the first hypothesis), or whether it is reduced to only a few metres (which would support the second). As regards the thickness, presuming that there is a faster

terrain at the base (for example 4000 m/sec which could be the velocity in the solid limestone) one could affirm that the layer between 2850 and 3200 m/sec is at least 12-15 m thick.

As regards the interpretation of the experimental data, it seemed useful to carry this out using Wyrobeck's procedure. Seeing the shallowness of the various horizons, we could have followed even relatively small undulations of their top surface starting from a calculation of the delay times of each geophone.

The particular geomorphological problem on which the geophysical survey was used, and the position and quantity of the seismic profiles, suggested that the best representation would be by means of velocity/depth sections, as shown in Figs. 3-4.

Regarding Dolina 1, (fig.3.) it can be seen that the morphology of the top of the fastest horizon is rather smooth, with a tendency to deepen towards the central part where it reaches a maximum depth of about 7-8m. The superficial layer, including both the humus and a principally clayey underlying level, is less than 2m thick, and is present over the whole area covered by the profiles.

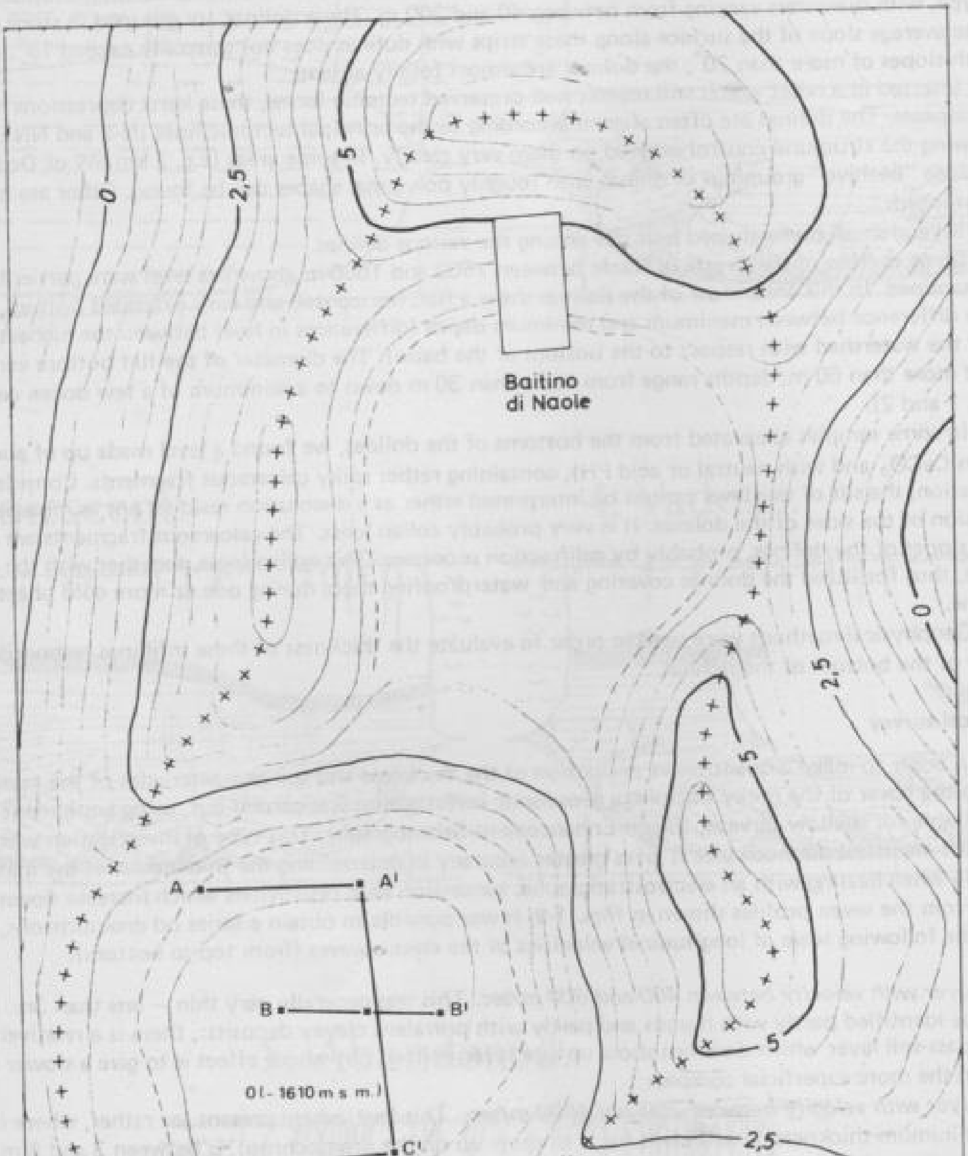


Fig. 1. Topographical sketch of dolina 1. This morphology is a typical example of a fossilized karst relief (see legend of fig. 2).

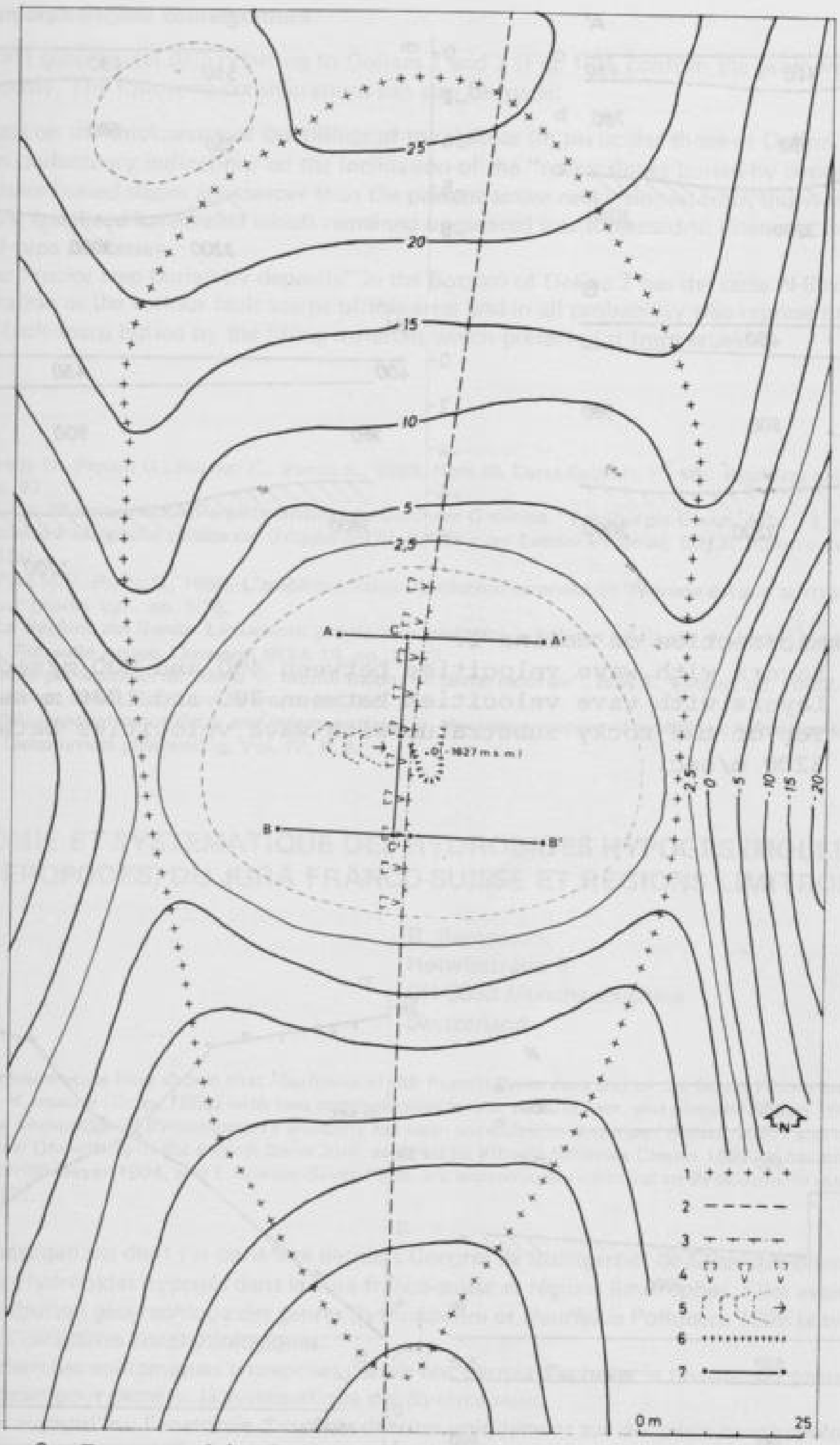


Fig. 2. Topographical sketch of dolina 2.
Legend: (1) watershed; (2) supposed fault line; (3) supposed fault line, buried by deposits; (4) supposed fault scarp, buried by deposits; (5) supposed "gorge" cut in solid rock, buried by deposits; (6) depression in the flat bottom surface; (7) seismic profile.

In Dolina 2, (fig.4.) the presence of a sharp morphological step can at once be seen. Its vertical throw is about 3 m and its strike is roughly N-S. This step in levels separates two compartments in which the morphology of the top surface of the layer is substantially very regular: about 6-7 m deep in its higher parts, and about 9-10 m in the deeper parts.

On Profile C-C' the dromochrons suggest the presence of a narrow depression of the roof of the fast level (quantitatively difficult to define) which may be related to the nearby buried "ponor."

Regarding the cover, it can be seen that the two layers making up the bottom of Dolina 2 are generally faster than the same layers of Dolina 1. This can be related to the presence of elastic elements, more or less numerous and more or less well-defined within a clayey matrix, starting practically from the surface.

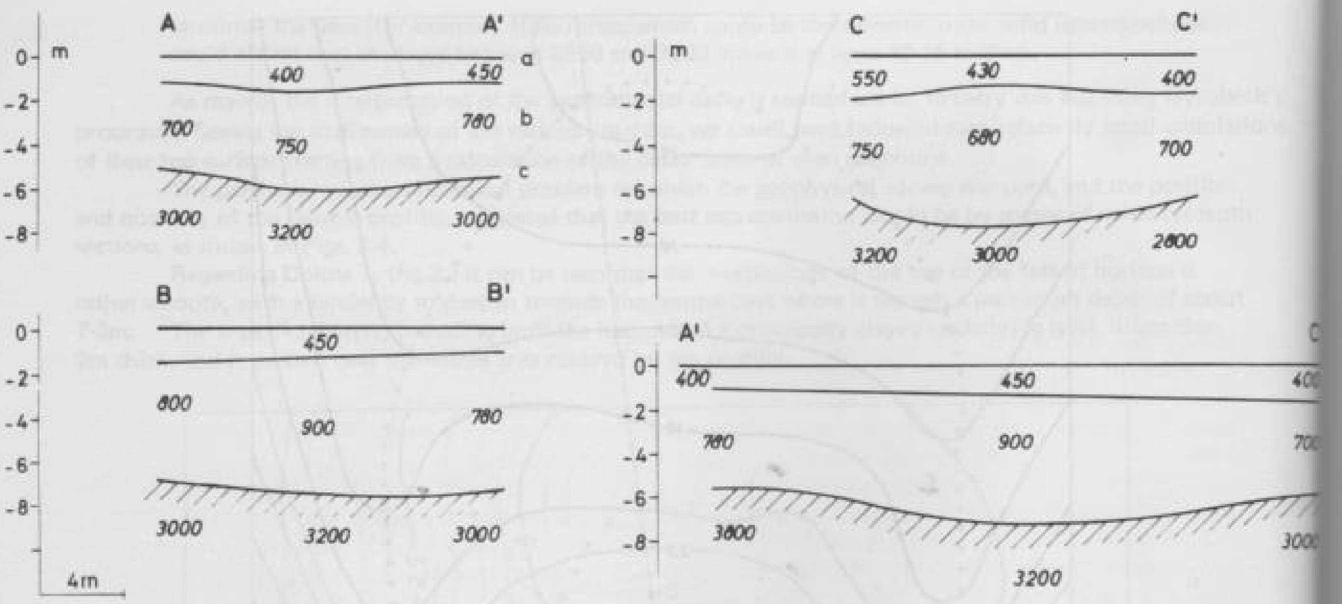


Fig. 3. Seismic section on dolina 1.
(a) Layers with wave velocities between 400 and 600 m/sec.
(b) Layers with wave velocities between 700 and 1000 m/sec.
(c) Top of the rocky substratum with wave velocities between 2800 and 3200 m/sec.

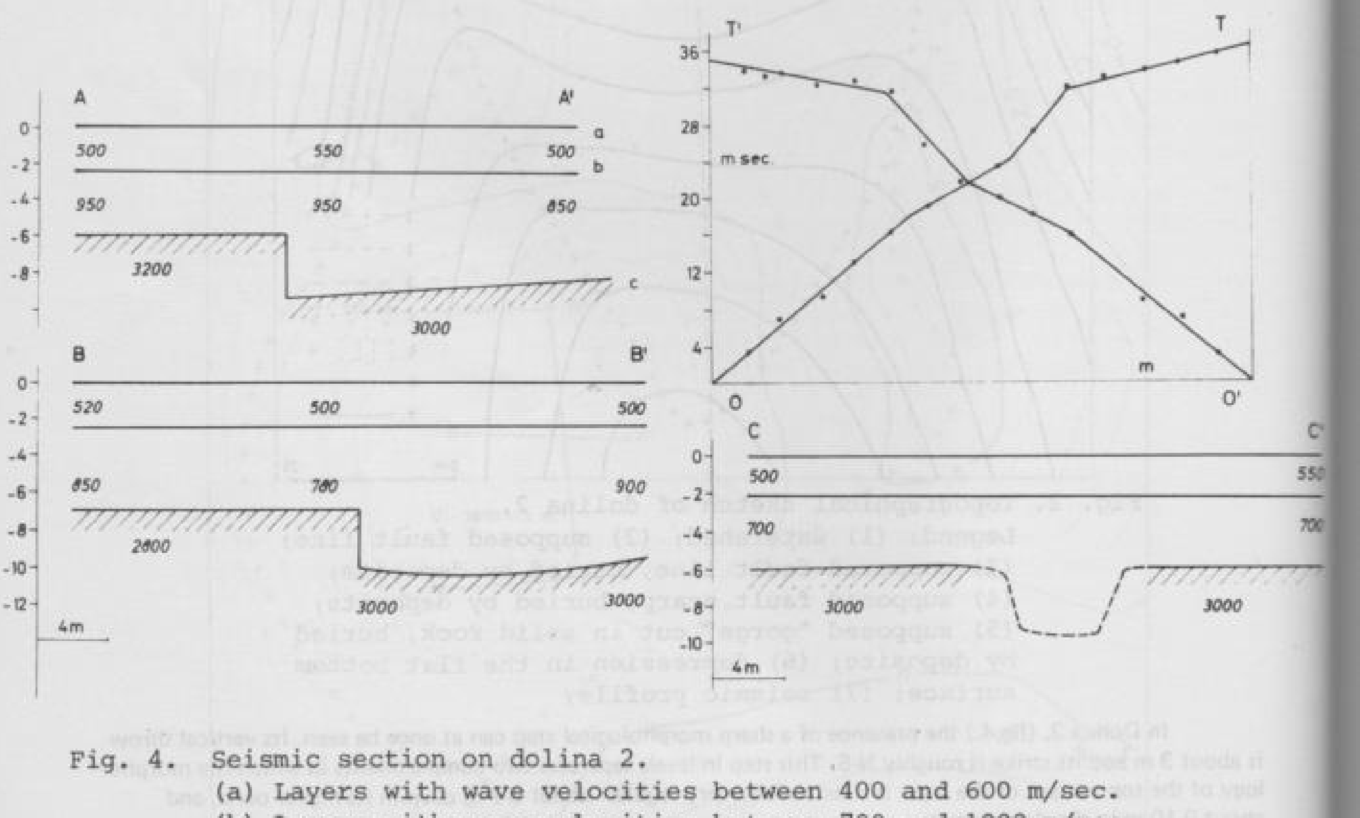


Fig. 4. Seismic section on dolina 2.
(a) Layers with wave velocities between 400 and 600 m/sec.
(b) Layers with wave velocities between 700 and 1000 m/sec.
(c) Top of the rocky substratum with wave velocities between 2800 and 3200 m/sec.

OT and OT' - direct and inverse time-distance curves referring to profile CC'.

Conclusive geomorphological considerations

The first geophysical data referring to Dolinas 1 and 2 (Fig. 1-2), confirm the geomorphological picture sketched previously. The following considerations can also be made:

— the data on the thicknesses of the fillings of the dolinas (in particular those of Dolina 1) allow us to obtain preliminary indications on the inclination of the "rocky slopes buried by deposits". It seems that these buried slopes are steeper than the present active rocky slopes; from this it can be reduced that the fossilized karst relief which remained uncovered was subjected to intense attack by peri-glacial-type processes.

The "rocky step buried by deposits" in the bottom of Dolina 2 has the same N-S running orientation as the various fault scarps of this area, and in all probability also represents a small neotectonic fault scarp buried by the filling materials which preserved it from erosion.

R eferences

Carraro G., Malaroda R., Piccoli G., Sturani C., Venzo S., 1969, Note ill. Carta Geol. It. F° 48:: Peschiera del Garda, Serv. Geol. d'It. pp. 97.

Habbe K.a. 1969, *Die Wurmzeitlische Vergletscherung des Gardasee Gebietes,* "Freilburger Geogr. Arb.", 3, pp. 254.

Pasa A. 1954 *Carsismo e idrografia carsica nel Gruppo del M. Bal do e nei Lessini Veronesi,* C.N.R., Centro Studi Geogr. Fis., 5, pp. 150.

Pasa A. Durante Pasa M.V. Ruffo S., 1960, L'ambiente fisico e biologico veronese, in "Verona e il suo territorio", Vol 1°, 1st. Studi Storici Ver., pp. 5-36.

Sauro U., 1976, *La Regione del Garda: Lineamenti geografici e geologici,* in volume sul "Lago di Garda" pubblicato a cura dell'Ist. Ric. sulle Acque, Quaderni IRSA 18, pp. 13-32.

Sauro U. 1975, *Cenni geologici sul M. Baldo* in Monte Baldo: un parco naturale". W.W.F. Verona, pp. 19-22.

Turri E. 1971, *Il Monte Baldo,* Ed. Corev, Verona, pp. 266.

Wyrobek S.M. 1956, *Application of delay and intercept times in the interpretation of multilayer refraction time-distance curves.* Geophysical prospecting, Vol. IV, N.2.

ANATOMIE ET SYSTEMATIQUE DES HYDROBIDES HYPOGES (MOLLUSQUES GASTEROPODES) DU JURA FRANCO-SUISSE ET REGIONS LIMITROPHES

R. Bernasconi
Hotwiestrasse 9
CH 3053 Munchenbuchsee
Switzerland

Anatomical studies have shown that *Hauffenia* of the French-Swiss Jura and of the South Rhone basin belong to a single species, *i.e. H. minuta* (Drap, 1805) with two conchological forms: *minuta* s.str. and *globulina* Palad 1866.

The rare knowledge of *Bythiospeum's* anatomy has been extended to *B.charpyi* (Palad, 1867) and to *B.helveticum* group. *Bythiospeum* Dinkelberg in the central Swiss Jura, ascribed to *Vitrella helvetica* Clessin 1882, *V.haussleri* Clessin 1887, *Lartetia clessini spirilla* Geyer 1904, and *L.suevica* Geyer 1905, are anatomically identical to *Bythiospeum quenstedti* (Wiedersheim, 1873).

Les investigations dont j'ai parlé aux derniers Congrès de Stuttgart et de Olomouc avient pour but le recensement des Hydrobides hypogés dans le Jura franco-suisse et régions limitrophes. Elles avaient permis de délimiter la distribution géographique des genres *Bythiospeum* et *Hauffenia* Pollonera 1898 la systématique étant limitée aux caractères conchyliologiques.

Les recherches anatomiques entreprises depuis ont permis d'achever la révision du genre *Hauffenia* et fournissent les bases pour démêler la systématique des *Bythiospeum.*

Etudier aujourd'hui l'anatomie d'espèces décrites uniquement sur des bases conchyliologiques il y a quelques 100 ans pose des problèmes particuliers. Les coquilles vides des holotypes ou lectotypes déposés dans les musées sont évidemment inutilisables. D'autre part, il s'agit le plus souvent de trouvailles d'alluvions de fleuves ou de sources où ils ne sont pas viables; le locus typicus ou le biotope sont souvent inconnus.

J'exposerai les résultats obtenus jusqu'ici, en premier lieu ceux concernant les Hauffenia, puis ceux relatifs aux *Bythiospeum.*

Les *Hauffenia* du Jura franco-suisse étaient prises pour des *Valvata minuta* Drap, 1805 et *Valvata globulina* Palad, 1866 du Sud de la France. Binder montra en 1966 qu'il s'agissait en fait d'Hydrobides. L'examen anatomique de nombreux exemplaires du Jura francais et suisse ainsi que du départment du Gard a permis d'établir que tous étaient attribuables au genre *Hauffenia* défini anatomiquement par Bole 1970. (Bernasconi, 1975).

L'anatomie comparée des tentacules, de la radula, des organes palléaux, reproducteurs et digestifs ainsi que de l'opercule a enfin montré qu'il n'y a pas de différence spécifique entre les formes conchyliologiques *minuta* et *globulina:* ces formes, établies et confirmées par biometrie statistique, sont donc des races géographiques d'une même espèce à qui revient le nom de *Hauffenia minuta.* Cette espèce semble inféodée exclusivement au bassin rhodanien avec la forme *minuta* au nord et la forme *globulina* à l'est et au sud; elle présente des affinités très marquées avec la *(Neohoratia) subpiscinalis* (Kuscer 1932) Bole 1967 de Slovénie, tandis qu'elle se distingue de la s.str. *tellini* (Pollonera 1898) Bole 1970 également de Yougoslavie.

fique à Sauve, départment du Gard. Les *Bythiospeum* du Jura franco-suisse et de l'Allemagne méridionale sont connus par une cinquantaine d'espèces attribuées successivement aux genres *Paludina, Hydrobia, Vitrella*, et *Lartetia.* La première description anatomique d'un *Bythiospeum* est celle de Seibold 1904 pour le *Bythiospeum quenstedti* (Wiedersheim 1873) d'une grotte de la Schwabische Alb. Des données fragmentaires sont fournies par Boeters en 1971 sur un exemplaire mâle du départment du Jura; en 1974 j'ai pu étudier l'anatomie complète des *Bythiospeum* de la résurgence sous-lacustre du lac de Thoune qui draine les grands massifs karstiques de la Schrattenfluh et des Sieben Hengste (Bernasconi 1974)' D'une importance toute particuliere a été la découverte en 1975 d'exemplaires vivants du *Bythiospeum charpyi* (Palad, 1867) du locus typicus (Bernasconi 1976). Actuellement, l'anatomie de deux espèces bien définies, *B. quenstedti* et B. *charpyi*, est donc connue et permet d'y référer celle d'autres *Bythiospeum.*

Des recherches effectuées dans ce sens ont en pour objet les *Bythiospeum* du Dinkelberg et du Jura bâlois et soleurois, attribués par Bornhauser 1913 à *Vitrella helvetica* Clessin 1882, *Vitrella haussleri* Clessin 1887, *Lartetia clessini spirilla* Geyer 1904 et *Lartetia suevica* avec la variété *abnobae* Geyer 1905, espèces que Bolling 1966 avait réunies conchyliologiquement sous *Bythiospeum acicula clessini* (Weinland 1883). Les exemplaires retrouvés vivants dans des cours d'eau souterrains des trois régions citées ci-dessus sont anatomiquement identiques. Notamment la fine dentelure des dents de la radula, les lamelles branchiales et les glandes annexes de l'oviducte proximal des différents exemplaires ne présentent aucune différence notable. Cette anatomie est en outre identique à celle du *Bythiospeum quenstedsti* (Bernasconi, sous presse). Pour la suite de nos recherches il sera indispensable de retrouver des exemplaires vivants correspondants à la *Vitrella clessini* de Franconie et à la *Paludina acicula* Held 1837 de Bavarie.

Mais le temps presse, la pollution croissante des eaux souterraines et l'industrialisation sont en train de menacer aussi nos Hydrobides . . . . .

References

Bernasconi. R.

1974. Anatomie du *Bythiospeum acicula helveticum* du lac de Thoune. *Ann. speleol.* 29 (nr. 4): 627-629.

1975. Révision des *Hauffenia* Pollonera. *Ann. speleol.* 30 nr. 2: 303-311.

1976. Anatomie de *Bythiospeum charpyi* Palad. *Ann. speleol.* 31/33 (1977): (sous presse)

THE DEVELOPMENT OF BISBINO Mt. HYPOGEAN KARSTIC SYSTEM IN CORRELATION WITH THE PALEOGEOGRAPHICAL EVOLUTION OF THE REGION

Alfredo Bini
Via Ceradini II,
20129 Milano, Italy.

Giulio Cappa
Piazza 8 Novembre 6,
20129 Milano, Italy.

The present paper is a first report on the investigations of karstic phenomena pertaining to the limestone areas surrounding Como lake (Fig. 1) carried on in recent years by the writers in co-operation with Members of Gruppo Grotte Milano SEM-CAI and Speleo Club "I Protei". The authors believe that the conclusions obtained up to this time should be considered representative of some fundamental problems of many other karstic regions within the Mediterranean area.

General evolution of the area

According to the most recent paleogeographical hypotheses, from Oligocene up to late Miocene times a paleo-Adda river flowed from the Valtellina and Valchiavenna valleys, through a valley corresponding to the present Como arm of the lake, carrying to the sea the sediments which presently form the "Gonfolite" (subalpine molasse) hills, surrounding the town of Como.

At the end of the Miocene, during Messinian times, the water-table underwent a very important and general lowering: this phenomenon was common to the whole Mediterranean area (desiccation model: Hsü, Cita, Ryan — 1972); consequently the paleo-Adda river cut a deep canyon down to 700 (m) below the present sea-level (Finck — in press; Bini, Cita, Gaetani — in press) (Fig. 2). During the Pliocene the sea-level rose again, up to the present lake-level or even more.

At the same time (during the Pliocene and, perhaps, part of the Pleistocene) the last important tectonic events took place: the Pre-alps front arose, the Gonfolite sediments were tilted along a fault (which joins the base of Bisbino Mt. and the town of Como) and lifted up to 600 (m) above sea-level. During the Pleistocene, at least five main glacial tongues, from Donau to Würm, fully removed the Pliocene sediments, slightly modified the valley sides and obstructed the canyon mouth with morainic deposits. On Bisbino Mt. the surface of these glaciers, according to Pracchi (1954), reached some 840 (m) above s.l.

As the origin of the Como lake is dependent on these last modifications it has been in existence only since the Pleistocene.

The karstic system of Bisbino Mt.

The Bisbino Mt. karstic system is fully hypogean, with no appreciable extent of surface phenomena. It is mainly composed of four caves (figs. 3, 4, 5), developed at quite different heights.

"Zocca d'Ass" cave (2212 Lo CO), 970 (m) above s.l., is the highest: its entrance is presently fossil but originally it was a resurgence. The cave is composed by some short shafts joining a few superimposed horizontal passages. Waters flow through an almost vertical branch ending into a sump. The cave has been filled, since very ancient times, with deposits up to the roof of the passages which were later re-opened: the deposits were probably laid down and disturbed several times; their remains are still large.

These sediments comprise both rolled and unrolled pebbles, locally cemented, coarse and thin sand, clay; rolled pebbles are mainly calcareous and exotic, easily distinguished from local material.

The passages are cut by many faults: many of them show displacements of some centimetres which evidently took place after the completion of cave development, as they cut both the walls and the deposits (flow-stones, cemented pebbles, etc.).

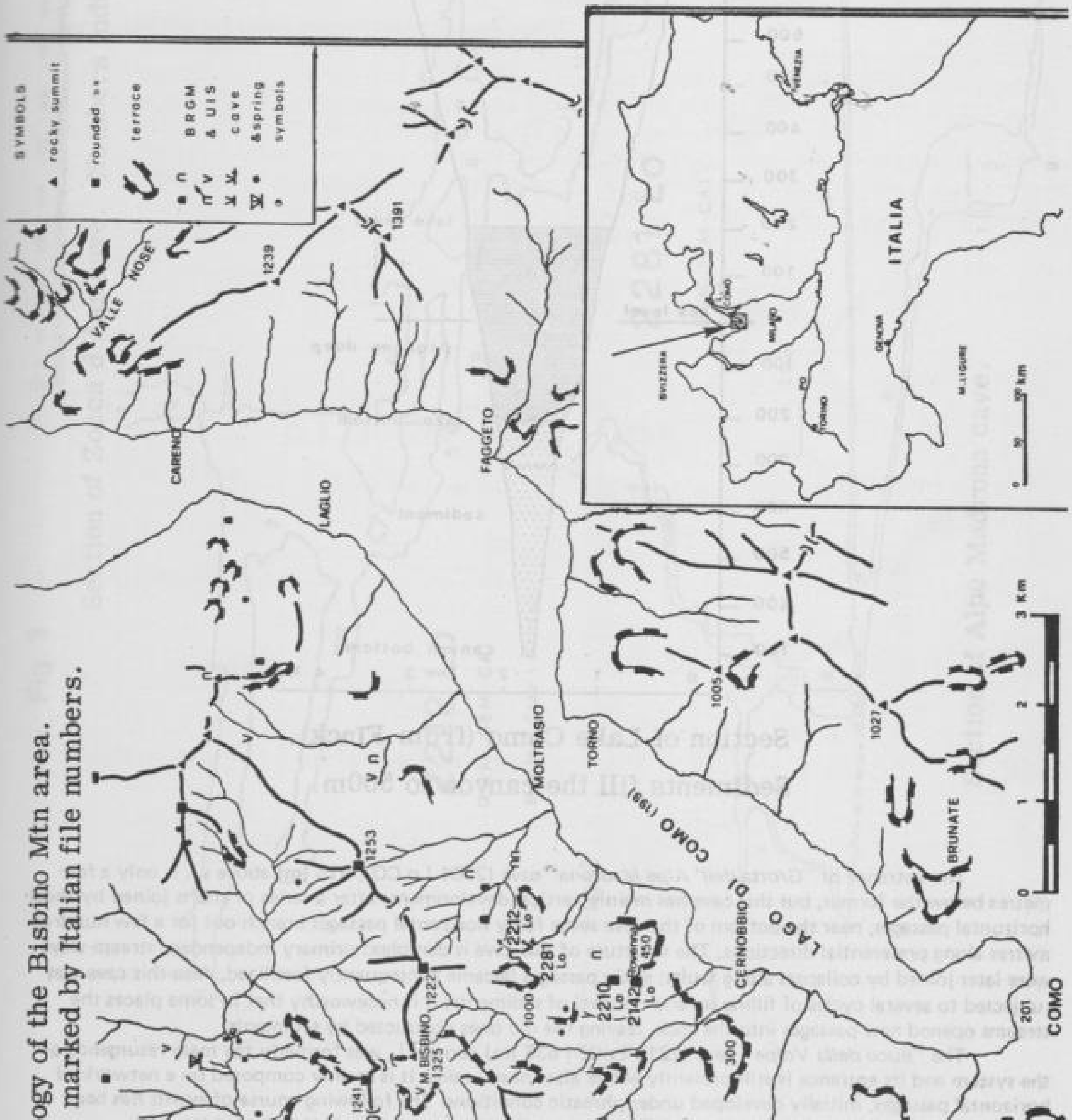
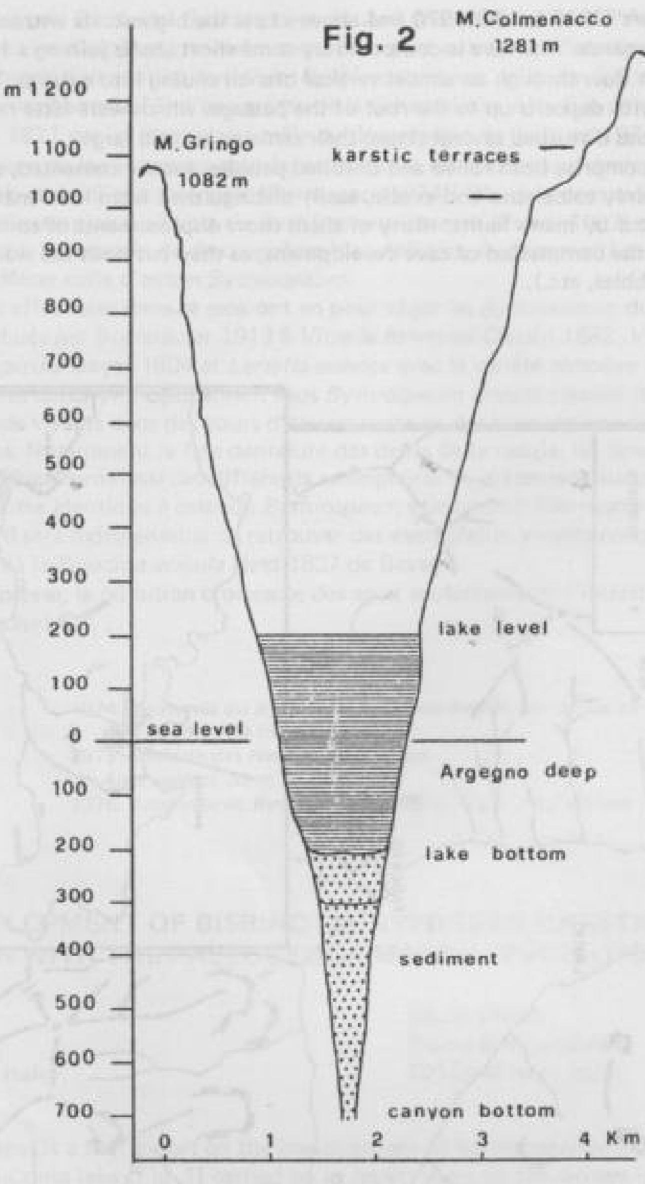


Fig. 1 Geomorphogy of the Bisbino Mtn area. Caves are marked by Italian file numbers.



Section of Lake Como (from FInck).
Sediments fill the canyon to 500m.

The entrance of *"Grotta dell' Alpe Madrona"* cave (2281 Lo CO), 915 (m) above s.l. is only a few metres below the former, but this cave has mainly vertical development: after a series of shafts joined by short horizontal passages, near the bottom of the cave some fairly horizontal passages branch out for a few hundred metres along preferential directions. The structure of this cave is complex: primary independent stream-ways were later joined by collapses along faults; a few passages became consequently fossilized. Also this cave was subjected to several cycles of filling up and removal of sediments; it is noteworthy that in some places the streams opened new passages into the rock, leaving the old ones obstructed by sediments.

The *"Buco della Volpe"* cave (2210 LoCO) 635 (m) above s.l., was formerly the main resurgence of the system and its entrance is still presently active after heavy rains. It is mainly composed by a network of horizontal passages, initially developed under phreatic conditions. The following course of events has been reconstructed with fair reliability:

1) First development of the cave systems along a network of phreatic passages.
2) Further development in vadose conditions leading to engraving of canyons.
3) Widening of passages; deposition of considerable flowstone, up to one metre thick.
4) Wide-spread clastic deposits, joints and faults both in the rock and in concretions likely denote a period of important tectonic events. The faults displace both the scallops on the walls and the ancient flowstones.
5) At least four concretional phases, alternating with pauses or decalcification events, follow the phases 3 and 4. During the intervals, the cave was filled with exotic sediments, once at least fully up to the roof. In many sites remains of deposits of quite different colours, from red to dark

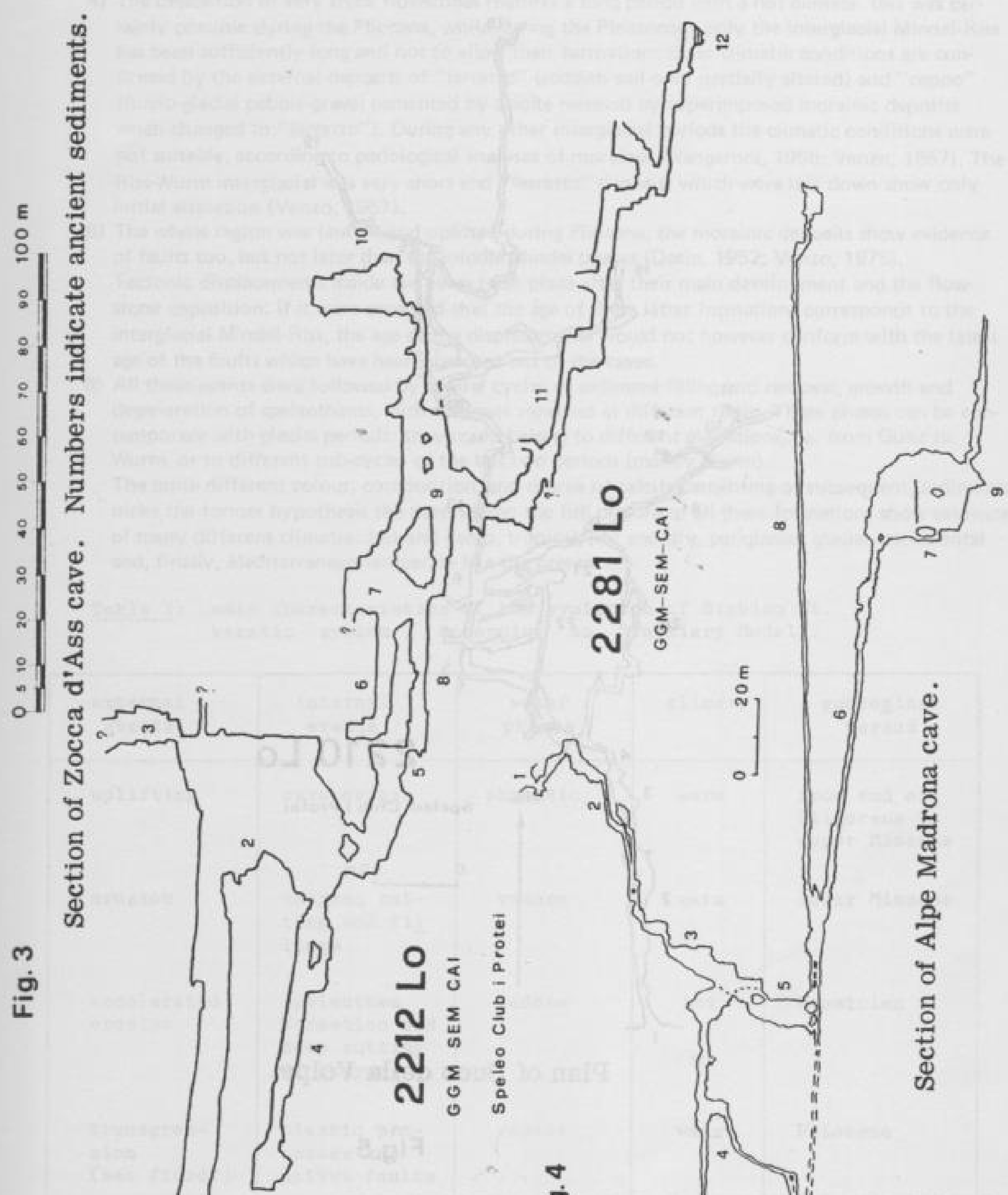


Fig. 3 Section of Zocca d'Ass cave. Numbers indicate ancient sediments.

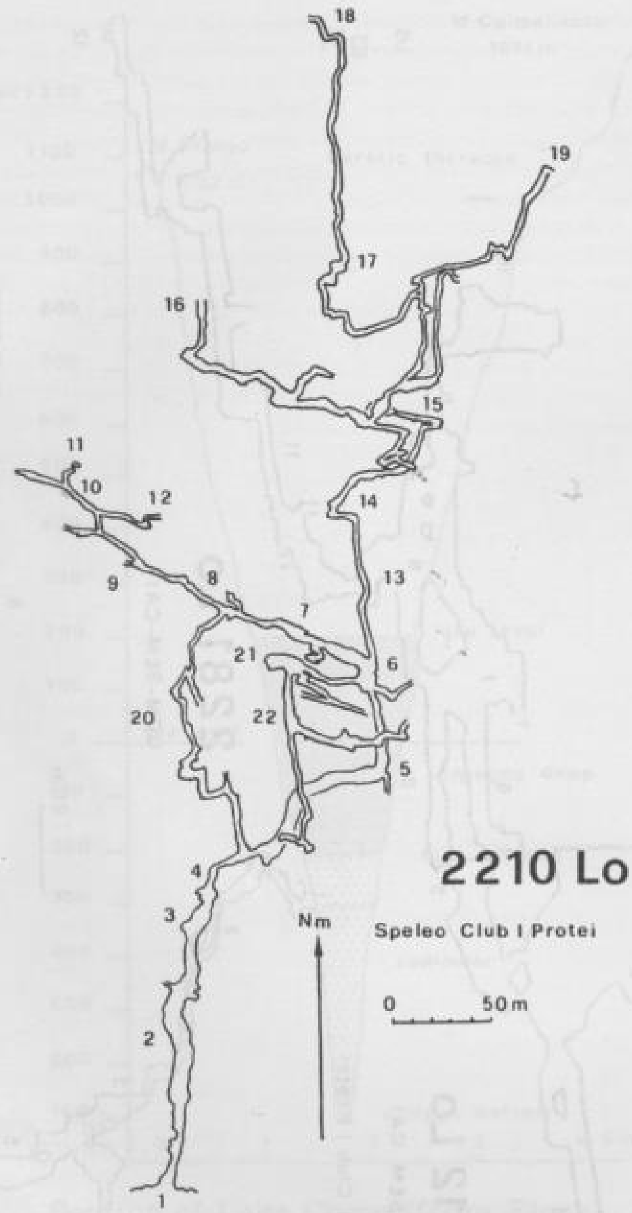
Fig. 4 Section of Alpe Madrona cave.

grey, are superimposed. The most interesting remains of these phases are pebbles (5-10 cm max. dia) attached to deteriorated stalactites some metres above present floor level: both are covered with younger speleothems and even helictites.

6) Lately the cave was mainly emptied: both clay and pebbles (up to 15 cm) were carried out. Flowstones were deeply eroded. This phase is still under development, but at a very slow rate.

"Boeucc de la Val" cave (2142 Lo CO), 520 (m) above s.l., is presently the active resurgence: water comes from an impenetrable sump and is taken into the municipal aqueduct.

Approximately at the same height as "Buco della Volpe", a few other caves have been found, completely filled with sediments. They probably belong to the same system: inside "Bucco della Volpe" some thirty passages are blocked with the same kind of deposits.



Plan of Buco della Volpe.

Fig.5

Correlations between hypogean and external morphological development

All the caves show evidence of a considerable series of events, which repeatedly affected the system. The following considerations have been taken into account in order to present a correlation between this evolution and the external geological events, with the purpose of establishing the most likely age of each stage:

1) Phreatic networks are common even at the highest levels; these indicate that the karstic development started when the regional water-table was at least 1000 m above present sea level. This happened during the Tertiary up to the Miocene, but almost certainly not later.
2) During late Miocene (Messianian) the regional water-table dropped dramatically but probably not in a single step the development of different superimposed cave levels is consistent with this regional evolution. During the whole Pliocene the water-table rose again: consequently cave development did not take place during this period. On the contary the multi-stage course of Glaciations, during the Pleistocene, could easily explain it, but this should involve a very recent formation of the thick flowstones, unacceptable on account of climatic considerations (see point 4).
3) The cemented pebbles found inside the "Zocca d'Ass" cave are above the highest limit of external morainic deposits (Mindel): it is very difficult to explain how glacial flood waters could bring such huge deposits in these caves, if we consider that streams carrying a great amount of debris usually flow at lower levels, at the front of the glacier. More probably these pebbles belong to fluvial deposits of Paleo-Adda river and were laid down before the Pliocenic uplift, in the caves at the same time as the exotic pebbles found in Monfenera caves (Fiedmont): (Fedele, 1974).

4) The deposition of very thick flowstones requires a long period with a hot climate: this was certainly possible during the Pliocene, while during the Pleistocene only the interglacial Mindel-Riss has been sufficiently long and hot to allow their formation: these climatic conditions are confirmed by the external deposits of "ferretto" (reddish soil only partially altered) and "ceppo" (fluvio-glacial pebble-gravel cemented by calcite released by superimposed morainic deposits when changed to "ferretto"). During any other interglacial periods the climatic conditions were not suitable, according to pedological analyses of moraines (Nangeroni, 1956; Venzo, 1957). The Riss-Wurm interglacial was very short and "ferretto" deposits which were laid down show only initial alteration (Venzo, 1957).

5) The whole region was faulted and uplifted during Pliocene; the morainic deposits show evidence of faults too, but not later than the middle Mindel phases (Desio, 1952; Venzo, 1975).
Tectonic displacements inside the caves took place after their main development and the flowstone deposition: if it were accepted that the age of these latter formations corresponds to the interglacial Mindel-Riss, the age of the displacements would not however conform with the latest age of the faults which have been observed out of the caves.

6) All these events were followed by several cycles of sediment filling and removal, growth and degeneration of speleothems, with collapses repeated at different times. These phases can be contemporary with glacial periods: they could belong to different glaciations, i.e. from Gunz to Wurm, or to different sub-cycles of the last two periods (mainly Wurm).
The quite different colour, composition, and degree of calcite cementing of subsequent, sediments, make the former hypothesis the most likely: the full picture of all these formations show evidence of many different climates: hot and damp, tropical, hot and dry, periglacial, glacial, continental and, finally, Mediterranean-temperate like the present.

<u>Table I</u>: main characteristics of the evolution of Bisbino Mt. karstic system , according to "Tertiary Model".

external events	internal events	water phases	climate	geological period
uplifting	cave origin	phreatic	warm	from end of Oligocene to upper Miocene
erosion	canyons cutting and fillings	vadose	warm	lower Miocene
accelerated erosion	speleothem formation and deep cutting of canyons	vadose	hot to	Messinian
transgression (sea fiord?)	clastic processes and active faults	vadose	warm	Pliocene
regression due to uplifting	filling events	phreatic?	climatic alternances	upper Pliocene to
	emptying events	vadose	to warm	Quaternary
glaciations	speleothem formation	vadose	cold	Quaternary
	latest clay-filling	vadose	cold	last Glaciations
regional water table to present level	last erosion of deposits	mainly vadose		from fluvio-glacial Wurm to present days

Table II: main characteristics of the evolution of Bisbino Mt. karstic system, according to "Quaternary Model".

internal events	water phases	climate	geological period
cave origin	phreatic	?	before Mindel
canyons cutting filling	vadose	warm	fluvio-glacial Mindel
speleothem (flowstone) formation	vadose	hot	Mindel-Riss
clastic processes	vadose		Mindel-Riss or
active faults	vadose		Riss
filling events	phreatic and/or vadose	warm or	cata-glacial Riss
emptying events	phreatic?	cold	fluvio-glacial Riss-Wurm
speleothem formation	vadose	warm	ana-glacial Riss-Wurm
latest clay-filling	phreatic to vadose	cold	cata-glacial Wurm
last erosion	vadose	warm	from fluvio-glacial Wurm to present

In conclusion, the series of events which have been recognized in the cave morphologies requires very long geological time, and a model involving at least part of the Tertiary becomes more and more reliable. In this paper both a fully "Quarternary" (in the attempt to match the ideas of "Quarternarists") and a "Tertiary" (which is also partially Quarternary) model of cave development have been proposed (see tables I and II) but on the basis of the arguments reported above the first appears rather unlikely. It can be more reasonably assumed that the development of the highest section of this karstic system (e.g. "Zocca d'Ass" cave) started during lower Miocene (the initial development of the fissures network took place perhaps in the later Oligocene); the lower sections developed as a consequence of the water-table drop during Mesinian; the thick flowstones were deposited during the Pliocene and later faulted at the end of this period or at the beginning of the Pleistocene. The pebble-to-clay deposits belong partly to the Pliocene (upper caves) and mainly to the glaciations, during which the caves underwent many cycles of filling and removal of sediment.

References

Bini, A., Cita, M.B., Gaetani, M. Are the south alpine lakes related to the Messinian entranchement? in press.

Desio, A. 1952. Movimenti orogenetici quarternari nella Pianura Padana. *Rend. Acc. Naz. Lincei*, s. 8, 12 (6): 658-660.

Fedele, F. 1974. La serie stratigrafica della grotta Cuitarun (Monfenera, bassa Valsesia) *Atti XI Congr. Naz. Spel. Genova* 1972 Rass. Spel. It. Mem XI (I): 189-194.

Fedele, F., Nisbet, R. 1974. Il problem dei ciottoletti esotici nei depositi pleistocenic del Monfernera (Bassa Valsesia) *Atti XI Congr. Naz. Spel. Genova* 1972 Rass. Spel. It. Mem XI (I): 171-187.

Finckih, P. In press. Seismic researches on the Alpine lakes.

Hsü, K.J., Cita, M.B., Ryan, W.B.G. 1972. The origin of the Mediterranean evaporites *Initial Rep. Deep Sea Drilling Project* XIII:1203 — 1231 Washington.

Nangeroni, G. 1956. Alcuni suoli fossili come indici d'evoluzione climatica in Italia. *Atti Congr. Geogr. Int. Rio de Janeiro.*

Pracchi, R. 1954. Il Quarternario nel Lario Occidentale *Atti Soc. It. Sc. Nat.* XCIII.
Renault, P. 1970. *La formation des cavernes* Press. Univ. France, Paris.
Venzo, S. 1957. Rilevamento geologico dell'Anfiteauro Morenico del Garda. Parte I: Tratto occidentale Gardone-Desenzano *Mem. Soc. It. Sc. Nat.* XII (II).

SOME CONSIDERATIONS ON THE APPLICABILITY OF SPELEOGENETIC AND MORPHOGENETICAL THEORIES

Alfredo Bini - Giulio Cappa,
(Gruppo Grotte SEMI-CAI Milano;
Società Speleologica Italiana.

Following geomorphological investigations on the main karstic systems in the area of Como lake (Lombardy, Northern Italy), e.g. the Bisbino Mt. Hypogean complex described in these proceedings, we faced the problem of classification of the morphologies according to established theories on the evolutional processes of caves. When we started, some years ago, according to former geomorphological reports the evolution of these phenomena seemed rather homogeneous and linear. Our conclusions demonstrate, on the contrary that the morphogenetical processes are only apparently simple: a careful investigation of geological events (Bini et al., in press) has completely changed the paleogeographical picture of the region. These results combined with the discovery of very complex hypogean features had led germorphologists to consider karstic processes in a new way their general picture is now much more complex but it gives an interpretation of single hypogean morphologies.

Our observations show that the caves developed through poly-cyclic events, following substantial climatic and hydrogeological variations, which took place both outside and inside the caves. As a consequence of that situation, the interpretation of single morphologies becomes very intriguing. In this short communication we intend to briefly discuss some of the results we have attained: namely those concerning the structure of the passages and the origin of the scallops.

i. The distinction between syngenetic and paragenetic galleries (Renault, 1967), while there is no objection to the validity of the principle, is quite difficult and somewhere even impossible: along the same passage ("New series" in Buco della Volpe 2210 Lo CO), some sections show evidence of paragenetic flat ceiling channels, then the passage suddenly divides (fig 1) in two superimposed tubes of quite rounded section (i.e. of "phreatic" origin): which, some metres further, join again into a single paragenetic passage, the section of which becomes soon rounded as far as a room where the channel continues crossing the roof, then suddently drops down along a wall and finally comes out horizontally, forming the roof of another lower passage (fig. 2). There is no continuity on the roof morphology between such different structures. It has been ascertained that usually the paragenetic ceiling channels are quite independent from the fissure network: indeed in Bisbino Mt. caves a channel meanders freely for a few metres but further on follows the fractures at acute or right angles.

The only acceptable conclusion is that these passages developed under both very complex and variable conditions in which different processes, e.g. phreatic, vadose or paragenetic, were tied together so that it is quite difficult to tell them apart.

Generally speaking, we would suggest that a clear distinction between paragenetic and syngenetic processes is possible only in very restricted circumstances and we wonder whether these theories are really maintainable for widespread application.

ii. The examination of scallops leads to similar conclusions; Bisbino Mt. caves are engraved with scallops: near them, in many sites, the passages are filled with pebble deposits which sometimes cover the scallops or even encrust them with thin-to-medium debris (scallops length = 20 cm; max diameter of pebbles = 15 cm). Renault (1963) proposed a theory on scallop origin, involving the action of pebbles, and the examples found in these caves could be taken as a confirmation. But such a conclusion is not reliable, since many cycles have been ascertained in the cave development and a careful investigation has demonstrated that, at least in some sites, those scallops were generated well before the deposition of the sediments laying today in the same place.

For the same reason we have been compelled to abandon the reconstruction of quantitative evaluation of water flows which caused these features, although possible in theory, because we ought to assume that such scallops reached their present shape and dimensions following a single homogeneous stage, which certainly did not happen.

iii. Similar consideration could be made with regard to other phenomena, like clastic and clay deposits — particularly dendritic marks — and ceiling features like "cupolae": we have found dome-pits appa-

rently caused by corrosion by mixing of waters, erosional bell-holes, glyptoclastic cupolae, etc., in which several different processes are superimposed so that it is not easy to say what really has been their origin.

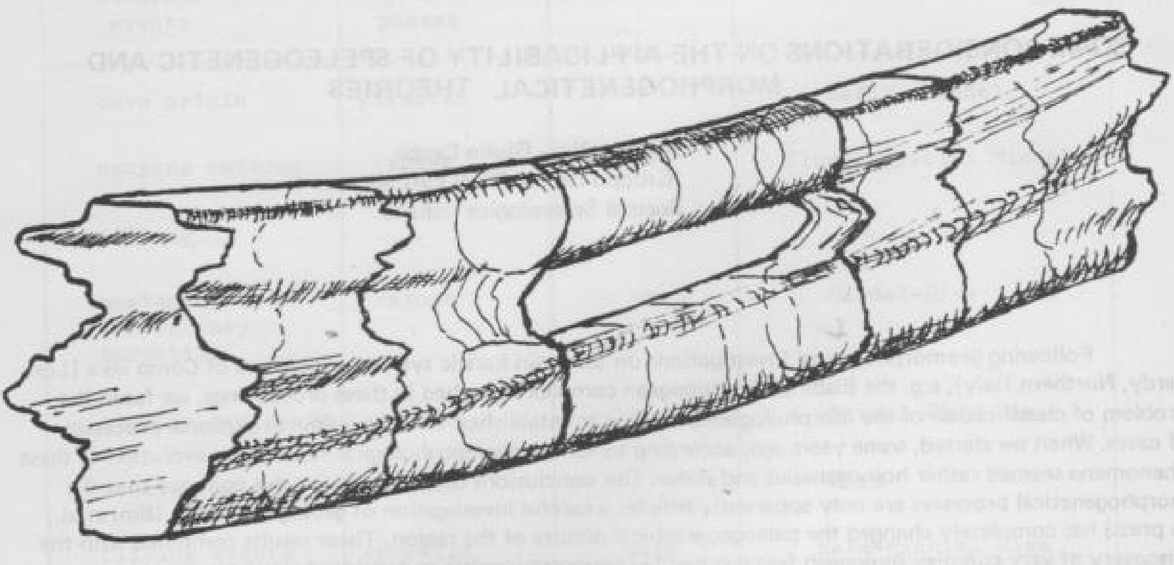


Fig. 1. Perspective view of one passage ("Gallerie Nuove") of Buco della Volpe cave: the single gallery with flat ceiling channel suddenly divides into two superimposed phreatic tubes, then joins again the former morphology.

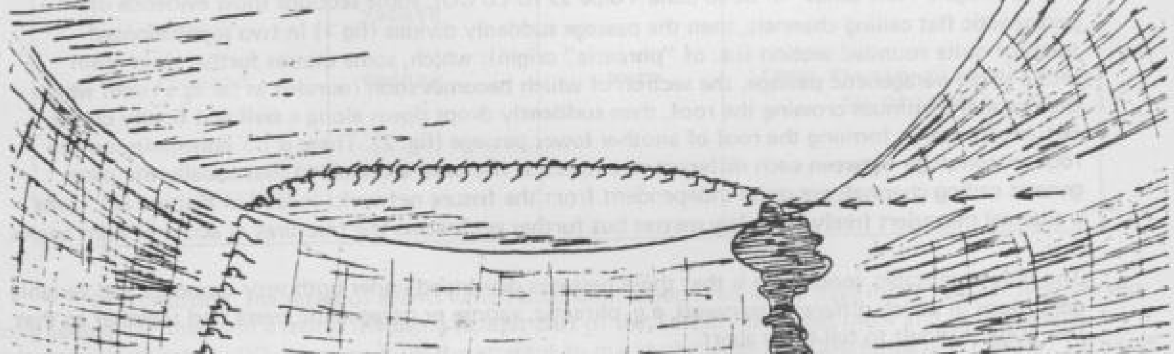


Fig. 2. Perspective view of a room with a semicircular ceiling channel which crosses the roof, drops down vertically along a wall and goes out through a second lower horizontal passage.

The difficulty of giving satisfactory answers to the questions that arise when one tries to reconstruct the sequence of genetical and evolutional events of complex cave systems, has already been emphasized (Cappa, 1972). From the examples which have been now illustrated it can be argued that these difficulties arise even during the investigation on apparently very local phenomena.

It is well known that geological processes are very complex: a lot of experimental data must be taken into account and the use of computers is widespread, although the results can be scarcely significant.

The karst morphology results from complex superimposition of many different events, each following very complicated laws, and any further progress in this science ought to require careful investigations not only on single phenomena but especially on the combined — and not obvious — effects of the interaction among elementary speleogenetic processes.

We do not mean that basic theories ought to be revised or rejected, but only that their practical application must be considered very carefully: if, following the initial investigations we soon find evidence of proofs in favour of one theory, we must all the same continue and examine the facts more closely, because the signs of other processes, even more pertinent to the case, may still exist although disguised by events which were not more important but merely more recent.

Consequently it becomes clear that the study of a cave requires to take into account the whole karstic system. This is fairly easy when many caves, from absorption points to resurgences, are fully known, but such a task can become troublesome where some parts of the systems, e.g. their upper sectors, have disappeared as a consequence of landscape evolution. Where the area has been involved in geological events, like faulting, uplifting, etc., which took place fairly recently, i.e. after the beginning of the hypogean karstic development — like in Bisbino Mt. — the investigations on cave morphologies require to widen considerably the spectrum of the branches of Earth Sciences to take into account.

References

Allen J.R.L., 1972 - "On the origin of cave flutes and scallops by the enlargement of inhomogeneities", *Rass. Speleol. It.* XXIV (I): 3-23

Bini A., Cita M.B. & Gaetani M., "Are the south alpine lakes related to the Messinian entrenchment?" (in press)

Bini A. & Cappa G., "The development of Bisbino Mt. hypogean karstic system in correlation with the paleogeographical evolution of the region" *Proc. 7th Internat Speleo Cong. Sheffield.*

Cappa G., 1975, "Considerazioni sull 'applicabilità delle teoriet evolutive del fenomeno carsico in zone a forte perturbazione tettonica", *Atti Semin. Speleogenesi, Varenna* 1972 — Le Grotte d'Italia (4) IV (1973): 377-385

Curl R.L., 1974 "Deducing flow velocity in cave conduits from scallops", Nat.Speleo *Bull.* 36 (2): 1-5

Nangeroni G., 1974, "La geomorfologia delle montagne lariane", *Atti Soc. It. Sc. Nat.* 115 (1): 5-116

Renault P., 1963, "Caractères des vagues d'érosion selon la morphologie des conduits karstiques", Act.III *Congr. Int. Spel., Wien* 1963, II: 105-113

Renault P., 1967/68, "Contribution à l'étude des actions mécaniques et sédimentologiques dans la spéléogenèse", *Annales Speleol.* XXII (1) 5-21 ; XXII (2): 209-267 ; XXIII (1): 259-307 ; XXIII (3) : 529-593.

TECTONIC CAVES IN SOLUBLE ROCKS: COMPARISON OF MORPHOLOGICAL FEATURES

Roberto Bixio

Via Pacinotti 5/6, 16151 Genova, Italy

In this paper some remarks on the morphology of tectonic caves, where karst phenomena also took place, are reported. The main features of different kinds of caves (caves developed mainly by excavation of the pavement; caves developed mainly by excavation of roof channels; caves developed mainly by upward solution by the backing-up of floodwaters) are considered.

Speleogenetic or geologic aspects are not considered here. A comparison (also graphic) is carried on to emphasize the different morphological features which can possibly be utilized to identify and classify the pathways followed by natural caves during their development in soluble rocks.

Les Grottes Tectoniques

La roche calcaire, en raison des caractères lithologiques et mécaniques qui lui sont propres, subit sous l'effet des forces de l'orogénèse un procès plus ou moins intense de fracturation qui est indispensable pour le développement d'un réseau karstique profond.

La fissuration peut avoir des dimensions différentes et telles que dans certain cas le façonnement des cavités sera strictement lié à la circulation de l'eau, tandis que dans d'autres cas les fissures seront dès leur naissance des cavités explorables où l'action de l'eau aura un effet tout-à-fait secondaire sur le développement de la cavité.

L'idée de cavités qui dérivent d'une action simplement mécanique, directement par l'écartement d'un joint ou d'une diaclase et dans lesquelles l'action érosive de l'eau ast nulle ou négligeable, a été exprimée par des nombreux auteurs, notamment par Gèze (1937-1953), Denizot (1939), De Joly (1939) et ensuite reprise par Renault (1967). Ils ont indiqué ce type de cavite par le terme "gouffre tectonique".

Dans la suite de ce travail ce terme sera étendu aussi aux cavités qui doivent leur origine non pas à la tectonique au sens strict mais à des simples mouvements de versant (fentes de décollement ou de rappel au

vide — Renault 1961/1967).

Les grottes tectoniques, à leur naissance, ne seront pas "karstiques" au sens strict du terme, bien qu'il s'agit de cavités en roche calcaire: des cavités du même type peuvent se rencontrer en principe dans n'importe quelle roche cohérente. Dans une succession hétérogène, elles recoupent indifférement couches solubles et insolubles (Renault 1967). Dans le cas qu'une altération chimique agisse sur ces fissures en terrain non karstique, on pourra parler de phénomènes pseudokarstiques (Anelli F. 1973).

Il ne faut pas oublier aussi que dans de nombreaux cas le remplissage ou l'action de dissolution d'un cours d'eau souterrain ou l'erosion inverse (Maucci 1973), pourront changer d'une facon determinante la morphologie originaire de la cavité tectonique qui aura la tendance à évoluer vers des formes plus complexes, caractéristiques d'un procés karstique au sens strict.

Il sera très utile de pouvoir disposer de caractéres de comparaison des élements morphogiques des cavités dans leurs divers aspects en plan, en coupe longitudinale et en coupe transversale, se rapportant à Maucci (1973) pour ce qui concerne les grottes directes et inverses et à Renault (1968) pour ce qui concerne les grottes syngénétiques et paragénétiques.

Elements de Comparaison

1) Planimétrie.

D'après l'allure en plan nous remarquerons l'élément principal de différence entre les galeries tectoniques et les galeries inverses de Maucci (1973). Ces dernières dérivent de l'assemblement de plusieurs cavités simples plus ou moins alignées, séparées par des étroitures. L'aspect des galeries tectoniques, en plan, sera tout-à-fait semblable à celui des galeries directes, c'est-à-dire un couloir long et étroit, sans retrecissements ou élargissements remarquables, si évidemment il n'y a pas de superposition de phénomènes postérieurs à la genèse de la cavité.

Les galeries tectoniques auront en général une allure rectiligne avec des changements de direction très secs, au croisement avec les autres diaclases, tandis que les galeries directes auront une forme adoucie par l'érosion, voir même méandriforme, mais elles seront surtout différentes en coupe transversale.

2) Coupe transversale.

Les galeries directes auront une section transversale presque elliptique (par circulation phréatique ou en pression), ou bien à gorge, par circulation libre et érosion gravitative, d'ou le contour sera très irrégulier et presentera des paliers liés aux varations de niveau des eaux ou des remplisages et aux changement de chimisme des eaux. Les parois ne seront point parallèles et concordantes comme dans le cas des galeries tectoniques. Ces dernieres, plustôt, pourront présenter un profil transversal semblable à celui décrit plus haut, seulement dans leur partie inférieure à cause de l'action érosive d'une circulation libre sur le fond de la diaclase.

Le rapport entre largeur et hauteur dans une galerie directe sera d'autant plus semblable à celui d'une galerie tectonique (qui est caractérisée par un développement vertical prédominant sur le fond de la grotte tectonique aura duré plus longtemps.

Les mêmes considérations pourront être faites pour ce qui concerne les grottes paragénétiques de Renault (1968), bien que l'évolution du canyon souterrain (Bourgin 1942) se sera développée de bas en haut (forra antigravitativa — Pasini 1973).

En tout cas, les caractères de la voûte des cavités tectoniques et de celles phréatiques seront très différents. Le toit des diaclases pourra être constitué par la surface plane de la face inférieure d'une couche et dans ce cas il serait possible une confusion avec la morphologie de quelques grottes paragénétiques de Renault, où la voûte sera "rigoureusement plane" (bien que le point de contact entre voûte et parois dans le cas d'une galerie paragénétique surcreusée et complètement dépourvue de son remplissage originaire (cas assez rare) soit toujours assez arrondi par l'erosion por permettre d'éviter — en même temps que nombreux autres caractères typiques — toute confusion).

Plus fréquemment, comme nous avons vu, le "toit" sera représenté par une ligne imaginaire non définie, puisque la fissure sera tellement étroite qu'elle ne sera pas explorable directement, bien qu'elle ne soit pas fermée, ou bien elle sera irrégulièrement délimitée par du material clastique encastré à mi-hauteur entre les parois.

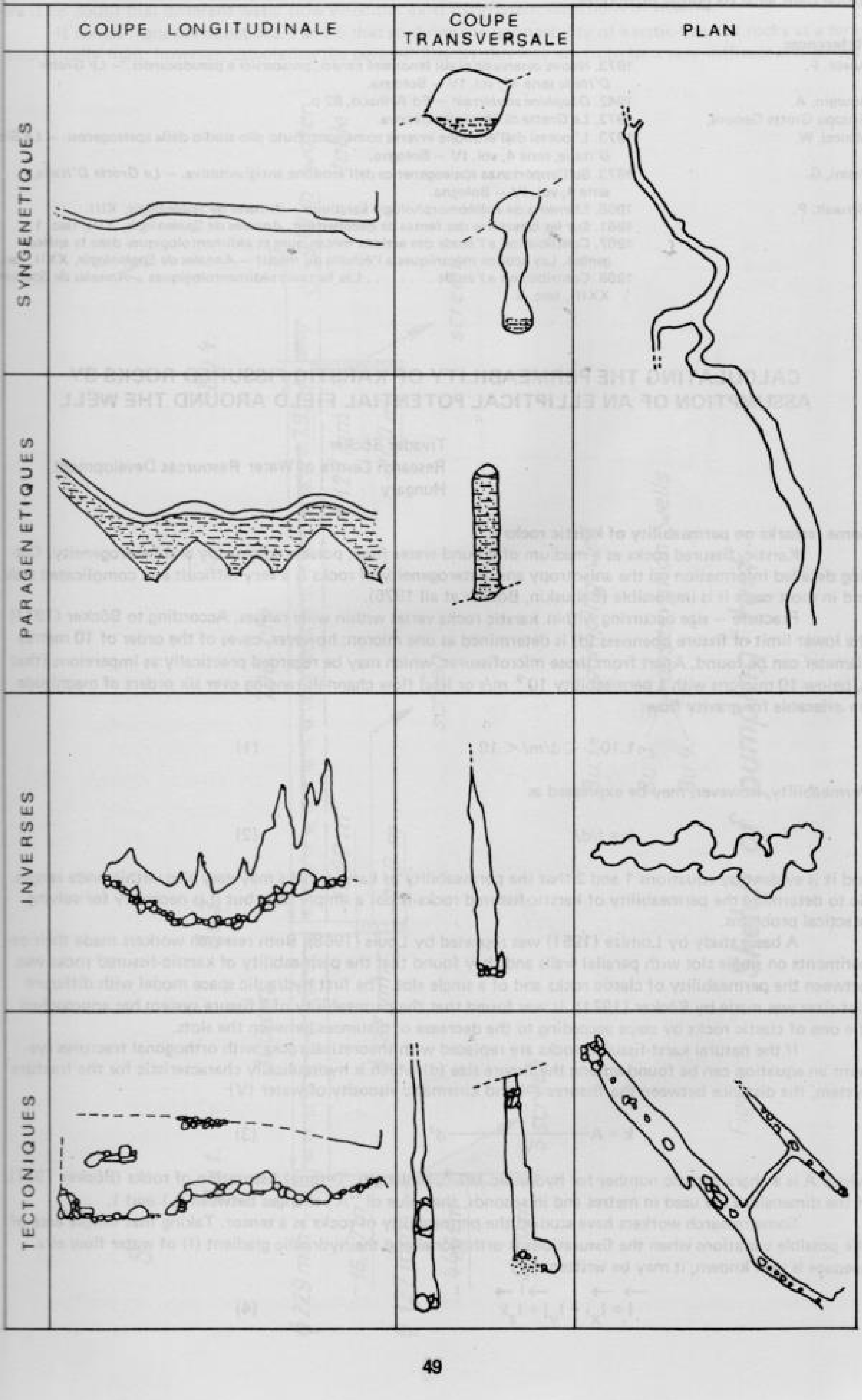
En tout cas il y aura une différence très nette par rapport aux galeries gravitationelles où la voûte sera creusée dans la roche vive avec la typique section presque circulaire ou elliptique (galeries syngenetiques — Renault 1968, et galeries de creusement peripherique — Renault (1958), ou par rapport aux "gallerie d'erosione antigravitativa (Pasini 1973) (ou de creusement remontant — Renault 1958) où, lorsque le remplissage aura atteint la voûte, la morphologie sera très semblable à celle d'une galerie syngénétique comblée dans sa partie inférieure (Renault 1968).

Moins évidentes à l'analyse graphique des levés topographiques seront les différences entre les galeries tectoniques et celles inverses (Maucci 1973) dans le cas que la voûte de ces dernières ne soit pas visible puisque leur section typique, en entonnoir renversé, pourra être confondue parfois avec celle d'une diaclase à parois convergentes vers le haut.

3) Coupe longitudinale.

Les différences seront au contraire bien évidentes à l'examen des coupes longitudinales où, tandis que les galeries tectoniques auront une allure assez régulière et linéaire de la voûte, sauf quelques interruptions dues au matériel clastique encastré, les galeries inverses seront le résultat de l'alignement d'une série de cheminées remontantes, et auront pourtant une allure, et donc une coupe, très accidentée.

TABLEAU DE COMPARAISON DES CARACTERES MORPHOLOGIQUES



Les galeries directes (Maucci 1973) pourront être très semblable en profil aux galeries tectoniques, puisqu'elles auront une voûte assez régulière qui sera cependant toujours creusée dans la vive roche.

Le rapport dimensionel hauteur-longueur sera au contraire différent, puisque dans les cavités simples des grottes tectoniques aura un développement vertical prédominant sur celui horizontal, tandis que dans les galeries directes ce rapport sera assez bas, puisque la longueur sera toujours très grande par rapport à la hauteur, même dans lecas de gorges profondes.

References

Anelli, F. 1973. Nuove osservazioni sui fenomeni carsici, paracarsici e pseudocarsici. – *Le Grotte D'Italia* serie 4ª, vol. IV – Bologna.

Bourgin, A. 1942. *Dauphiné souterrain* – Ed Arthaud, 82 p.

Gruppo Grotte Genova, 1972. *Le Grotte di Magliolo,* Genova.

Maucci, W. 1973. L'ipotesi dell'erosione inversa come contributo allo studio della speleogenesi. – *Le Grotte D'Italia*, serie 4, vol. IV – Bologna.

Pasini, G. 1973. Sull'importanza speleogenetica dell'erosione antigravitativa. – *Le Grotte D'Italia*, serie 4, vol. IV – Bologna.

Renault, P. 1958. Eléments de spéléomorphologie karstique – *Annales de Speleologie,* XIII.

1961. Sur les caractères des fentes de decollement. *Annales de Speleologie,* XVI, fasc. 1.

1967. Contribution a l'étude des actions mécaniques et sédimentologiques dans la spéléogenèse. Les actions mécaniques a l'échelle du massif – *Annales de Speleologie,* XXII, fasc. 2.

1968. Contribution a l'étude .... Les facteurs sédimentologiques – *Annales de Speleologie,* XXIII, fasc. 3.

CALCULATING THE PERMEABILITY OF KARSTIC FISSURED ROCKS BY ASSUMPTION OF AN ELLIPTICAL POTENTIAL FIELD AROUND THE WELL

Tivadar Böcker
Research Centre of Water Resources Development
Hungary

Some remarks on permeability of karstic rocks

Karstic, fissured rocks as a medium of ground-water flow, possess anisotropy and heterogeneity. Getting detailed information on the anisotropy and heterogeneity of rocks is a very difficult and complicated task and in most cases it is impossible (Babuskin, Böcker at all 1975).

Fracture – size occurring within karstic rocks varies within wide ranges. According to Böcker (1971) the lower limit of fissure openness (d) is determined as one micron; however, caves of the order of 10 metres diameter can be found. Apart from those microfissures, which may be regarded practically as impervious (that is, below 10 microns with a permeability 10^{-9} m/s or less) flow channels ranging over six orders of magnitude are aviacable for gravity flow:

$$1.10^{-5} < d/m/ < 10 \qquad (1)$$

Permeability, however, may be expressed as

$$k = f/d/ \qquad (2)$$

and it is evident by equations 1 and 2 that the permeability of karstic rocks may vary also within wide ranges. So to determine the permeability of karstic-fissured rocks is not a simple task, but it is necessary for solving practical problems.

A basic study by Lomize (1951) was repeated by Louis (1968). Both research workers made their experiments on single slot with parallel walls and they found that the permeability of karstic-fissured rocks was between the permeability of clastic rocks and of a single slot. The first hydraulic space model with different slot-sizes was made by Böcker (1971). It was found that the permeability of a fissure system has approached the one of clastic rocks by steps according to the decrease of distances between the slots.

If the natural karst-fissured rocks are replaced with theoretical rocks with orthogonal fractures systems an equation can be found among the fissure size (d) which is hydraulically characteristic for the fracture system, the distance between the fissures (△) and kinematic viscosity of water (V)

$$k = A \frac{1}{\triangle V} d^3 \qquad (3)$$

where A is a characteristic number for hydraulic MT^{-2}, M=length, T=time) fissuration of rocks (Böcker 1971). If the dimensions are used in metres and in seconds, the value of "A" changes between 0.1 and 1.

Some research workers have studied the permeability of rocks as a tensor. Taking that simple case of the possible variations when the fissurations is orthogonal and the hydraulic gradient (I) of water flow as a seepage is well known, it may be written:

$$\vec{I} = I_x \vec{i} + I_y \vec{j} + I_z \vec{k} \qquad (4)$$

when I_x; I_y; I_k are the hydraulic gradients in the fissures paralleling with the X;Y;Z planes. It can be seen from equation 4 that in different directions of fissures there are different hydraulic gradients (I_x; I_y; I_z) and taking into consideration that the velocity of water flow along the fissure is

$$v = f(I) \qquad (5)$$

there is no doubt that different water flow velocities exist in different directions of fissures.

It comes from the equations 4 and 5 that studying the permeability of karstic-fissured rocks as a tensor is theoretically right; however, calculating the permeability by this way seems to be a very difficult and compli-

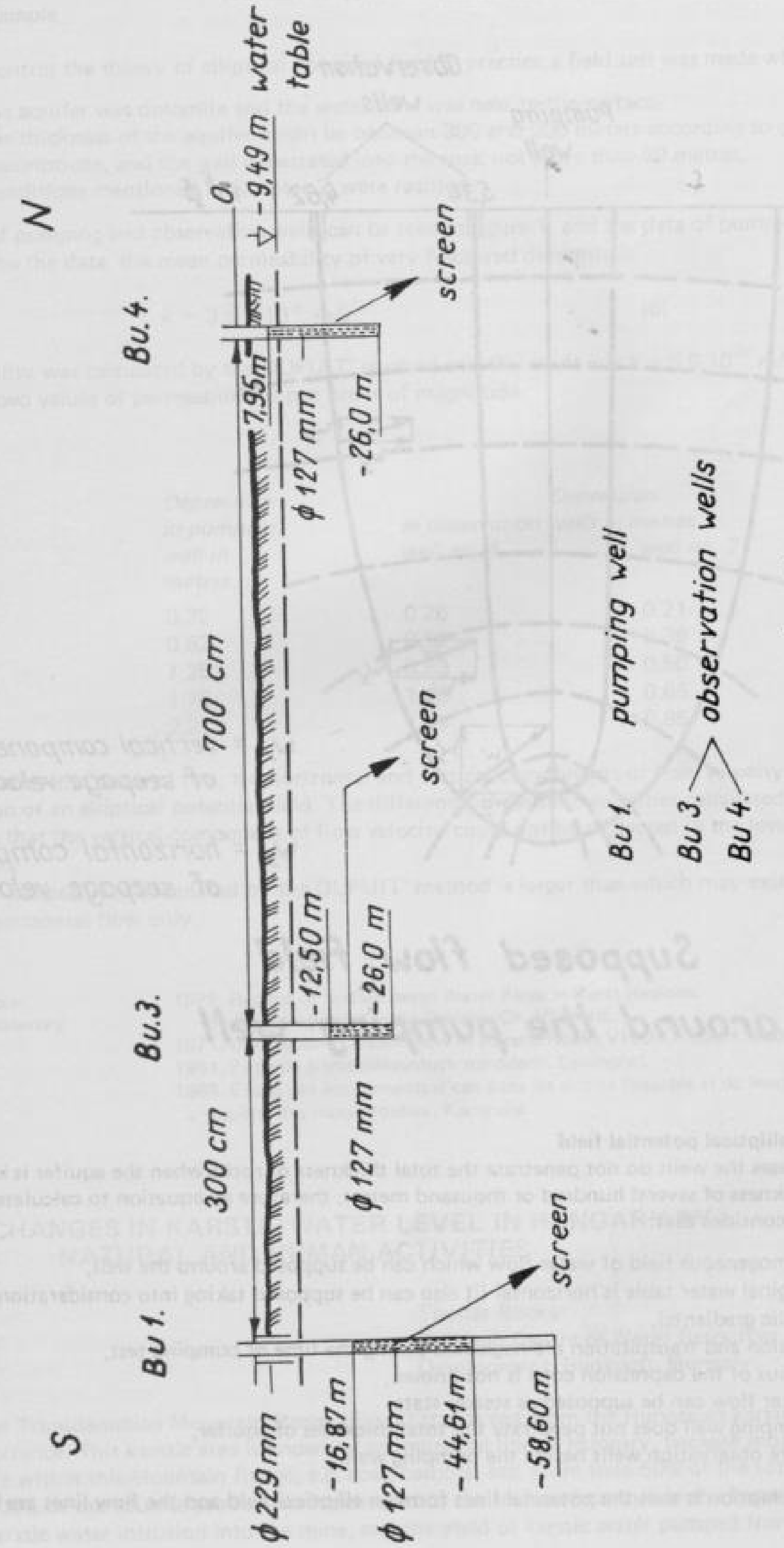


Figure 1. Sketch of pumping test

cated task, and in most cases it is impossible. It is the reason that the methods for solving practical problems are based upon the equations made by DUPUIT, DUPUIT – THIEM, THEIS, or THEIS – JACOB, but it should be pointed out these equations can be used beside determined conditions as follow:

- the field of water flow has no anisotropy and it is homogeneous,
- the aquifer is bounded with horizontal planes,
- the infiltration and the transpiration are neglected,
- the radius (R) of the depression cone is known,
- the water flow is steady state, except the THEIS' or THEIS – JACOB' methods,
- the well penetrates the total thickness of the aquifer.

In practice, however, only one or two of these conditions may be realised.

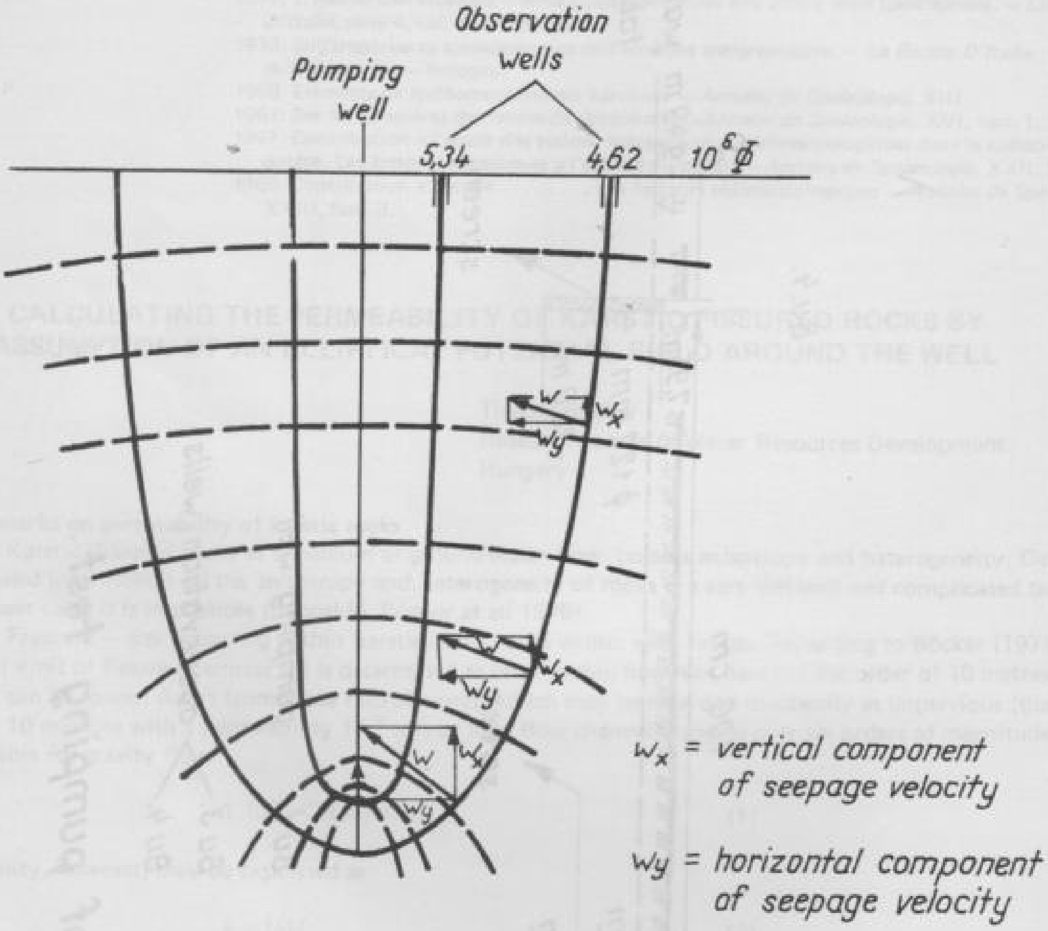


Figure 2. **Supposed flow field around the pumping well**

Assumption of an elliptical potential field

In most cases the wells do not penetrate the total thickness of rocks when the aquifer is karstic rocks. Owing to their thickness of several hundred or thousand metres, therefore an equation to calculate the rock permeability must consider that:-

- the homogeneous field of water flow which can be supposed around the well,
- the original water table is horizontal (it also can be supposed taking into consideration the natural hydraulic gradients),
- infiltration and transpiration are neglected during the time of pumping test,
- the radius of the depression cone is not known,
- the water flow can be supposed as steady state,
- the pumping well does not penetrate the total thickness of aquifer,
- there are observation wells beside the pumping well.

In this case the assumption is that the potential lines form an elliptical field and the flow lines are hyperbolic ones.

It can be deduced (Böcker 1971) that the potential difference between two wells is as follows

$$\emptyset_2 - \emptyset_1 = \frac{q}{4\pi}\, 1n\, \frac{1 - s_2\sqrt{r^2 \quad +/1\text{-}s_2/^2}}{1 - s_1\sqrt{r^2{}_1 \quad +/1\text{-}s_1/^2}} \qquad (6)$$

where ϕ_1 and o_2 are the values of potential in the observation wells 1 and 2; $q = \frac{Q}{1s}$ (Q = pumping yield /s = length of screen), 1 = penetrated length of pumping well into the rock r_1 and r_2 are the distance of observation wells from the pumping well, and s_1 and s_2 are the depression in the observation wells.

The permeability can be calculated by equation 7.

$$k = \frac{\phi_2 - \phi_1}{s_2 - s_1} \qquad (7)$$

A Practical example

To control the theory of elliptical potential field in practice a field test was made where

- the aquifer was dolomite and the water level was near to the surface,
- the thickness of the aquifer might be between 300 and 500 meters according to geological assumptions, and the well penetrated into the rock not more than 50 metres,
- conditions mentioned in Chapter 2, were realised.

The scheme of pumping and observation wells can be seen in figure 1. and the data of pumping test are in table 1. According to the data, the mean permeability of very fractured dolomite is

$$k = 3.5 \times 10^{-5} \text{ m/s} \qquad (8)$$

The permeability was calculated by the DUPUIT' method and the result was $k = 5{,}5.10^{-4}$ m/s. The difference between the two values of permeability is one order of magnitude.

TABLE 1

Yield 1000x m³ /s	*Depression in pumping well in metres*	*Depression in observation wells in metres* well no. 1.	*well no. 2*
0.92	0.32	0.26	0.21
1.75	0.62	0.53	0.36
2.50	1.25	0.83	0.50
3.42	1.75	1.10	0.65
3.83	2.27	1.29	0.85

To study the cause of this, the horizontal and vertical components of flow velocity were calculated by assumption of an elliptical potential field. The difference in the permeabilities calculated by two different methods was that the vertical component of flow velocity could not be neglected in the lower part of the pumping well.

The permeability calculated by the DUPUIT' method is larger than which may exist in reality, because it supposes horizontal flow only.

References

Babuskin, Böcker, Borevsky, Kovalevsky — 1975. Regime of Subterranean Water Flow in Karst Regions. Hydrogeology of Karstic Terrains Ch. VI; Paris.

Böcker, T. — 1971. Underground Water Flow in Karstic Rocks VITUKI report. Budapest.

Lomize, G.M. — 1951. Filtratia b treschinavatuch porodach. Leningrad.

Louis, G. — 1968. Etude des écoulements d'ean dans les roches fissurées et de leurs influence sur la stabilité des massif rochax. Karlsruhe.

CHANGES IN KARSTIC WATER LEVEL IN HUNGARY BY NATURAL AND HUMAN ACTIVITIES

Tivadar Böcker
Research Centre of Water Resources
Development, Budapest, Hungary.

The Transdanubian Mountain Range (Fig. 1) stands out from the Hungarian karstic areas on its economic importance. This karstic area is known as an industrial line of Hungary, because most reserves of mineral resources are within this Mountain Range; e.g. coal, bauxite, etc. More than 50% of the total coal production, almost of 100% of the bauxite production is delivered to the surface from below the karstic water level. The danger of karstic water intrusion into the mine, and the yield of karstic water pumped from the mines have

been very high. The necessity of establishing an observation network was very strong to register the changes in the karstic water system caused by mining activity, to plan the development of mining and to estimate the influence of pumped karstic water from mines on the environment in the future.

The basis of this observation network has been developed from the early 1950's in slow steps, but its development was very fast between 1968 and 1970 based on the author's ideas. At present there are a few hundred observation wells in the area of Transdanubian Mountain Range, over 2,500 Km^2 in area.

Changes in the karstic water level

Analysing the data produced by the observation network it was concluded about ten years ago (Böcker 1969) that the use of the concept of static water level was misleading, as it comes from a purely mechanical approach by which a condition is selected arbitrarily from the continuously changing interaction between different factors. It means the karstic water level continuously changes in time, but locally and regionally these changes can be determined by long term observation.

Change in karstic water level by natural factors.

The natural changes in karstic water level may be caused by different factors as follows:-

1) In the caseof water table in karstic rocks with passages open toward the surface
   a. long-term meteorological effects
   b. annual meteorological effects
   c. tidal phenomena in the earth's crust,
2) under confined circumstances karstic rocks by impervious formations preventing the development of a water table, the pressure conditions within the water system are influenced by
   a. the hydrostatic head controlled by water table fluctuations,
   b. the water temperature in karstic rocks,
   c. the chemical composition of karstic water of which the amount of dissolved gases is most important.
3) Under both water table and confined circumstances the petrographic conditions play a very impor- role in water level changes in time.

Fig. 1. Situation of the Transdanubian mountain range.

Influence of long-term meteorological variations on water level.

The long-term changes of karstic water level can be caused by the long-term meteorological variation. The changes between 1955 and 1974 are shown in Fig. 3. based on a 20 years of data. It has been found that the water level sank almost without a break from the beginning of 1957 to 1962, by more than eight metres during this period. The rate of sinking was 1.2m/year. A period of rising water level was observed between 1962 and 1969. The increase of water level was 13 metres and its velocity was 1.86 m/year, It could be observed that the velocity of increase was a little larger than the decreasing rate. A decrease tendency has been restored from 1969 and the beginnings or increase in water level can again be seen in the last part of 1976, and in 1977.

According to these facts above mentioned, it seems to be a 14-year long period consisting a seven year long "dry" half-period and a seven year long "wet" one. During the time of the total long-term period the change in the water level may be in the range of 10 metres.

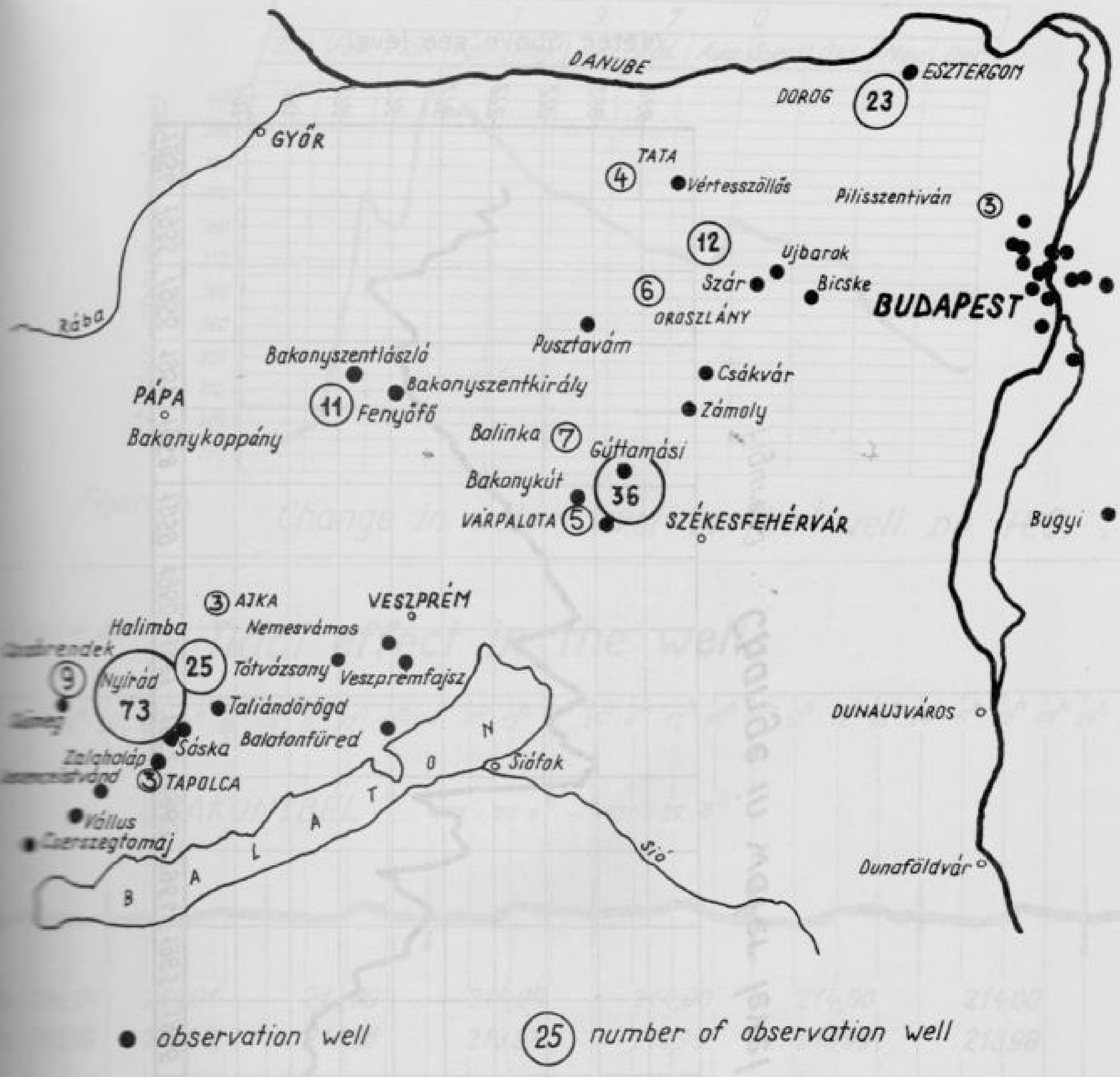


Fig. 2. Observation well network in the Transdanubian mountain range.

Annual change in water level

Favourable or unfavourable annual precipitation with infiltration can cause an annual change in water level within the long term period. The maximum water levels in the observation wells have followed the infiltration period, but their times are different from each other. The range of annual change in water level is also different in the wells depending on the local geological, structural situation around the wells. If the porosity and permeability of rocks change vertically to a great degree, e.g. they decrease, then there will be a great increase in the water level following the infiltration period (Fig. 4). The increase of water level in wells H.6 was 105 metres from beginning of February to the end of March 1970. The velocity of increase was 1.87 m/day. The dispersal velocity of water cone around this well was 0.28 m/day.

Daily change in water level

The daily change in water level can be caused by very fast infiltration together with a relatively poor permeability of rocks around the wells. Their result may be a few metres increase in water level.

Daily fluctuations with some kind of time period have been observed by the tidal phenomena of earth crust (Melchior 1956). To observe this phenomenon is very important for hydrogeologists because of an appropriate analysis gives the possibility of calculating the storage capacity and porosity of aquifers.

Fractures, caves and caverns systems on different bearings do not all respond uniformly to earth tides within karstic systems. The tests made so far seem to indicate that fracture systems striking nearly N-S are the most sensitive to earth tide effects.

Daily changes in some observation wells are shown by Fig. 5. The time period of fluctuations tends to be nearly 24 hours and it refers to the influence of "K" ($23^h54'4''$) and "O" ($24^h49'10''$) lunar waves. The

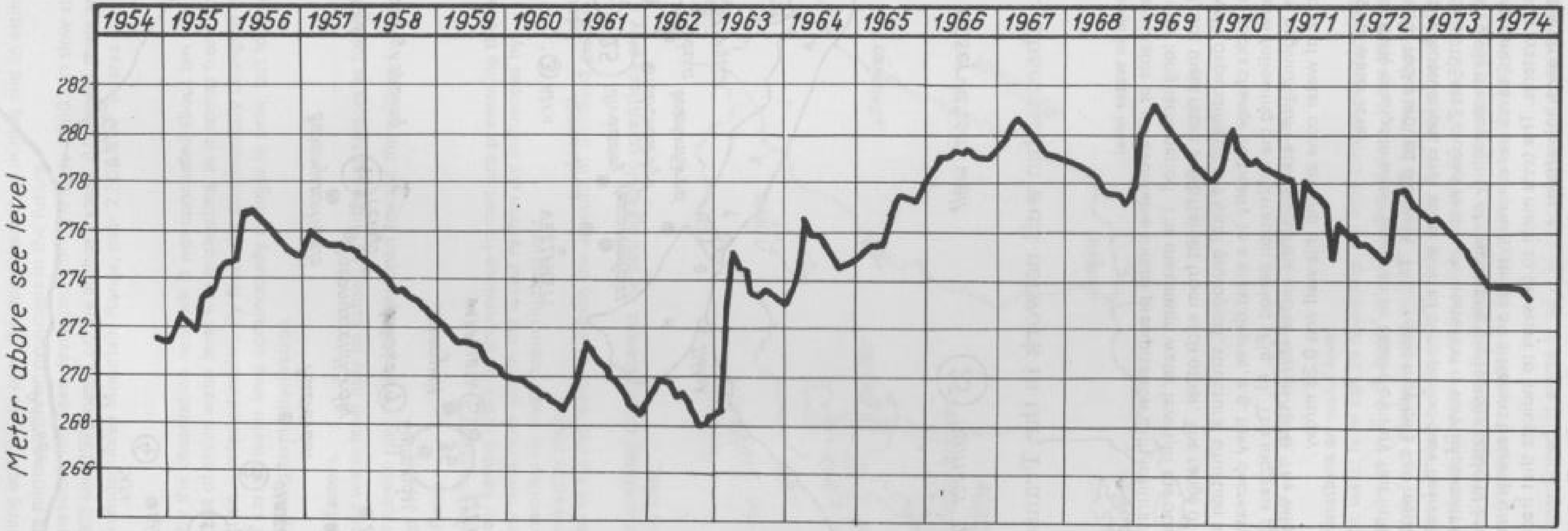


Figure 3. **Change in water level in the well no. Nv. 1**

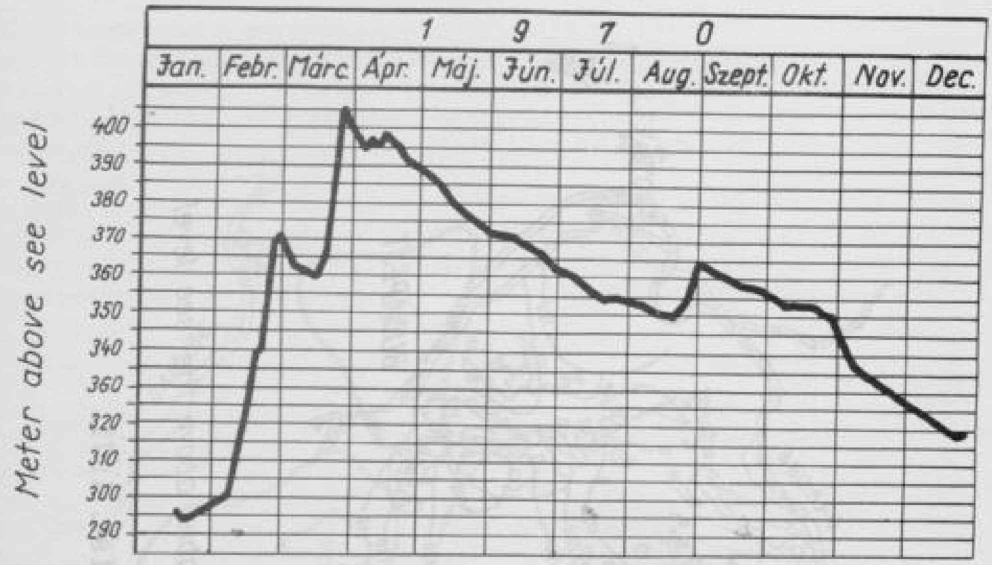
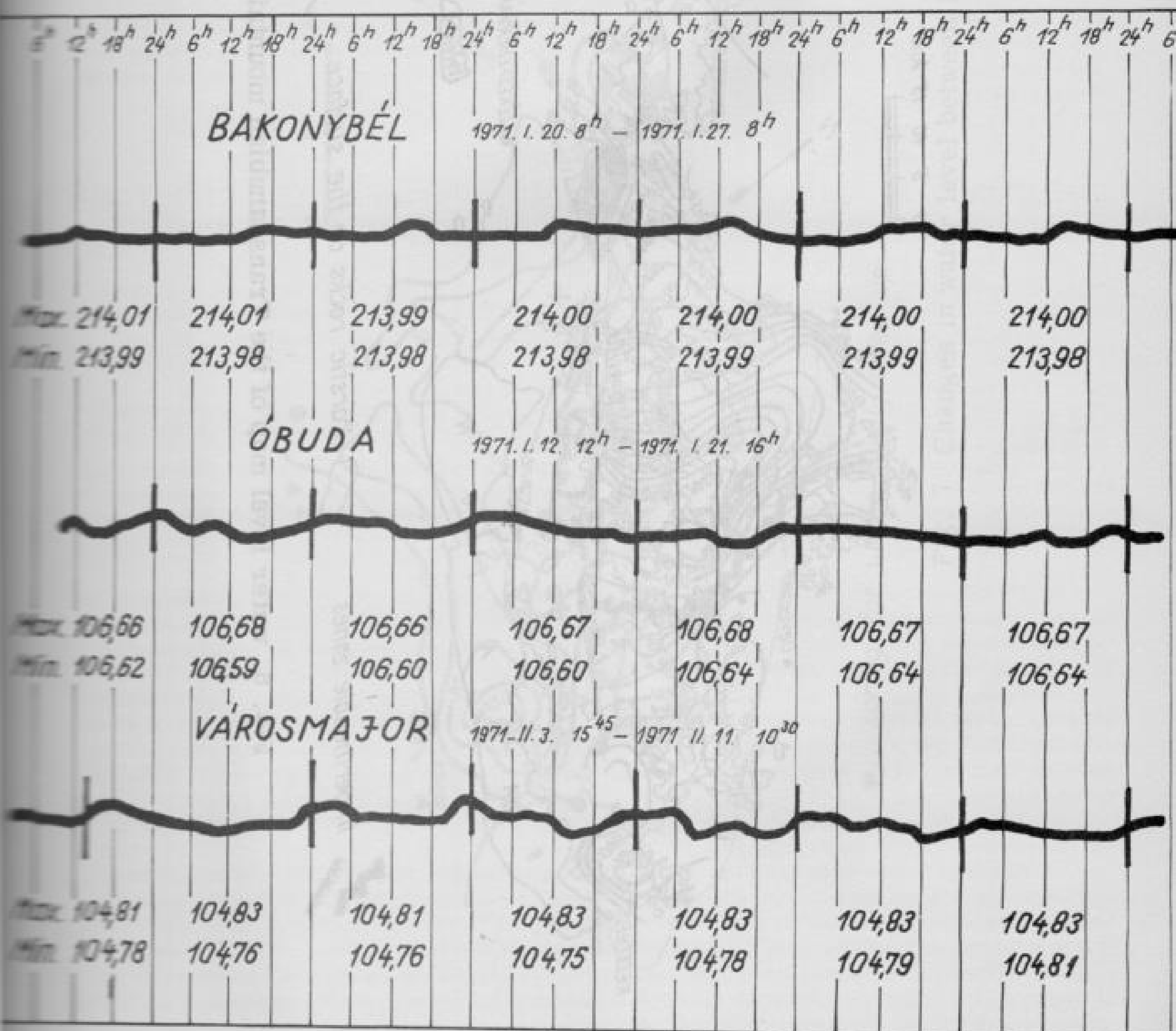


Figure 4. Change in water level in the well no. H.6.

Figure 5. Tidal effect in the wells



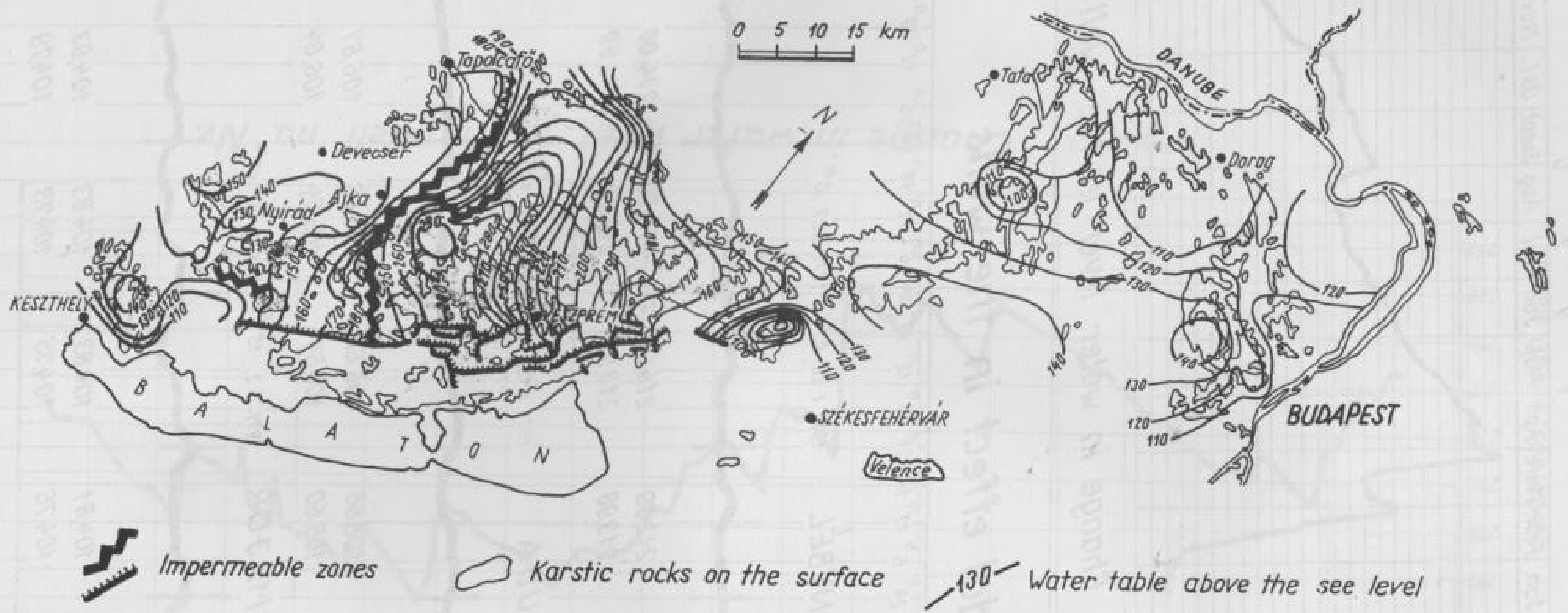
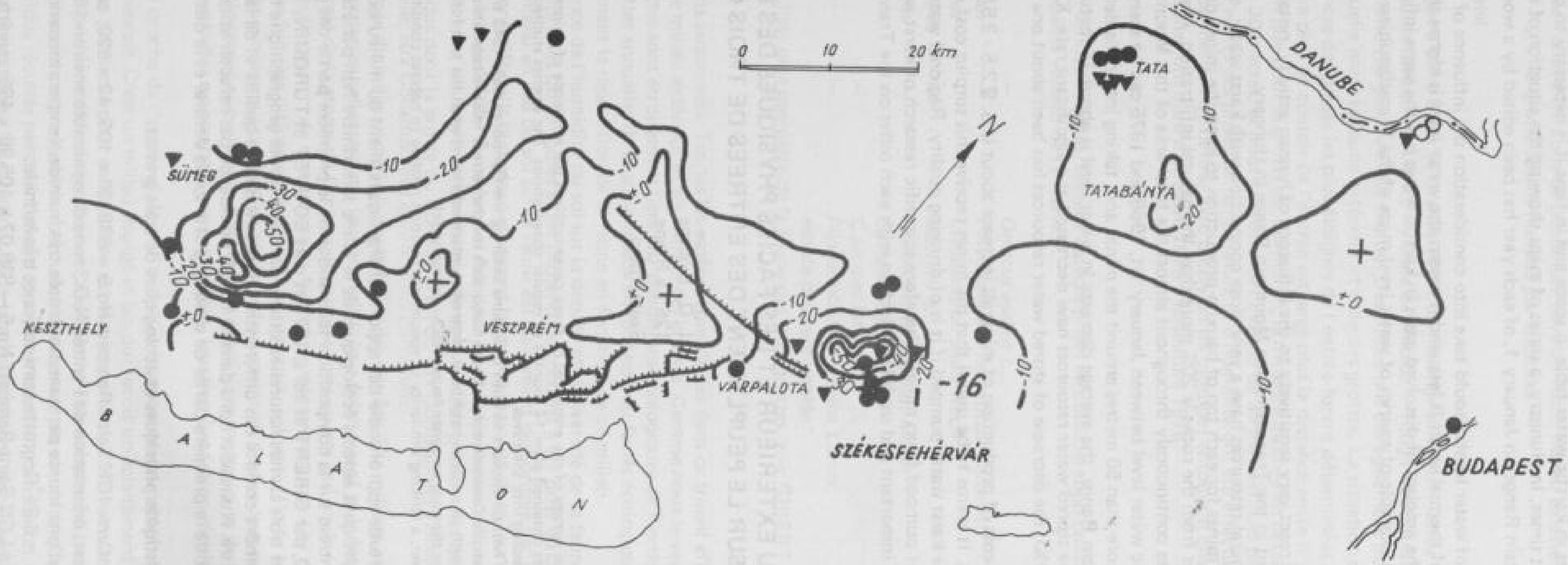


Fig. 6. water level map of the Transdanubian mountain range. Jan.1st. 1971.



▼ spring for water supply dried up ● spring dried up

Fig. 7. Changes in water level between 1968 and 1975.

amplitude of fluctuations in water levels may be between 2 and 6 centimetres in these cases.

Each influence mentioned above can be observed in both water table and confined circumstances.

To study the changes in karstic water table in space and in time it is necessary to compare maps of water levels made at different times. In Hungary, a series of maps showing the situation of karstic water levels on the Transdanubian Mountain Range on January 1, of each year has been edited by a working group headed by the author from 1969.

Preparing the maps of water levels should take into consideration the influence of water temperature, because the specific gravity of thermal water is less, and it means the water level is higher than cold water would be in the same well. The amount of dissolved gases in karstic water has the same influence on the water level as the temperature. One example of a series of water level maps of the Transdanubian Mountain Range can be seen in Fig. 6.

Influence of human activity

Karst water systems react very sensitively to the influence of human activity, notably mining activity, which has been very important in the Transdanubian Mountain Range in Hungary.

Most reserves of mineral resources have a very close connection with karst water, e.g. 140 m^3 of karst water must be pumped from mines for each ton of bauxite production to keep the mines dry. Presently the yield of pumped karstic water from the rocks is 20% more than the natural infiltration. According to this activity the karst water table decreases continuously throughout almost the total area of this Mountain Range.

The change in karstic water level between January 1st, 1968 and 1975 can be seen in Fig. 7. The decrease of the water table is more than 50 metres around the mines and, taking into consideration the total area of the Transdanubian Mountain Range, the average decrease in water level is about 15 metres.

According to this the stored water resources have decreased at a significant rate. Knowing the average porosity of karstic rocks (2.4%), the decrease of stored water resources has been about one milliard m^3 of water from 1968.

Pumping makes the cost of production of minerals increase about U.S. $2.5 - 3.5/ton depending on the kind of mineral resources. It seems to be useful that the mines receive this surplus cost or some part of it back by the way of selling the karst water pumped if it is of drinking quality. Regional water supply systems have been based upon karstic water pumped from mines. Therefore scientific research of karst water, mining activity and water supply have a very important and useful connection with each other on the Transdanubian Mountain Range in Hungary.

INFLUENCE DU MILIEU EXTERIEUR ET DES FACIES PHYSIQUES DES BIOTOPES CAVERNICOLES SUR LE PEUPLEMENT DES ENTREES DE TROIS GROTTES

J. D. Bourne
126 La Rippe,
Switzerland.

A comparative ecological survey of the entrances of three caves outlines the influence of epigean habitats on the cave entrance fauna, as shown by results obtained after 14 months of regular observations. The species studied include the majority of the seasonal migratory fauna passing into the caves.

A dampy rocky epigean habitat appears to limit this fauna entering the Cormoran Cave (343 trapped/year), whereas the much drier habitat near the Eveque Cave entrance is more favourable for the retreat to cave habitats by the same species (1573 trapped/year). The Cinq Cave with its epigean neighbour somewhat intermediate between the two former caves revealed a corresponding situation concerning the cave entrance fauna (592 trapped/year).

Within the caves, however, a striking similarity of species distribution relative to habitat conditions has been revealed.

Dans le cadre d'une étude approfondie des apports énergétiques allant du milieu extérieur vers le milieu hypogé, cette notice aborde quelques aspects écologiques de la faune saisonnière non-pariétale. L'importance du milieu extérieur proche des entrées sur la composition faunistique de la première partie des grottes a été étudies par CULVER et POULSON, 1970, par GIBERT et col's, 1975 et part BOUVET et TURQUIN, 1976.

En examinant de près trois cavités naturelles situées dans une limite géographique très restreinte (même massif), nous avons pu nous rendre compte des différences importantes de la qualité et de la quantité de la faune saisonnière d'une grotte à l'autre. Nous abordons dans ce travail l'influence des caractéristiques écologiques du milieu extérieur, de l'entrée et de la première partie de chaque grotte sur la densité et la distribution spatiale de sept espèces humicoles.

Résumé des caractéristiques physiques et écologiques de trois grottes.

Grotte du Cormoron Carte IGN Saint-Rambert No.5 – 838, 20 x 105, 42 x 520, ouverture petite et abritée par végétation et rochers; orientation de l'entrée N.O.; zone de pénombre environ 10m.; milieur extérieur humide toute l'année à cause d'une source permanente; entrée très humide, temperature annuelle moyenne pour la premiere partie de la grotte = 6.81°C; grotte semi-active et très humide.

Grotte des Cinq Carte LGN Saint-Rambert No.5 – 838,07 x 105,96 x 480; ouverture large et abritée en partie par la végétation; orientation de l'entrée N.E. zone de pénombre environ 10m.; milieu extérieur humide (surtout en hiver); entrée humide, temperature annuelle moyenne pour la premiére partie de la grotte = 7–63°C;

grotte fossile et humide au fond; suintements.

Grotte de l'EVEQUE Carte IGN Saint-Rambert No.5 – 837,91 x 106,08 x 470; ouverture large et libre; orientation de l'entrée E. zone de pènombre environ 10m.; milieu extérieur sec; entrée humide, temperature annuelle moyenne = 9,1° C grotte fossile humide par endroits.

Methodes et materiel

Seize pièges à bière Bière (11t. plus 10ml. du mélange suivant/ – acide acétique – 50ml., Formol – 20ml., acide lactique – 10ml., Hydrate de chloral – 100g.) furent installés dans chaque grotte allant de l'entrée vers le fond (8à gauche et 8à droite). Des pièges ont été également posés à l'extérieur pour établir une relation eventuelle entre la faune extérieur et celle des grottes. La situation de chaque piège fut choisie au hasard et les distances des pièges les plus éloignés de l'entrée furent déterminées en fonction de la largeur des couloirs, e'est-à-dire plus de couloir de l'entrée est large plus la distance entre le premier et le dernier piège est courte. Ceci fait que pour la grotte du Cormoran, la distance étudiée en détail est de 25 mètres, pour la grotte des Cinq de 30 mètres, et pour la grotte de l'Evêque de 35 mètres!. Les pièges furent changés chque mois et lors de ces visites des prises de température et d'humidité ont été effectuées' Des analyses pédologiques ont été faites qui permettent de définir avec précision les biotopes entourant chaque piège.

Les recherches ont duré d'octobre 1975 à novembre 1976.

La Faune

Mis à part les Collemboles, les sept espèces prises en consideration constituaient environ 90% des récoltes par piègeage des espèces versant de l'exterieur.

Isopodes	–	*Oniscus asellus* L.	(O.A.)
Diplopodes	–	*Polydesmus h. helveticus* Verheoff	(P.h)
Chilopodes	–	*Lithobius cf. agilis* Koch	(L.)
Thysanoures	–	*Machilis sp.*	(M.)
Coléoptères	–	*Quedius mesomelinus Marsh*	(Q.m.)
	–	*Catops picipes* F.	(C.p.)
	–	*C.picipes* larves	(C.p.l.)
Diptères	–	*Niphadobota luctscens* Lunds. espèce peu representée.	(N.1.)

Pour une liste plus compléte de la faune des trois grottes, voir GIBERT et colis' (1975).

Resultats

a) Aspects saisonniers. Toutes les espèces considérées dans ce travail effectuent des mouvements saisonneirs entre le milieu extérieur et les entrées des grottes. Comme nous le verrons, les différences observées entre les trois grottes sont étroitement liées auz conditions écologiques de l'extérieur.

b) Récoltes annuelles de chaque espèce en fonction du faciès écologique de biotopes. La figure 1 illustre plus clairement la répartition de la faune en fonction de ce milieu.

c) Influence de l'humidité du sol sur la densité et la diversité de la faune. Dans cette analyse la totalité de la faune (y compris les Collemboles et les Diptères humicoles) à été prise en consideration (relevé mai 1976). L'influence du contenu en eau du sol sur la faune est clairement démontrée par la figure 2. Les biotopes composés essentiellement d'éboulis humides herbergent la grande majorité de la faune. Le pourcentage en eau des sols, effectué par séchage à 105° C, ne fut pas fait pour les éboulis couverts d'une pellicule d'eau (p.e.). Pour les autres stations d'éboulis, seule la fraction composée de particules plus petites que 1 cm' fut analysée. Le nombre important d'individus pour la grotte du Cormoran est dû aux Collemboles *Tomocerus unidentatus* et pour la grotte de l'Evêque, aux Collemboles *Lepidocyrtus curvicollis*.

d) Influence du milieu extérieur sur la faune des entrées. Les milieux extérieurs proches de chaque entrée se distinguent essentiellement par leur humidité, leur éclairement et le faciès physique du sol.

Vers l'entrée de la grotte du Cormoran se trouve une source qui coule toute l'année. Le sol est caractérisé par un éboulis couvert de mousses et de feuilles en décomposition. Les nombreux arbres (chênes et hêtres) assurent une lumière diffuse et l'humidité au niveau du sol reste élevée toute l'année. Ce biotope convient aux espèces humicoles qui peuvent se déplacer facilement en profondeur parmi les blocs pour trouver des conditions climatologiques convenables. Bien que les conditions biotopiques de l'entrée et de la première partie soient apparemment celles recherchées par ces espèces, leur nombre (selon récolte annuelle) est peur important, *343 individus.*

Le milieu proche de l'entrée de la grotte de l'Evêque contraste nettement avec celui du Cormoran, surtout par sa sécheresse. C'est un milieu dégagé et sec qui recoit un éclairement substantiel. Il semblerait que l'at trait de la faune humicole pour cette entrée est très important, *1573 individus.*

Nous pouvons considérer la grotte des Cinq comme étape intermédiare entre les grottes précédentes. L'entrée est partiellement ombragée et le sol plus caillouteux et plus humide que vers la grotte de l'Evêque. Le nombre d'individus récoltés pendant l'année appuyerait une telle constation, *592 individus.*

Enfin il est à noter que les variations de la température sont plus étendues dans les milieux extérieurs que dans les entrées. Cependant dans les cas de toutes ces espèces sauf *N.lutescens*, l'influence sur le peuplement des entrées semble peu importante. La tolérance élevée à ce facteur accentue l'importance de l'humidité.

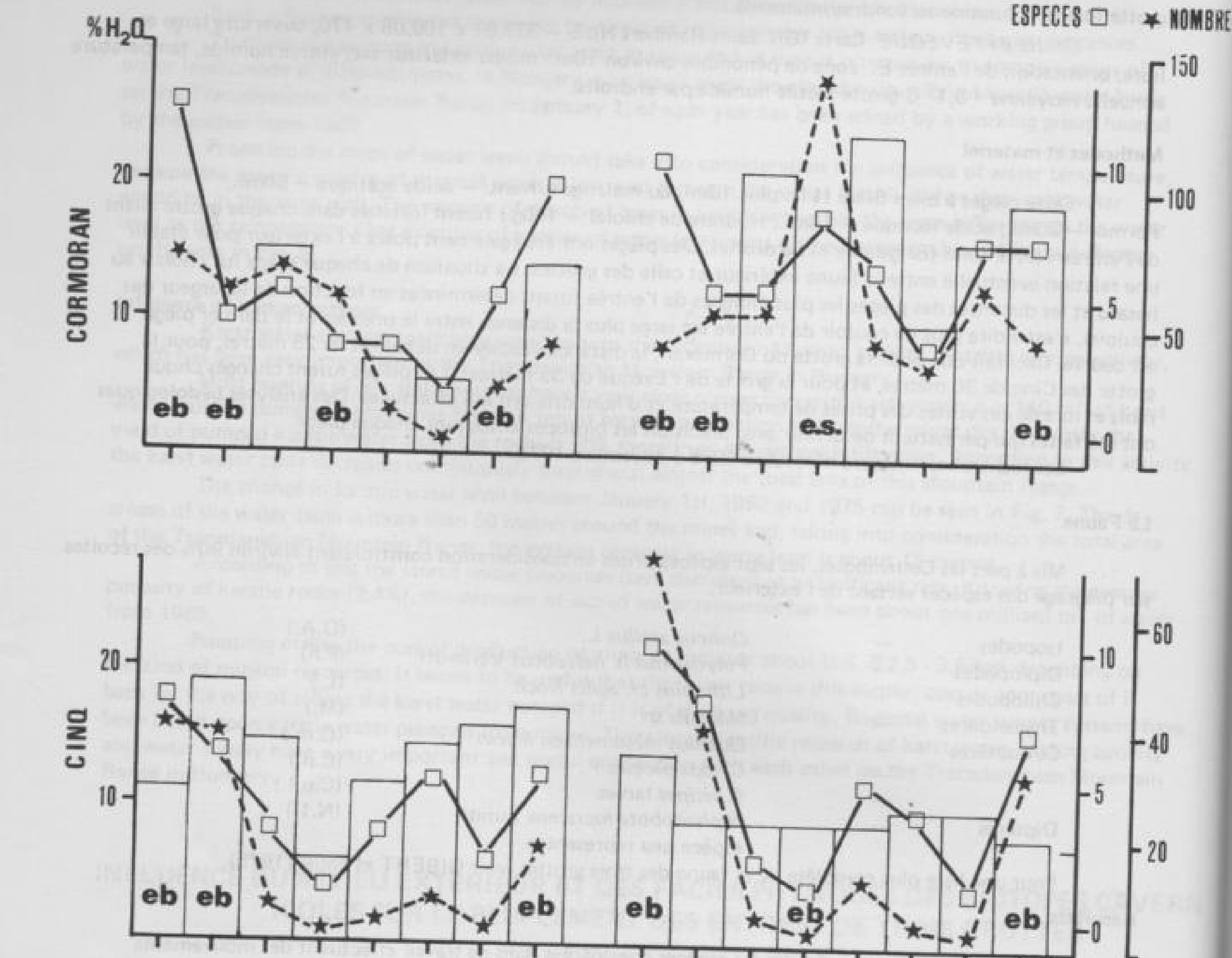


Figure 1. Totaux des 7 espèces récoltées dans les 3 grottes en fonction du biotope - éboulis humide. (En blanc: moyennes pour les 3 grottes; hachures: autres biotopes).

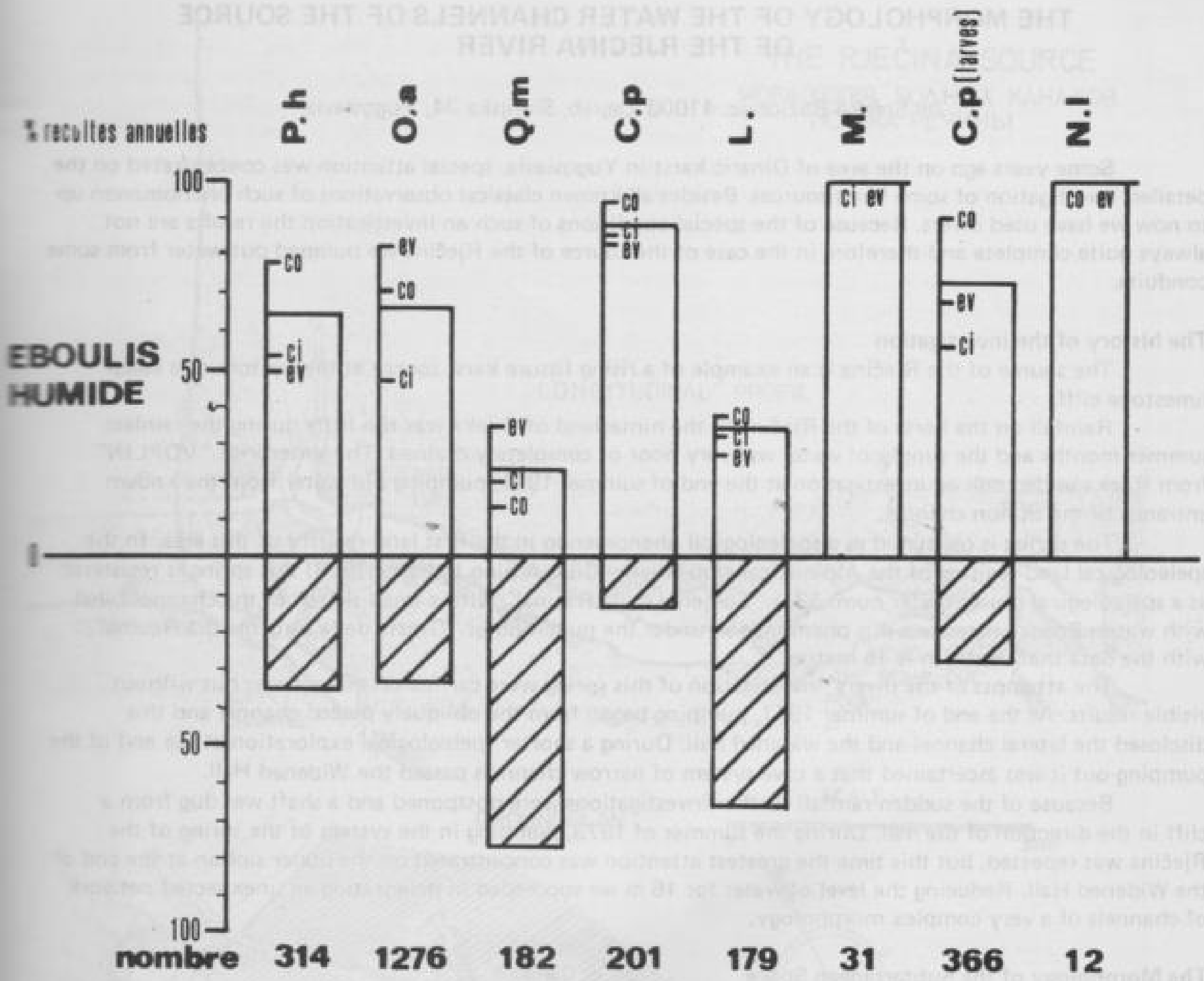


Figure 2. Densité et diversité de la faune aux entrées des 3 grottes en fonction du contenu en eau des sols.

(eb = éboulis; es = éboulis suintant)

Conclusions

L'influence des caractéristiques écologiques du milieu extérieur des trois grottes sur la composition faunistique des entrées a été démontrée. Nous avons également évoque l'importance du faciès pédologique comme facteur écologique contrôlant les distributions spatiales des sept espèces à l'intérieur des grottes. Il semblerait que les milieux épigés d'éboulis humide juxtaposant les entrées des grottes tendent à limiter le nombre des formes trogloxenes et troglophiles passant dans le milieu hypogé. Par contre, les milieu sec amplifieraient ce mouvement d'une faune humicole.

Il reste à déterminer à quel point la densite des formes trogloxènes et troglophiles influence les populations de troglobies (terrestres et aquatiques). Cependant, la pauvreté relative des apports au milieu hypogée par des fissures donnerait à penser que le flux d'engergie biodisponible arrivant par les entrées n'est pas à négliger.

Bibliographie

Bouvet, Y et M-J Turquin. 1976. Influence des modules d'ouverture du Karst vers l'extérieur sur la répartition et l'abondance de son peuplement' Bull.Soc. Linn.Lyon 45, 7, 245-257.

Culver, D.C. et T.L. Poulson. 1970. Community boundaries/faunal diversity around a cave entrance. Ann.Spéléol. 24, 4. 853-860.

Gibert, J. Laurent, R; Mathieu J; Reygrobellet, J. — L. 1975. Contribution à l'étude des biocenoses cavernicoles de la région de Torcieu.
AIN(Mem. et Doc.), 1, 21-46.

THE MORPHOLOGY OF THE WATER CHANNELS OF THE SOURCE OF THE RJECINA RIVER

by Srécko Bozicevic. 41000 Zagreb, Slunjska 34, Yugoslavia

Some years ago on the area of Dinaric karst in Yugoslavia, special attention was concentrated on the detailed investigation of some karst sources. Besides all known classical observations of such phenomenon up to now we have used divers. Because of the special conditions of such an investigation the results are not always quite complete and therefore in the case of the source of the Rječina we pumped out water from some conduits.

The history of the investigation

The source of the Rječina is an example of a rising fissure karst source at the bottom of a steep limestone cliff.

Rainfall on the karst of the Rječina in the hinterland of Rijeka was too little during the rainless summer months and the supply of water was very poor or completely drained. The enterprise "VOPLIN" from Rijeka undertook an investigation at the end of summer 1971, pumping out water from the known entrance of the siphon channel.

The spring is registered as a speleological phenomenon in the first land-registry of this area. In the speleological land-registry of the Alpinistical club Rijeka (Club Alpino Italiano, 1928) this spring is registered as a speleological object under num. 33 – "Sorgente della Recina", with a small sketch of the channel filled with water. Boegan mentions this phenomenon under the num. 685 as "Grotta della sorgente del Recina", with the data that its depth is 15 metres.

The attempts of the divers' investigation of this spring were carried on many times but without visible results. At the end of summer 1971, pumping began from the obliquely placed channel and this disclosed the lateral channel and the widened hall. During a shorter speleological exploration at the end of the pumping-out it was ascertained that a cave system of narrow channels passed the Widened Hall.

Because of the sudden rainfall further investigations were postponed and a shaft was dug from a cliff in the direction of the hall. During the summer of 1973, pumping in the system of the spring of the Rječina was repeated, but this time the greatest attention was concentrated on the upper siphon at the end of the Widened Hall. Reducing the level of water for 16 m we succeeded in penetrating an unexpected network of channels of a very complex morphology.

The Morphology of the Subterranean Space

If we examine the known channels and hollows of the subterranean space of the spring of Rječina the following morphological elements are:-

- the lower obliquely placed supply channel which is active for a longer time, with its uninvestigated continuation probably of the siphon type.
- the Widened Hall with collapsed blocks, high joints on the ceiling, with smoothed out rocks and piles of gravel along to-days approach.
- the lateral channel which connects the Widened Hall with the lower supply channel.
- the supply channel of the upper siphon now hydrologically active, which in its investigated continuation bifurcates in some interconnected channels.

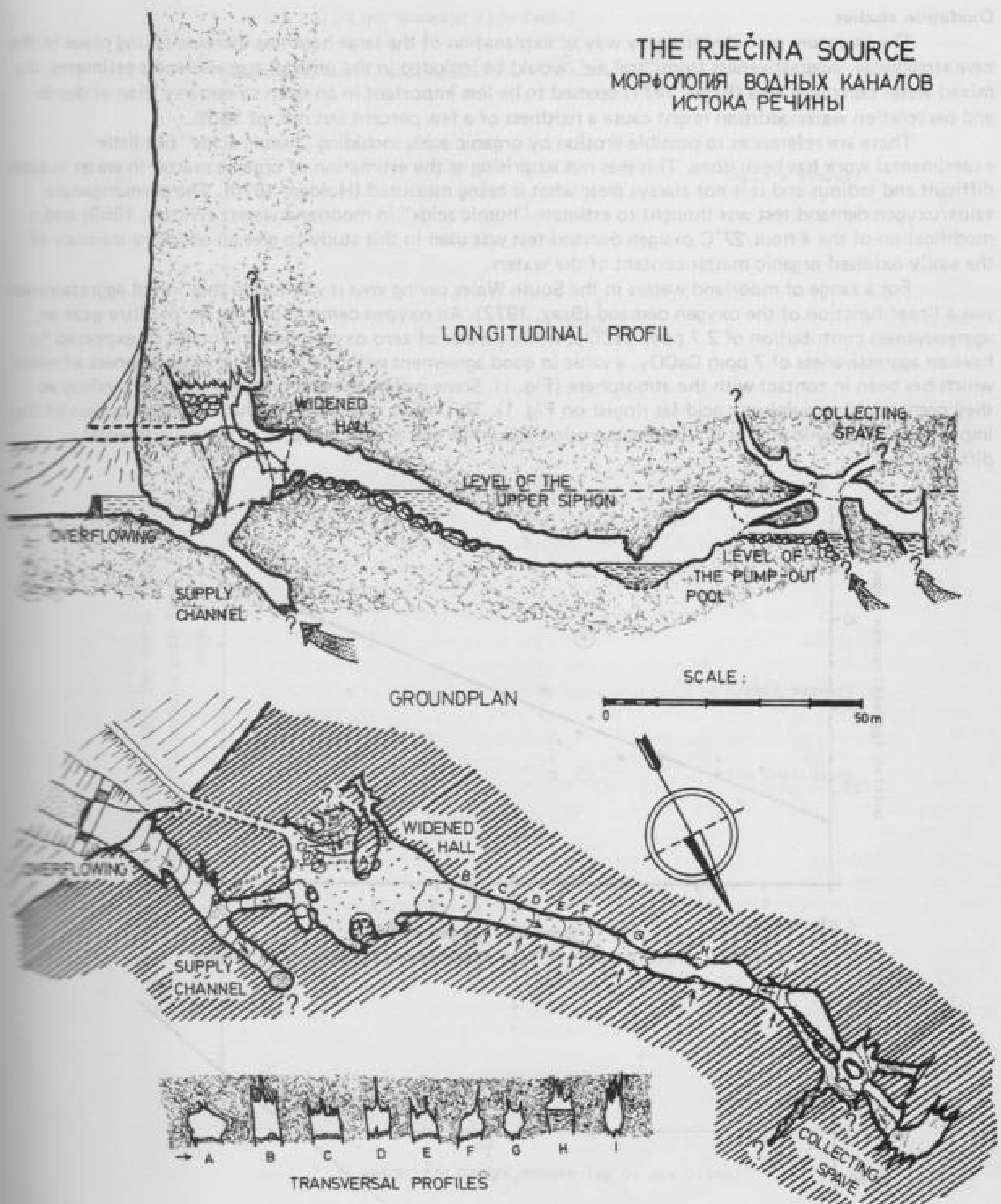
In the interpretation of the genesis of this subterranean object we must begin from the fact that the Rjecina "represents the source connected with the subterranean circulation concentrated in the upper Cretaceous or Palaeogene limestones". In this case the joint systems have formed with the erosive work of water widening channels of tunnel-like type. The rush-explosive rise of subterranean water (after the first pumping) in quantity near 50 m^3 sec. indicated that there exists a bigger accumulation of subterranean water behind this spring.

During its percolation through the subterranean channels water penetrates into all joints and dissolves and widen the walls. The mechanical power of water is intensified in flood in the underground when the pressure and the speed of flow set in motion small or bigger fragments of collapsed or drifted material. If this material is sandy, (as in the case of Rječina) then the widening of the channel is much faster.

According to the observations we have so far, that the channel of the upper siphon with the network of the collecting channels is the result of previous long activity of this spring on the cliff face higher than it is today. The lower supply channel is the result of the youngest phase of hydrological activity and of the reduction of the subterranean water level in the area of this spring.

The Hydrogeology of the Spring of the Rječina

The main direction of the inflowing water is now through the lower supply channel and water from the upper siphon flows only in the period of longer rainfall. It is interesting, that accumulated water in the upper siphon did not run to the supply channel during the investigation of 1971 but also the accumulated water in the supply channel in time of pumping of 1973, did not run back into lower parts of the pumped-out channel of the upper siphon. The depth and the connexion between siphons in the collecting area is not yet researched in detail, but it is noticed that the both pools have nearly the same level. This should be one of the tasks during the next pumping-out. In this case it will be necessary to determine the shortest distance between the central collecting area and the surface by means of a precise survey and enter through a new shaft.



THE ROLE OF ORGANIC MATTER IN LIMESTONE SOLUTION IN THE OGOF FFYNNON DDU STREAMWAY

L. G. Bray
39, High Street, Northwood, Middlesex, HA6 1EB

Introduction

Water enters the Ogof Ffynnon Ddu cave system at the Pwll Byfre sink with a total hardness of 22 ppm $CaCO_3$ and an initial aggressiveness of +16 ppm $CaCO_3$, yet leaves the system at the Ffynnon Ddu resurgence with a total hardness not of 22 + 16 i.e. 38 ppm $CaCO_3$ but of 110 ppm $CaCO_3$. Similar discrepancies had been noted for other cave systems in South Wales but the Ogof Ffynnon Ddu system was especially suitable for investigation of chemical changes taking place in the streamway as this was relatively uncomplicated, most of it was known, access to it was controlled and as the excellent field laboratory at the Penwyllt Headquarters of the South Wales Caving Club was nearby.

Oxidation studies

The literature provided little by way of explanation of the large hardness increase taking place in the cave streamway. Aggressiveness from "soil air" would be included in the original aggressiveness estimates, the mixed water corrosion idea (Bögli, 1971) seemed to be less important in an open streamway than at depth and percolation water addition might cause a hardness of a few percent but not of 300%.

There are references to possible erosion by organic acids including "humic acids" but little experimental work has been done. This was not surprising as the estimation of organic matter in water is both difficult and tedious and it is not always clear what is being measured (Holden, 1970). The permanganate value/oxygen demand test was thought to estimate "humic acids" in moorland waters (Wilson, 1959) and a modification of the 4-hour 27°C oxygen demand test was used in this study to give an arbitrary measure of the easily oxidised organic matter content of the waters.

For a range of moorland waters in the South Wales caving area it was found that initial aggressiveness was a linear function of the oxygen demand (Bray, 1972). An oxygen demand of 1mg O_2 per litre gave an aggressiveness contribution of 2.7 ppm $CaCO_3$, while a water of zero oxygen demand could be expected to have an aggressiveness of 7 ppm $CaCO_3$, a value in good agreement with the anaerobic aggressiveness of water which has been in contact with the atmosphere (Fig. 1). Some waters showed high aggressiveness values as they contained free sulphuric acid (as ringed on Fig. 1). This result indicated that further investigation of the importance of organic matter in limestone erosion should be carried out, in spite of the experimental difficulties.

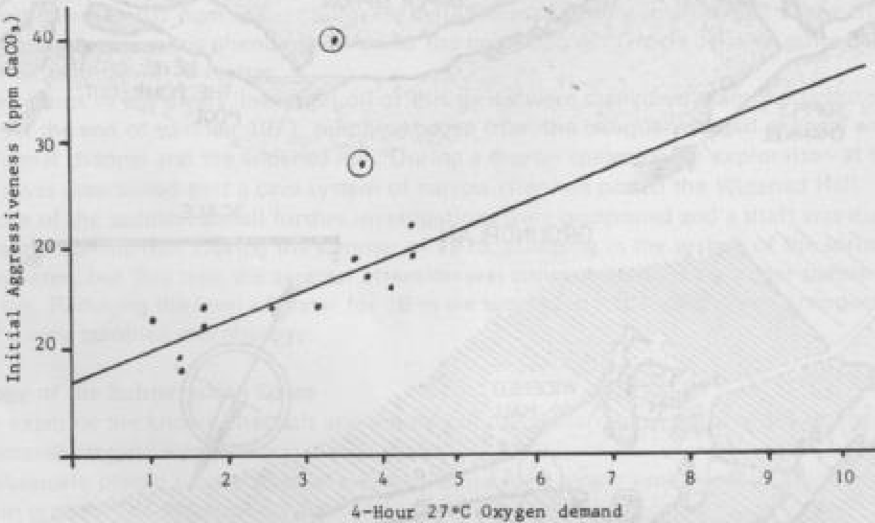


FIGURE 1: RELATIONSHIP BETWEEN AGGRESSIVENESS AND OXYGEN DEMAND

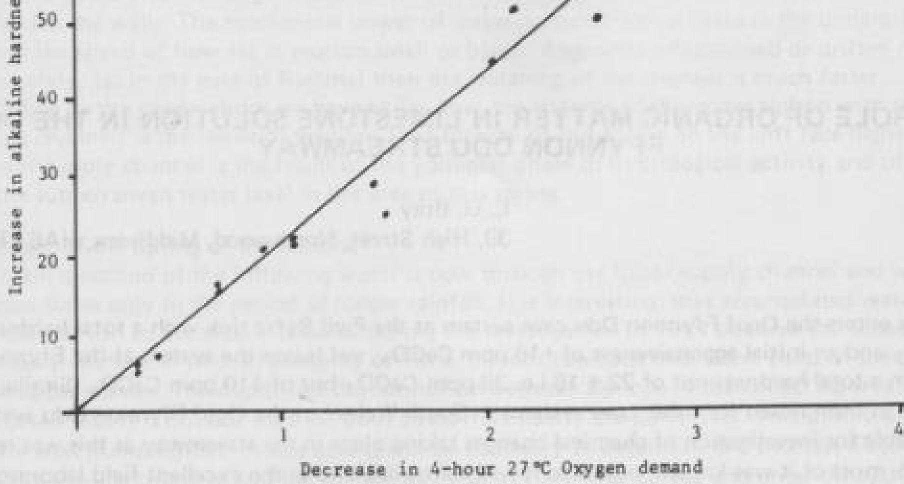


FIGURE 2

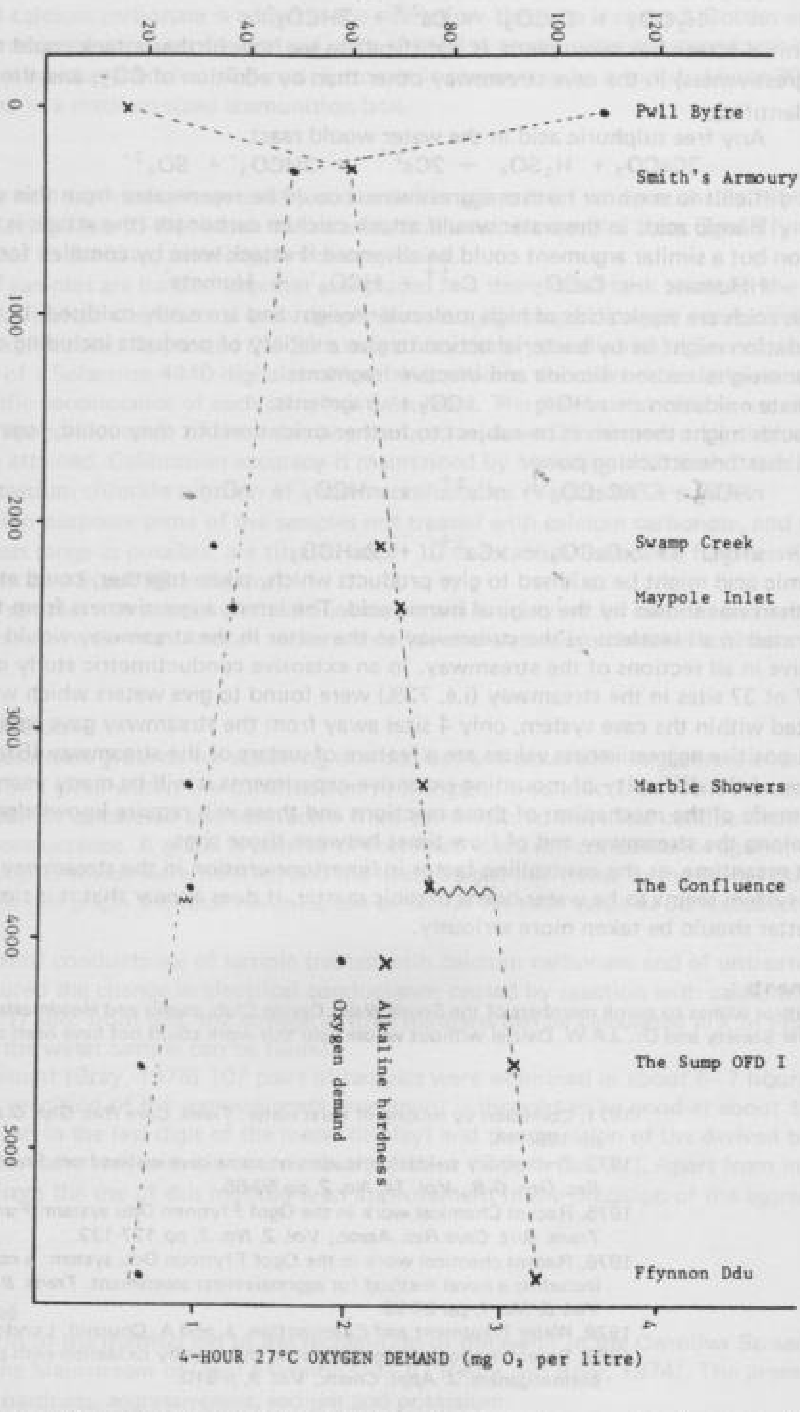


FIGURE 3: CHEMICAL CHANGES ALONG THE OGOF FFYNNON DDU STREAMWAY

It is possible to arrange sampling experiments throughout a system as extensive as Ogof Ffynnon Ddu only rarely but these experiments can give valuable information. From such experiments it was apparent that, as water passed from the Pwll Byfre sink along the streamway to the Ffynnon Ddu resurgence, the alkaline hardness of that water increased and the oxygen demand (indicating organic matter content) decreased (Bray, 1975).

For each section of streamway it was possible to calculate the increase in alkaline hardness and the decrease in oxygen demand (with allowance being made for the addition of very hard but organically "clean" water from the Cwmdwr Stream). When these changes were plotted a straight line graph was obtained, the slope indicating that a decrease in oxygen demand of 1mg O_2 per litre would be accompanied by an increase of 21.7 ppm $CaCO_3$ alkaline hardness (Fig. 2). In the cave streamway easily oxidised organic matter seemed to be able to cause reaction with almost 7 times as much calcium carbonate as it could in the initial aggressiveness test. This was a real indication of how the very large hardness increases might be taking place. The changes along the Ogof Ffynnon Ddu streamway are shown in Fig. 3. Percolation water addition will be responsible for part of these changes but cannot account for the full extent of the changes.

Organic matter in the cave streamway

A moorland water can be considered to attack calcium carbonate by three routes in the initial aggressiveness test.

1) Carbonic acid will attack calcium carbonate

$$H_2CO_3 + CaCO_3 \rightleftharpoons Ca^{2+} + 2HCO_3^-$$

but, once this initial attack has taken place, it is difficult to see how further attack could take place (i.e. regenerated aggressiveness) in the cave streamway other than by addition of CO_2, and then the real source of CO_2 must be identified.

2) Any free sulphuric acid in the water would react

$$2CaCO_3 + H_2SO_4 \rightarrow 2Ca^{2+} + 2HCO_3^- + SO_4^{2-}$$

and, again, it is difficult to see how further aggressiveness could be regenerated from this source.

3) Humic acids in the water would attack calcium carbonate (the attack is assumed here to be by salt formation but a similar argument could be advanced if attack were by complex formation)

$$HHumate + CaCO_3 \rightarrow Ca^{2+} + HCO_3^- + Humate^-$$

However, humic acids are weak acids of high molecular weight and are easily oxidised. In the open streamway of the cave oxidation might be by bacterial action to give a variety of products including organic acids of lower molecular weight, carbon dioxide and inactive fragments

$$HHumate\ oxidation \rightarrow nHOrg + xCO_2 + fragments$$

These organic acids might themselves be subject to further oxidation but they could, together with carbon dioxide, exert limestone attacking power

$$nHOrg + nCaCO_3 \rightarrow nCa^{2+} + nHCO_3^- + nOrg^-$$

and

$$xCO_2 + xH_2O + xCaCO_3 \rightarrow xCa^{2+} + 2xHCO_3^-$$

In this way humic acid might be oxidised to give products which, taken together, could exert a greater aggressiveness than was shown by the original humic acid. The latent aggressiveness from the humic acid would be generated in all sections of the streamway so the water in the streamway would be expected to be slightly aggressive in all sections of the streamway. In an extensive conductimetric study of Ogof Ffynnon Ddu waters, 27 of 37 sites in the streamway (i.e. 73%) were found to give waters which were aggressive and, of 97 sites visited within the cave system, only 4 sites away from the streamway gave aggressive waters, suggesting that positive aggressiveness values are a feature of waters of the streamway (Bray, 1976).

In view of the difficulty of mounting extensive experiments it will be many years before detailed studies can be made of the mechanism of these reactions and these will require knowledge of flow rates at different sites along the streamway and of flow times between those sites.

In the meantime, as the controlling factor in limestone erosion in the streamway of Britain's most extensive cave system seems to be water-borne organic matter, it does appear that it is time that the role of the organic matter should be taken more seriously.

Acknowledgements

The author wishes to thank members of the South Wales Caving Club, pupils and Headmaster of Acton County School, The Royal Society and Dr. J.A.W. Dalziel without whose help this work could not have been conducted.

References

Bögli, A. 1971. Corrosion by mixing of karst water. *Trans. Cave Res. Grp. G.B., Vol. 13, No. 2,* pp 109-114.

Bray, L.G. 1972. Preliminary oxidation studies on some cave waters from South Wales. *Trans. Cave Res. Grp. G.B., Vol. 14, No. 2,* pp 59-66.

1975. Recent Chemical work in the Ogof Ffynnon Ddu system: Further oxidation studies. *Trans. Brit. Cave Res. Assoc., Vol. 2, No. 3,* pp 127-132.

1976. Recent chemical work in the Ogof Ffynnon Ddu system: a conductimetric study including a novel method for aggressiveness assessment. *Trans. Brit. Cave Res. Assoc., Vol. 3, No. 1,* pp 20-28.

Holden, W.S. 1970. *Water Treatment and Examination.* J. and A. Chuchill, London.

Wilson, A.L. 1959. Determination of organic matter in water by oxidation with potassium permanganate. *J. Appl. Chem., Vol. 9,* p 510.

RAPID AGGRESSIVENESS ASSESSMENT USING CONDUCTIMETRY

L. G. Bray
39, High Street, Northwood, Middlesex, HA6 1EB

Introduction

The chemical study of the waters of an extensive cave system presents several problems. For the results to be significant the water samples must be collected within a few hours during a period when water conditions in the cave have been steady for some days, and careful organisation of the teams of cavers is needed for sample collection to proceed without confusion. However, if ordinary titrimetric techniques are to be used, the analysts can be given so much work that the water samples begin to deteriorate before they can be analysed. The technique discussed provides a rapid way of gaining a useful amount of information from a large number of sites.

In the cave

Two samples are needed of the water at each site. One is collected in the usual manner but using a

66ml brown polystyrene bottle, and the other is collected in a 25ml white polypropylene tube and about 0.2g (excess) AnalaR calcium carbonate is added at the site before the tube is capped. Bottles and tubes carry numbers in different series to avoid confusion, and were chosen to accept a dip-type conductivity probe so that sample transfer at conductimetric and flame photometric stages may be avoided. About 30 pairs of samples can be carried in a medium-sized ammunition box.

In the laboratory

An efficient field laboratory is necessary and such a unit has been set up at the Penwyllt Headquarters of the South Wales Caving Club so that much of the analytical work on samples from Ogof Ffynnon Ddu may be performed very near to the cave, avoiding unnecessary delay.

The pairs of samples are banded together and placed in a thermostat tank to attain the 25°C working temperature. The electrical conductance of each sample is measured using a dip-type conductivity cell working into a Walden Precision Apparatus CM 25 conductivity meter, the discrimination of which is improved by the use of a Solartron 4440 digital multimeter applied to the chart recorder output terminals of the CM 25. The specific conductance of each sample is calculated. The thermostat tank in use can take 30 pairs of samples and the conductance of these can be measured in about 30 minutes once thermal equilibrium has been attained. Calibration accuracy is maintained by including with each batch of samples a bottle containing potassium chloride solution of known conductance (Vogel, 1962, p 974).

For calibration purposes some of the samples not treated with calcium carbonate, and selected to have as wide a hardness range as possible, are titrated at pH 10 to establish their total hardness (using EDTA and a screened Solochrome Black 6B indicator).

Each of the samples not treated with calcium carbonate is analysed for sodium and for potassium using an EEL flame photometer with AnalaR sodium chloride and potassium chloride solutions as standards (Vogel, 1962, p 882).

Calibration and calculation

There are reasonable grounds for assuming that sodium and potassium might have entered the waters as chlorides so that, for a given water, the contribution to the specific conductance from the sodium and potassium chlorides can be calculated and subtracted from the measured electrical conductance to give a corrected electrical conductance. A graph is plotted of corrected electrical conductance against total hardness for those samples which were titrated, and the best straight line fitted to the points using a least squares analysis. From this graph the total hardness can be found for each value of corrected electrical conductance (Fig. 1).

As the electrical conductance of sample treated with calcium carbonate and of untreated sample have both been measured the change in electrical conductance caused by reaction with calcium carbonate can be found (δY in Fig. 1) and, from this, the change in total hardness can be calculated (δX in Fig. 1) so that the aggressiveness of the water sample can be found.

In an experiment (Bray, 1976) 107 pairs of samples were examined in about 6–7 hours of laboratory time. The precision of the aggressiveness assessment is thought to be good at about ±1 ppm $CaCO_2$ (based on a ±2 precision in the last digit of the meter display) and the precision of the derived total hardness values is thought to compare well with titrimetric results (about ±2 ppm $CaCO_3$). Apart from improved speed of working the gain from the use of this method is an improvement in the precision of the aggressiveness assessment.

Some results discussed

An early form of the method led to the recognition of the water in the Cwmdwr Stream as being quite unlike that in the Mainstream of Ogof Ffynnon Ddu (O'Reilly and Bray, 1974). The present method gives values for total hardness, aggressiveness, sodium and potassium.

Most of the waters in the cave are non-aggressive: only 4 sites away from the Mainstream (of a total of 97 sites within the cave) gave aggressive waters while 27 of the 37 sites in the Mainstream of Ogof Ffynnon Ddu gave aggressive waters.

The water in the Mainstream becomes progressively harder as it flows from Smith's Armoury (first appearance in the cave) to the Ffynnon Ddu resurgence, with a distinct rise in hardness caused by the entry at The Confluence of relatively hard water from the Cwmdwr Stream which contributed some 18% of the water leaving the area of The Confluence. In general the tributaries have waters with hardness in the range 100–115 ppm $CaCO_3$ although those in the Marble Showers area have a hardness of 92–96 ppm $CaCO_3$ encouraging speculation that the waters have entered from close to the surface. Some of the waters of inlets in the OFD I area are hard (Waterfall 147 ppm $CaCO_3$) and others have rather high sodium and/or potassium contents which seem likely to originate from contamination from the surface (e.g. from road salt). In general sodium and potassium levels above The Confluence are quite constant (about 4ppm Na^+ and 0.4 ppm K^+). (fig. 2).

The value of sodium content measurements as such is illustrated in values from the Cwmdwr Stream. This has a hardness of about 139 ppm $CaCO_3$ in the Jama but only 129 ppm $CaCO_3$ at The Confluence but there is no evidence of calcium carbonate deposition. The suggestion that this fall in hardness might be brought about by entry of softer water (like Mainstream water but from a source at present unknown) was confirmed by the sodium content falling from 13 ppm Na^+ at the Jama to 10 ppm Na^+ at The Confluence. (Bray 1976).

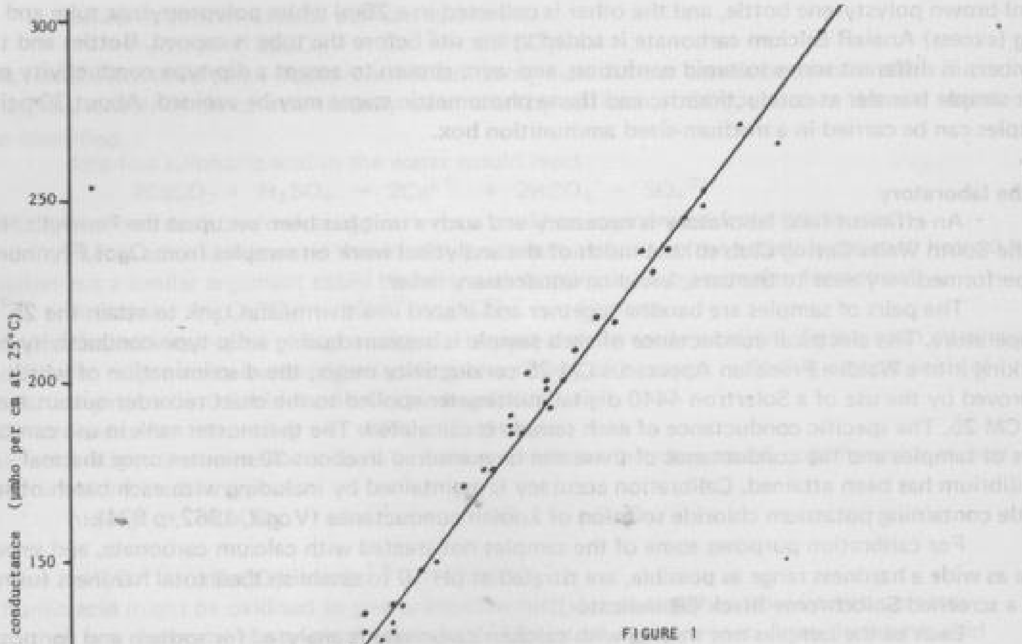
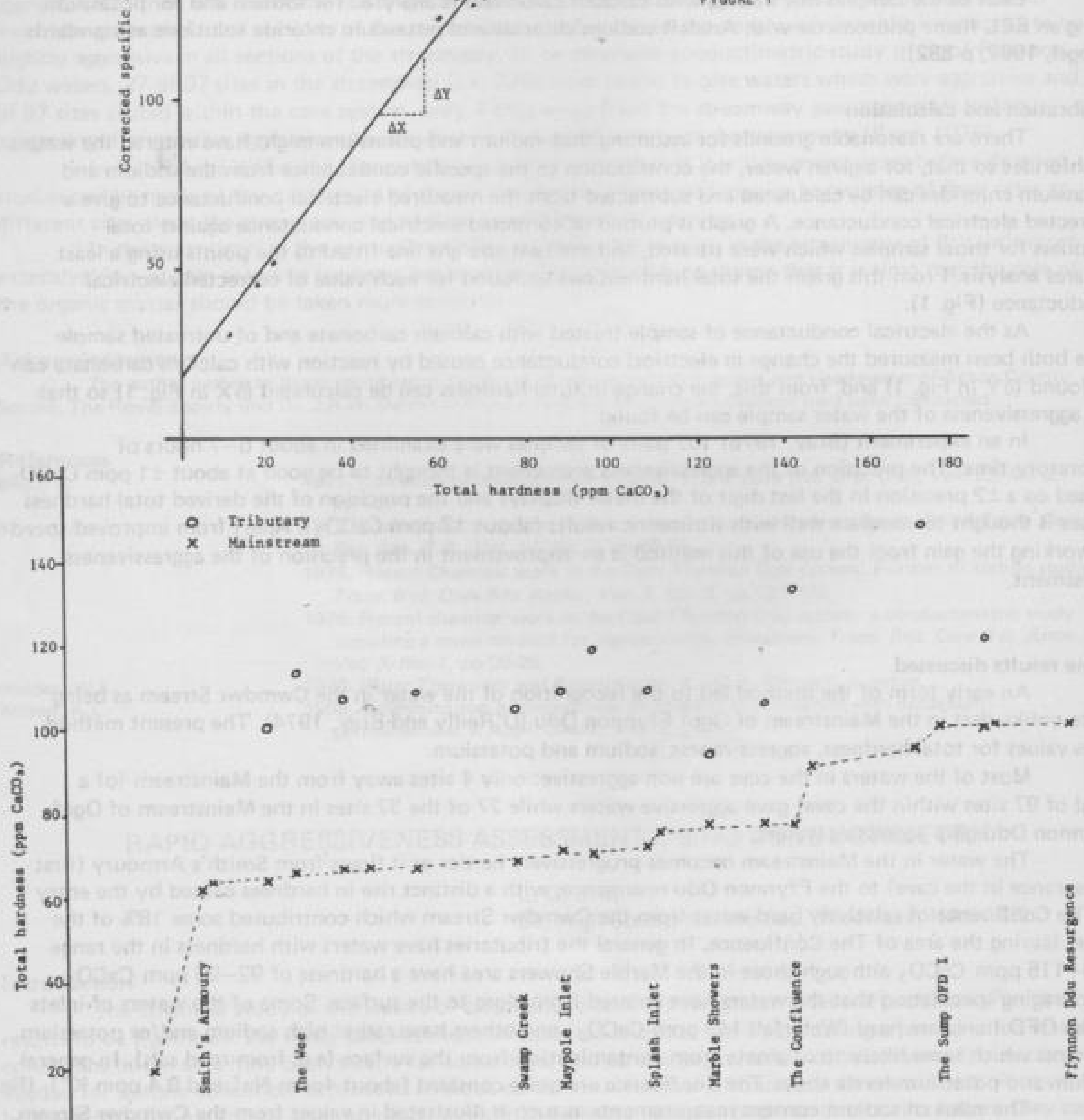


FIGURE 1



HARDNESS CHANGES ALONG OFD STREAMWAY

FIGURE 2

Limitations

As at present constituted the scanning technique cannot deal easily with acid moorland waters as the fast-moving hydrogen ion would cause a significant contribution to electrical conductance. Measurement of pH could help to solve this problem but such a measurement would need to be performed after conductance and flame photometer measurements to avoid contamination of the sample from the pH electrode. However a very aggressive water will show a considerable increase in conductance on reaction with AnalaR calcium carbonate.

It would be very helpful to have a rapid technique for estimation of oxygen demand on small samples of water. In the meantime it is felt that the present technique allows a more extensive investigation of the waters of a major cave system than was possible by conventional methods.

Acknowledgements

The author wishes to thank members of the South Wales Caving club, pupils and Headmaster of Acton County School, The Royal Society and Dr. J.A.W. Dalziel, without whose help this work could not have been performed.

References

Bray, L.G. 1976. Recent chemical work in the Ogof Ffynnon Ddu system: a conductimetric study including a novel method for aggressiveness assessment. *Trans. Brit. Cave Res. Assoc., Vol. 3, No. 1*, p. 20-28.

O'Reilly, P.M. & Bray, L.G. 1974. A preliminary hydrological study in Ogof Ffynnon Ddu, Breconshire. *Trans. Brit. Cave Res. Assoc., Vol. 1, No. 2*, p. 65-73.

Vogel, A.I. 1962. *A textbook of quantitative inorganic analysis.* Longman. London.

TEST METHODS FOR CAVING EQUIPMENT

Brendon Brew
Department of Physics, University of Leeds
Leeds, England.

Introduction

As caving methods have become more technical, cavers have been asking more pertinent questions about the equipment and the techniques they are using. These questions can only be answered after a series of tests have been carried out. The following paper lists and defines the main equipment tests used and tries to explain the actual meaning of the test results.

Conflicts can easily arise between manufacturers' specifications and equipment test reports if different test conditions are used. It is important that all equipment test reports state under what conditions the tests were carried out. It is to be hoped that published specifications and standard test conditions for all caving equipment will be quickly evolved.

Static Load Test

The equipment under test is loaded slowly and continuously until failure occurs (B.S. 3104, 1970). The load at failure is then quoted as the Ultimate Tensile Strength (U.T.S.) or the Breaking Load. The U.T.S. or Breaking Load is the maximum *STATIC* weight that the test item would be able to support. This test is mainly used for comparison of different brands of the same type of equipment. Figure 1 shows typical load/ extension curves obtained from a static load test.

The Static Load Test is also used in quality control checks especially for metal items e.g. karabiners (Hiatt catalogue). This proof testing of equipment is only of any use when the elastic limit of the item is not exceeded. If the elastic limit is exceeded then the item would be permanently deformed and weakened. Proof testing gives the minimum *static* strength of an item.

Dynamic Load Tests

The dynamic strength of an item is always lower than the static strength and is the maximum force that the item can just withstand in a shock load situation. There are two types of dynamic load test: (i) by fast moving machines which cause failure in the test item and (ii) a drop test.

(i) There are very few places which can carry out this type of test which measures the *dynamic* strength of an item. Testing of equipment by this method is very limited although it is the most relevant test for caving and climbing equipment.

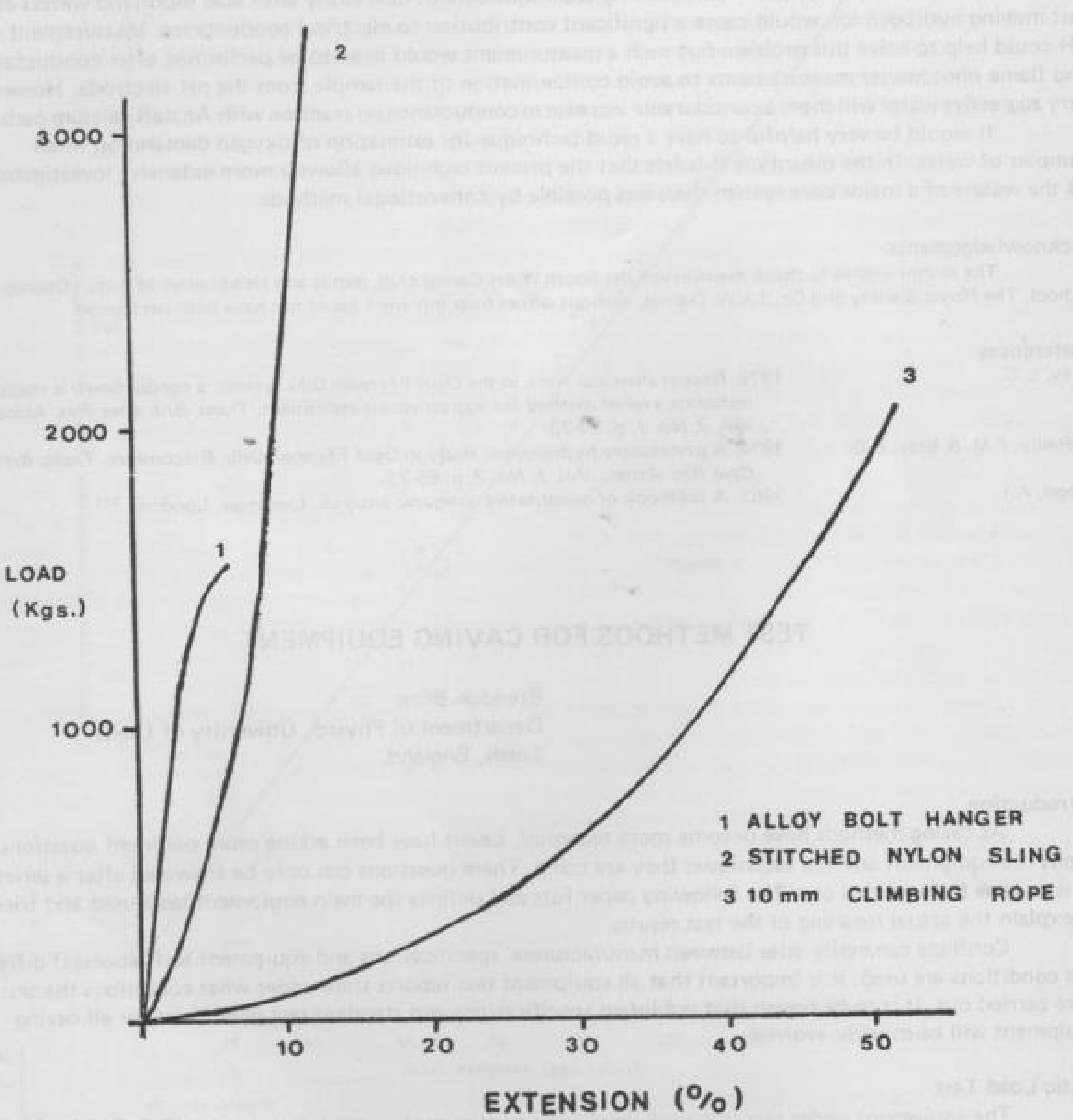
(ii) The most commonly known drop test is the "Dodero Test" (Fig. 1) as used by the U.I.A.A. for testing climbing ropes. In the "Dodero Test" a 70 Kg. weight is dropped through a distance of 5.0 metres on a rope length of 2.8 metres which gives a fall factor of 1.78 (Schwartz, 1974).

$$(\text{Fall factor} = \frac{\text{Height fallen}}{\text{Length of rope}})$$

The peak force developed in the rope is measured and the following equation applies:-

$$\text{Peak Force} = M + \sqrt{M^2 + \frac{4MHW}{L}}$$

Fig 1 TYPICAL LOAD/EXTENSION CURVES.



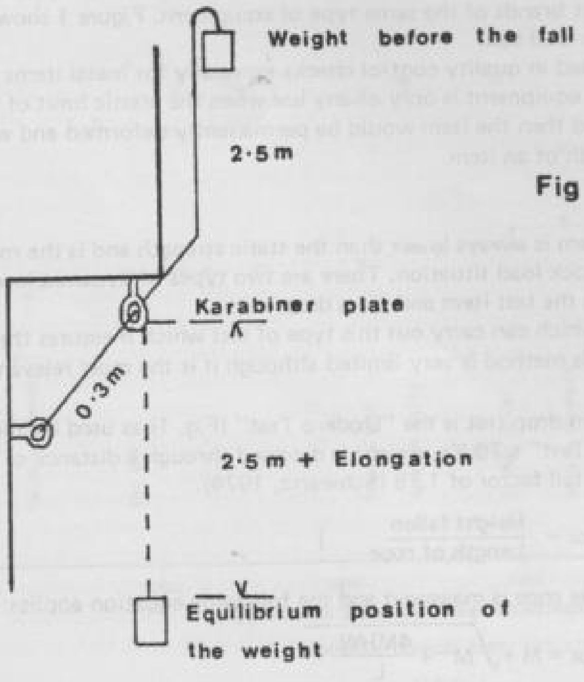


Fig 2 "DODERO TEST"

where M = Mass falling
H = Height fallen
W = Ultimate Tensile Strength or Breaking Load
L = Length of rope
(See Letheren, 1973; Eavis, 1974; & Edelrid)

The majority of falls in caving should be of a low fall factor (i.e. 1) and so the "Dodero Test" is too severe for testing caving ropes. A straight drop test using a smaller fall factor would be more relevant. Depending on the rope and mass involved in a fall factor 1 situation the peak force created would be in the region of 600-1000 Kgs. on the equipment being used. This means that there is not a very high safety margin in extreme situations.

The drop test method can be used to measure the dynamic strength of items but several tests would be needed since failure of the item cannot be guaranteed in every test.

Elongation

Most static load testing equipment provides a load/extension graph which enables calculation of extension under body weight and extension at failure. It can be measured by photographic means in dynamic tests. The extension in a dynamic test is smaller than in a static test since the time dependent factor of elongation does not have sufficient time to come into operation. Low extensions in ropes are required for prussiking whilst higher extensions are required for lifelines.

Energy Absorption

The energy absorption capacity of items such as ropes depends on the following properties; breaking load, extension charactecics, limiting velocity (i.e. rate of transmission of stress along a rope (British Ropes Pub. No. 555). The energy absorption capacity is approximately the area under the curve of the load/extension graph from a static load test. Mathematically it can be expressed as:-

Energy absorption capacity ≙ 1/3 x breaking load x breaking extension

The energy absorption capacity can be found experimentally by performing a series of fall factor 1 drop tests until failure occurs.

TABLE 1. Energy absorption capacity of different types of ropes

	Energy absorption capacity *m-kg per kg of rope*	*Energy absorption capacity per 10 metre length of rope.* *m-kg.*
Low stretch Prussik rope	1800	1720
Long staple polypropylene lifeline rope	4380	2190
Nylon climbing rope	> 6150	> 3690

Table 1 shows why low stretch ropes are not suitable for climbing and lifelining purposes. There is a fall off in energy absorption capacity along with strength through usage.

Impact Tests

Caving helmets are the only item on the British caving market which always appear to conform to a set standard (British Standards 5240, 2826, 2095). These specifications are designed for industrial helmets and their main requirements are that no undue damage should occur to the helmet when a variety of shaped objects are dropped on the helmet. A 5kg. object falling a distance of 1 metre onto the helmet should not have a deceleration in excess of 100g. This latter requirement is proposed so that the risk of neck or spine injuries is reduced whilst still providing reasonable protection to the skull.

Abrasion Tests

Abrasion tests are performed by rubbing the test items under tension against an abrasive material. This type of test can be performed on items such as ropes, nylon webbing and neoprene rubber. This method is used as a comparison between different items and is nominally measured by the number of reciprocations against the abrasive material needed to cause failure. The apparent abrasive resistance of an item depends on the properties of the abrasive material, dampness and temperature of the item, rate of reciprocation, angle of contact, etc. Results of this type of test should be treated cautiously as a lot of work is required to obtain optimum standard conditions.

Conclusion

The above test along with other types of tests (e.g. chemical resistance, ultra-violet degradation, flexibility, etc.) allow the performance of different brands of equipment to be ascertained, and equipment manufacturers are now beginning to take note of cavers, specialised requirements. By performing routine sample testing along with stringent quality controls manufacturers should be able to ensure that no rogue items reach the caving public.

It is extremely important for manufacturers and individuals testing equipment to state their test conditions and preferably use standard test methods so that meaningful comparisons can be made. It is to be hoped that in the future all major items of cavers' equipment will be subject to specified published standards. These standards could be set by bodies such as the British Standards Institution or the International Standards Organisations with the assistance of cavers, or maybe there is a need for a cavers' version of the U.I.A.A. (Union of International Alpine Associations).

Advantages of equipment tests should be better, safer and possibly cheaper equipment and techniques available to cavers. Dangerous faults in either equipment or techniques should be made known to as wide a section of cavers as possible. No amount of equipment testing will remove the human factor and caving safety is still highly dependent on the individual caver.

References

British Standards 3104, 1970, *Polyamide (nylon) mountaineering ropes.*

Schwartz, K. 1974. *Climber and Rambler, XIII*, 10.

Letheren, J. 1973. *"The Hardware Scene"*, Descent No. 25 Sept/Oct.

Eavis, A.J. 1974. The Rope in Single Rope Technique Caving, *B.C.R.A. Trans.* Vol. 1, No. 4.

Edelrid. *"A Guide to Mountaineering Ropes"*.

British Ropes Ltd. Publication No. 555, *"Ropes from Man-made Fibres"*.

EVIDENCE OF UPLIFT AND GLACIATIONS FROM SELMINUM TEM – PAPUA NEW GUINEA

D. Brook
40 Broadgate Crescent
Horsforth
Leeds, England

During the British Speleological Expedition to Papua New Guinea in 1975 a vast system of caves was explored and mapped beneath the Finim Tel Plateau 36 km W of Telefomin (Brook 1976). Four large rivers (Feram, Bitip, Kaakil and Finim) rise on the shales beneath the overthrust limestone scarp of the Bahrman Mountains and at altitudes of about 2,200 m they sink into the Finim Tel Limestone which forms a tilted plateau cut off abruptly at the escarpement of the Hindenburg Wall. Beneath the wall are resurgences and the sink of the Finim River was dye-tested in flood to the Kam and Kaakil outfalls.

Associated with the river sinks are 27 km of passages. The Feram and Finim caves are simple, shallow and end in sumps. The Bitip water also sumps in immature passages but abandoned tunnels form two distinct levels, the higher being 25 m above the present river sink at the shale/limestone boundary. The Kaakil enters the most extensive river caves and eventually descends a long vadose canyon to the inevitable sump. Beyon the last entrance, however, abandoned conduits continue at two distinct levels and the higher development is interrupted by a doline before entering the huge deserted cavern of Selminum Tem, 20.5 km in length.

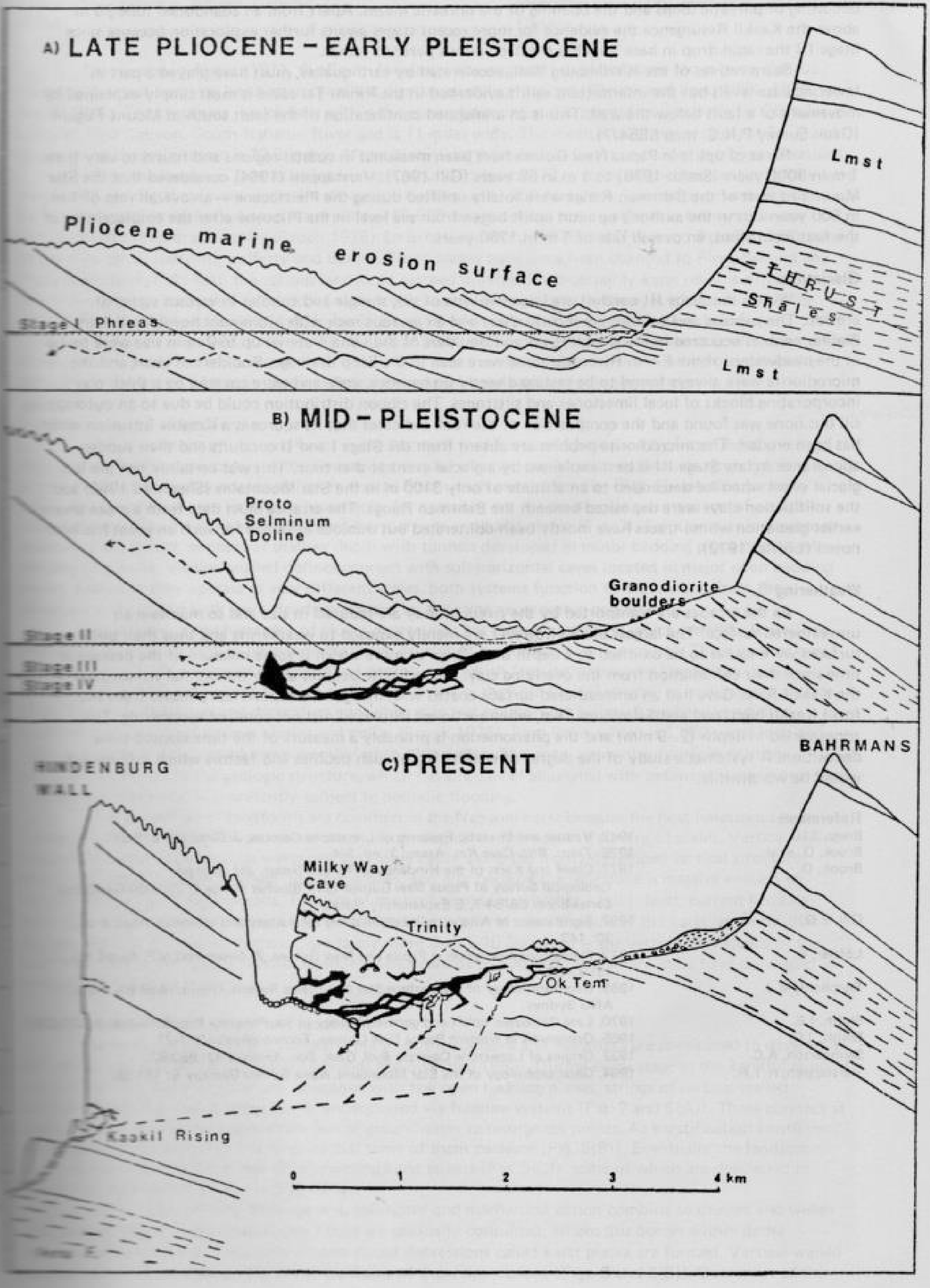
Within Selminum Tem the ancient Kaakil development unites with passages at a similar level from other entrances and forms the main trunk of the cave 30 to 50 m wide. A great canyon is cut in its floor but finally closes up in a mud choked tube. The trunk passage now undulates, the high points being bypassed by low level oxbows. Beneath the upper passages are mazes of tubes but no sign of the lost rivers, all percolation water dropping into deep sumps which are over 100 m above the Kaakil Resurgence. Selminum Tem is terminated by a giant doline 1500 m long and 130 m deep where another great cave 50 m above the trunk route is revealed (Upper Cave). On the plateau this same level was encountered once more in Trinity Cave, but even more significant are the stalagmite-encrusted tubes of the Milky Way Cave at the top of the Selminum Doline and 100 m above the altitude of the river sinks.

Speleogenesis and Uplift

The plan of Selminum Tem indicates that its deserted tunnels were once the main drains for earlier rivers sinking at the back of the plateau. Even the highest fragments of the Milky Way and Bitip caves mirror the course of later, more complete, passages. Apart from the present river caves, the fossil canyon of Selminum Tem and some minor trenches, all the conduits display the phreatic features of Bretz (1942) but the red clay of his fill stage is absent. All sediments are river-borne silts and gravels and it is concluded that Selminum Tem was formed under phreatic conditions by rivers powerful enough to transport pebbles and cobbles through large tunnels for 3 km or more. Because of the 20° dip to the north the caves run against the dip to reach the resurgences but in spite of 600 m of available limestone the chosen routes have not been deep phreatic as envisaged by Bretz. They approximate to Swinnerton's 1932 model and the trunk route takes advantage of dip variation to take a low gradient course along the strike. It extends obliquely through the

steeper beds and dip tubes in the trunk route and Trinity Cave indicate a phreatic amplitude of 50 m.

The elevation of the Finim Tel caves shows the wide extent of former water rest levels thus ruling out flood or perched phreas as a major influence (Brook 1977). They were probably directly related to old resurgence levels and are a record of the changes in base level since the region rose from the sea. Hence a reconstruction of stillstands within the general uplift is possible.



In Pliocene times the Bahrman massif was uplifted above sea level in response to compressive forces between the Australian and Pacific plates (Smith 1965). The Finim Tel Limestone became a marine erosion surface before uplift continued and a proto-Kaakil River formed the Stage I phreatic conduit of which the Milky Way Cave is a remnant. As uplift continued the whole block tilted northwards and Stage I was rapidly abandoned for a Stage II conduit (Upper Cave – Trinity) to a lower resurgence. A similar lowering of base level produced Stage III – the Selminum Tem trunk route and later Stage IV was marked by the short-circuiting of phreatic loops and the opening of the phreatic mazes. Apart from an abandoned tube 70 m above the Kaakil Resurgence the evidence for more recent stages awaits further exploration because since Stage IV the rapid drop in base level has created various perched sumps.

Scarp retreat of the Hindenburg Wall, accelerated by earthquakes, must have played a part in lowering base levels but the intermittent uplift evidenced in the Finim Tel caves is most simply explained by movement of a fault below the wall. This is an unmapped continuation of the fault south of Mount Fugulil (Geol. Survey P.N.G. map SB54/7).

Rates of uplift in Papua New Guinea have been measured in coastal regions and found to vary from 1 m in 5000 years (Smith 1970) to 1 m in 88 years (Gill 1967). Verstappen (1964) considered that the Star Mountains west of the Bahrman Range were totally uplifted during the Pleistocene – an overall rate of 1 m in 500 years but in the author's opinion uplift began from sea level in the Pliocene after the emplacement of the first instrusions, an overall rate of 1 m in 1200 years.

Glaciations

Within the Stage III conduit are large deposits of silt, shingle and cobbles in various states of erosion. The pebbles and cobbles are mostly chert and an igneous rock with prominent hornblende laths. Similar pebbles occurred in the Kaakil River and boulders of the same material up to 2 m in size were found in the headwaters of the Finim River but none were seen in the Bitip drainage. Boulders of chert and the microdiorite were always found to be resting directly on bedrock shale and were covered by a thick clay incorporating blocks of local limestones and siltstones. The ribbon distribution could be due to an outcropping sill but none was found and the composition of the rock indicates that its source is a sizeable intrusion which has been eroded. The microdiorite pebbles are absent from the Stage I and II conduits and their sudden appearance in late Stage III is best explained by a glacial event at that time. This was certainly not the last glacial event when ice descended to an altitude of only 3100 m in the Star Mountains (Shepherd 1965) and the solifluction clays were deposited beneath the Bahrman Range. The erratics must date from a more severe earlier glaciation whose traces have mostly been obliterated but dubious evidence for such an event has been noted (Löffler 1972).

Weathering

As the erratics are transported by the rivers so they are reduced in size and so maintain an unweathered surface. The largest blocks however are merely exposed to weathering and thus their upper surfaces were found to be oxidised to a depth of 1–2 cm or more which is some measure of the passage of time since their exhumation from the overlying clay. Microdiorite pebbles above the normal stream level in the Kaakil River Cave had an unweathered surface coated with manganese deposit but pebbles from the fossil Kaakil high level and Selminum Tem, when sectioned displayed distinct zones of weathering. The zones varied in depth (2–9 mm) and the phenomenon is probably a measure of the time elapsed since deposition. A systematic study of the degree of weathering of such pebbles and factors which influence it would be worthwhile.

References

Bretz, J.H. 1942. Vadose and Phreatic Features of Limestone Caverns, *J. Geol.* 59: 675-811.

Brook, D. et al 1976. *Trans. Brit. Cave Res. Assoc.* 3: no. 3/4.

Brook, D. 1977. Caves and Karst of the Hindenburg Ranges, *Geogr. Jnl.* in press.

Geological Survey of Papua New Guinea 1974 Blucher Range 1; 250,000 Geological Series Sheet SB/54-7, E Explanatory Notes.

Gill, E.D. 1967. Significance of Aitape radiocarbon dates for eustasy and tectonics. *Aust. J. Sci.* 30: 142.

Löffler, E. 1972. Pleistocene Glaciation in Papua and New Guinea. *Z. Geomorph N.F. Suppl.* Bd. 13: 32-58.

Shepherd, M.J. 1965. *Geomorphology of the Eastern Star Mountains Region.* Unpublished BA thesis, ANU Sydney.

Smith, I.E. 1970. Late Cainozoic uplift and geomorphology in Southeastern Papua. *Search,* 1: 222-225.

Smith, J.G. 1965. Orogenesis in Western Papua New Guinea. *Techno-physics* 2: 1-27.

Swinnerton, A.C. 1932. Origins of Limestone Caverns, *Bull. Geol. Soc. America* 43: 663-93.

Verstappen, H.T.H. 1964. Geomorphology of the Star Mountains. *Nova Guinea Geology* 5: 101-58.

THE SEQUENTIAL DEVELOPMENT OF KARST LANDFORMS IN THE NAHANNI REGION OF NORTHERN CANADA AND A REMARKABLE SIZE HIERARCHY

George A. Brook
Department of Geography
University of Georgia, Athens, Georgia
U.S.A.

Derek C. Ford
Department of Geography
McMaster University, Hamilton, Ontario
Canada

Discovered in August 1971, the South Nahanni karst region of the Mackenzie Mountains, Canada, contains the most complex karst assemblage yet discovered at high latitude (Brook and Ford 1974, 1976; Brook 1976). The karst area, which falls within the zone of discontinuous permafrost, extends for 28 miles north of First Canyon, South Nahanni River and is 11 miles wide. The mean annual temperature is 24°F and the mean total precipitation is 22.3 inches. Vegetation is northern boreal forest or tundra at higher elevations.

When the karst was first examined on the ground in June 1972, a series of spectacular landforms were discovered. Among these were vertical-walled pond dolines up to 100 feet deep, intersecting networks of karst streets with irregularly-shaped karst platea 400-600 feet deep and three poljes that later in the year were to flood rather dramatically (Brook 1975). (In Brook and Ford (1976) and Ford and Brook (1976) these poljes were called Nahanni, Lafferty and Barens. These names have since been changed to First, Second and Third respectively). At first, the various landforms seemed unrelated and certainly karst relief is often impressive because it appears "chaotic". In science, however, chaos is only in the eyes of the beholder for really things are highly ordered. If landforms in a karst are found to fall into developmental sequences (Jennings and Sweeting 1963; Paton 1963; Williams 1966), and if many seemingly different landforms can be shown to be similar, there is order and not chaos. This paper outlines the order that has been found in the Nahanni karst and the relevance of this order to theories of karst landform development.

The size hierarchy of landforms

Many of the solutional landforms in the Nahanni that have been produced by water moving along fractures and bedding structures in the limestones, display size hierarchies with individuals ranging from several inches to several hundreds of feet in depth. Forms such as solution pits (Fig. 1), solution tunnels, grikes and joint hollows on limestone pavements, for example, are the small-scale counterparts of vertical-walled dolines (Fig. 2), sub-horizontal caves, karst streets and karst platea (Fig. 3). Solution pits in limestone pavements do, in fact, connect at shallow depth with tunnels developed in minor bedding plane or current bedding structures. Vertical-walled dolines connect with sub-horizontal caves located in major open bedding planes. Although they operate at very different scales, both systems function to drain water from the limestone surface, and both were clearly produced by the same geomorphic processes.

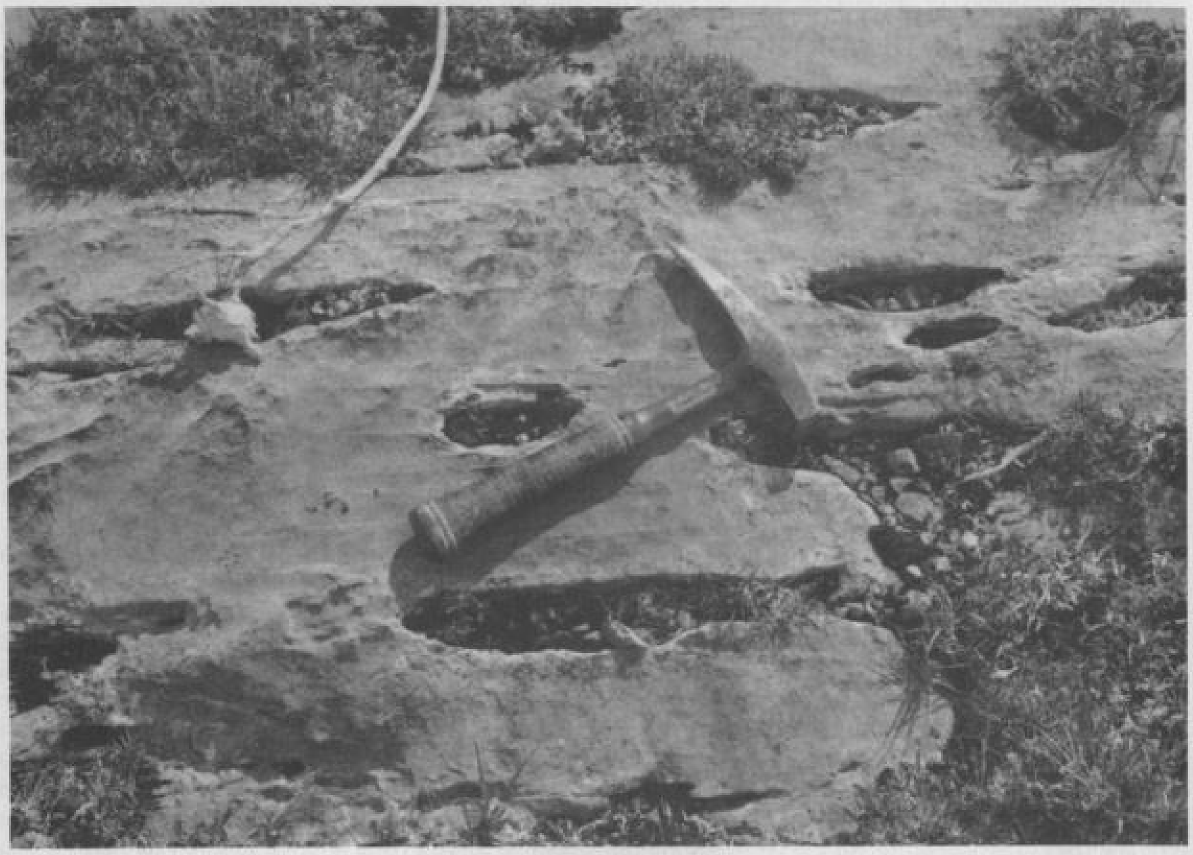
In addition, a size hierarchy of closed depressions has been identified in which individuals are little more than structural basins in limestone that have developed subsurface drainage routes. These may or may not be alluviated. On pavement surfaces these depressions, which frequently become kamenitzas, are irregularities in exposed current bedding surfaces. Elsewhere, they are basinal structures in the upper surface of the Nahanni limestones and depending upon their size and geomorphic history have been variously modified into structural dolines, uvalas and poljes (Brook 1976). First Polje, which is 1,600 yards long and 400 yards wide, is the largest known member of this hierarchy. The opening up of subsurface drainage routes preserved the initial geologic structure, which has since been alluviated with sediment transported into it by allogenic streams. It is presently subject to periodic flooding.

Size hierarchies of landforms are common in the Nahanni karst because the host limestones have similar structural, lithological and therefore, hydrogeological properties, at a variety of scales. Vertical-walled landforms predominate because water can pass more easily along the highly-developed vertical structures than it can along the tightly-closed horizontal ones, and also because the limestone is massive enough to support steep to overhanging walls. The size of the host structure, whether a joint, fault, current bedding parting, bedding plane or structural basin, imposes an upper limit upon the size of the karst landform that can develop in it. Grikes, for instance, are rarely more than 5-10 feet deep – the vertical persistence of the host joint. Karst streets, on the other hand, may be upwards of 500 feet deep where these have developed in extensive faults or fault zones.

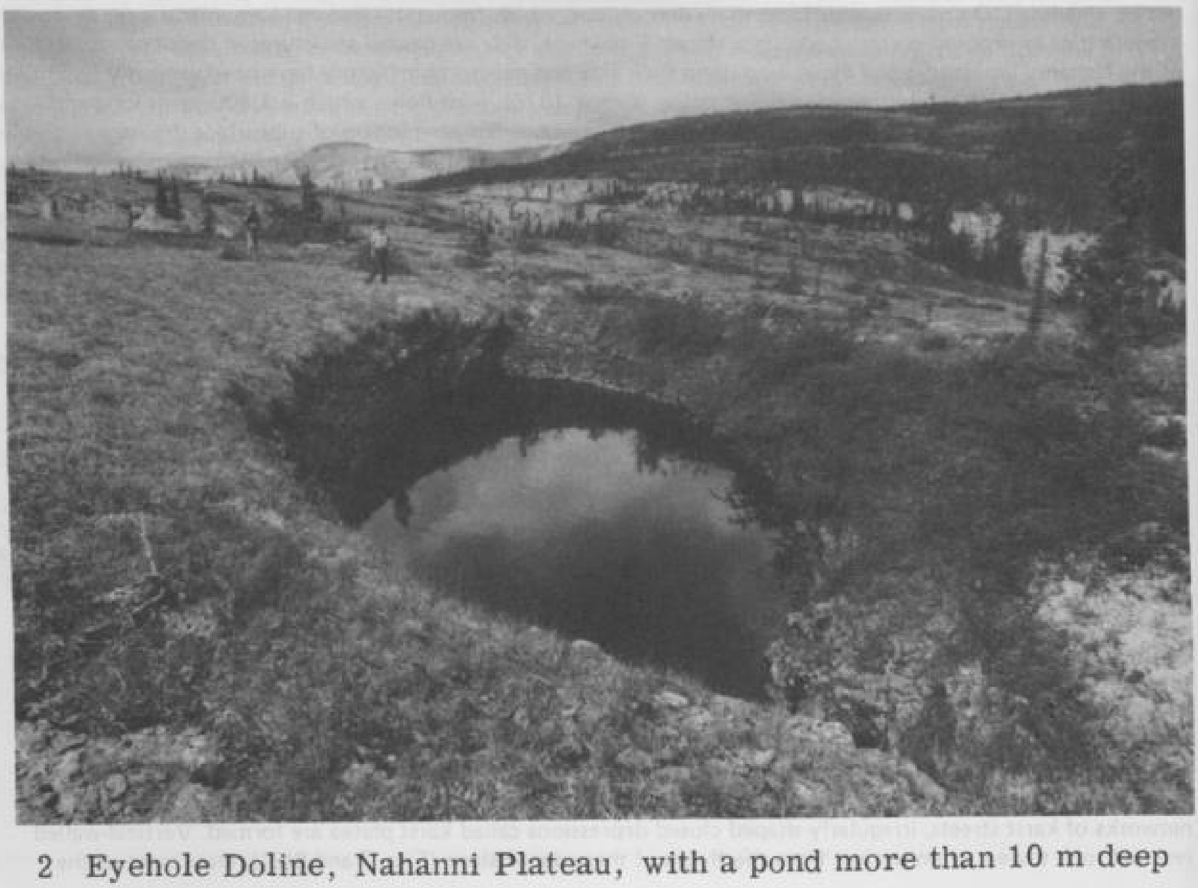
The sequential development of karst landforms

Networks of karst streets and karst platea in the Nahanni and elsewhere are considered to develop in the manner depicted in Figs. 5 and 6 (Jennings and Sweeting 1963). During every stage in the karstification of a heavily-faulted, massively-bedded, limestone with few open bedding planes, strings of vertical-walled solution dolines develop as water drains underground via fracture systems (Fig. 2 and 5(A)). These connect at depth with sub-horizontal caves which funnel groundwater to resurgence points. As karstification continues, the dolines enlarge along the fractures so that some of them coalesce (Fig. 5(B)). Eventually the landscape becomes a natural rock labyrinth of intersecting karst streets (Fig. 5(C)), some of which are developed in limestones still overlain by shales (Fig. 6(A)).

At this stage of karst development, solutional and mechanical action combine to deepen and widen individual corridors so that intervening ridges are gradually consumed. Where this occurs within dense networks of karst streets, irregularly-shaped closed depressions called karst platea are formed. Vertical-walled residual rock towers often project from the floors of these depressions (Figs. 3 and 6(B)). Over most of the



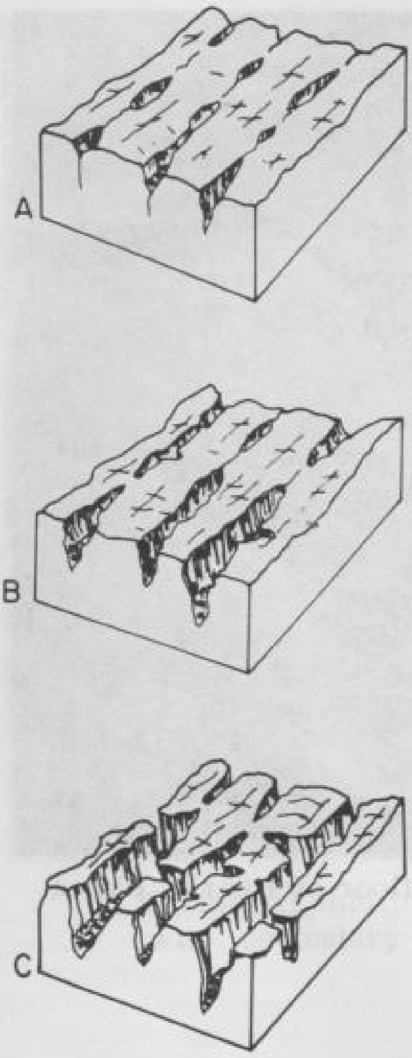
1. Elliptical solution pits developed in microfractures filled with secondary calcite, Nahanni Plateau, Canada



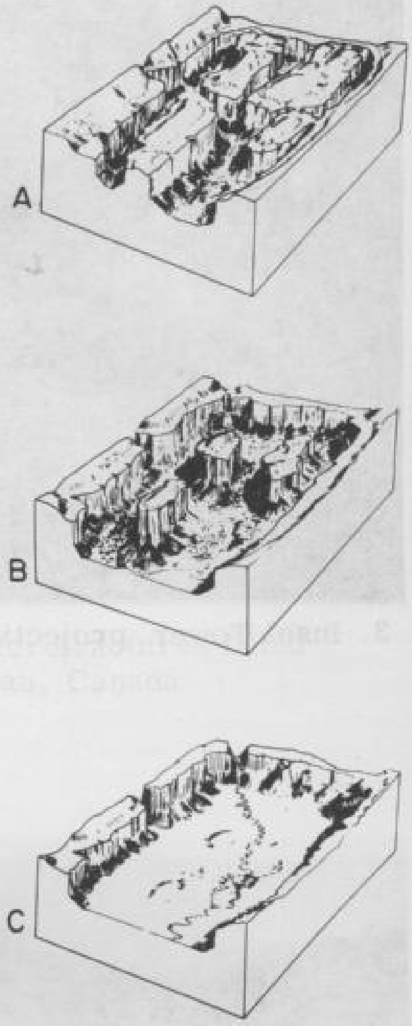
2 Eyehole Doline, Nahanni Plateau, with a pond more than 10 m deep

3. Insel Tower projecting over 50m from the floor of a karst platea.

4. Second Polje, an alluviated karst platea temporarily flooded 10 m deep.



5. Three stages in the development of a natural rock labyrinth in a highly fractured limestone surface with elliptical dolines coalescing (A & B) to become vertical-walled karst streets.



6. The development of karst platea, towers and poljes from networks of karst streets in limestones still overlain by shales.

Nahanni region karstification has not passed beyond the karst platea stage. However, in one limestone area, where there is substantial allogenic flow from shales, the landscape has evolved one step further. Two large karst platea have been alluviated by sediment transported into them from nearby areas of shale and glacial drift. During the period of alluviation residual karst towers were consumed further, floors became increasingly susceptible to flooding as ponors were choked with insoluble debris and the depressions became small poljes (Fig. 6(C)). Second and Third Poljes in the Nahanni, 700 and 1,300 yards long respectively, were formed in precisely this fashion (Fig. 4).

All stages in the evolution of a highly-fractured limestone surface to one displaying karst platea and poljes have been observed in the Nahanni Karst. Furthermore, the landscape model just outlined, although originally formulated to explain the larger karst features in the area, applies equally to small- and large-scale forms. For example, the same evolutionary sequence can be observed on limestone pavements. Here grikes are formed by the coalescence of strings of solution pits, and joint hollows by the destruction of clints within dense networks of grikes.

Discussion

First impressions of the Nahanni karst as a chaotic assemblage of large and small solutional landforms were extremely misleading. Subsequent, more detailed examination has revealed a high degree of order.

Morphologically-similar landforms, varying from several inches to several hundred feet in depth, have been explained in terms of the similar hydrogeological properties of the Nahanni limestone at a variety of scales. It is to be expected, therefore, that in a region where the structural and lithological properties of a karst rock vary considerably with scale, small-scale solutional landforms will differ substantially from the larger-scale forms. The identification of a developmental sequence that operates at the level of limestone pavements and at the level of karst platea and poljes, is a further indication that large- and small-scale karst forms should not be considered separately, for many are produced and evolve in exactly the same manner.

Sweeting (1972) has pointed out that in 1918, Cvijić "supposed a cyclic evolution of karst landforms, from the doline through the uvala to the polje." This, she argues, "both perpetuated an incorrect idea of the origin of the polje and also added to the confusion of the terminology" (p. 192). Today, majority opinion seems to be that most of these landforms are of structural rather than of solutional origin. The idea that they can form by the gradual coalescence of smaller depressions is no longer popular. The Nahanni karst furnishes conclusive evidence that some poljes are alluviated structural depressions in bedrock and that others are alluviated karstic depressions formed by the gradual coalescence of dolines. This is exactly what Cvijić argued as long ago as 1918.

References

Brook, G.A. 1975. *Surface and groundwater hydrology of a highly karsted sub-arctic carbonate terrain in northern Canada.* Memoirs Intern. Assoc. Hydrogeol., 12th Intern. Congr., Karst Hydrogeol., Huntsville, Alabama, Sept. 1975 (in press).

Brook, G.A. 1976. *Geomorphology of the North Karst, South Nahanni River region, Northwest Territories, Canada.* Unpubl. Ph.D. thesis, McMaster Univ., 627 pp.

Brook, G.A. & Ford, D.C. 1974. Nahanni karst: Unique northern landscape. *Canadian Geogr. Jour.*, 88(6), pp. 36-43.

Brook, G.A. & Ford, D.C. 1976. The Nahanni North Karst: A questionmark on the validity of the morphoclimatic concept of karst development. *Proc. 6th Intern. Congr. Speleol.*, Olomouc, Czechoslovakia, 1973, II, pp. 43-57.

Cvijić, J. 1918. Hydrographie souterraine et évolution morphologique du karst. *Rec. Trav. Inst. Géograph. Alpine*, 6(4), pp. 376-420.

Ford, D.C. & Brook, G.A. 1976. The Nahanni North Karst, Northwest Territories, Canada. *Proc. 6th Intern. Congr. Speleol.*, Olomouc, Czechoslovakia, 1973, II, pp. 157-168.

Jennings, J.N. & Sweeting, M.M. 1963. The Limestone Ranges of the Fitzroy Basin, Western Australia: a tropical semi-arid karst. *Bonner Geogr. Abhand.*, 32, 60 pp.

Paton, J.R. 1963. The origin of the limestone hills of Malaya. *Jour. Trop. Geogr.*, 18, pp. 134-147.

Sweeting, M.M. 1972. *Karst Landforms.* Macmillan, London, 362 pp.

Williams, P.W. 1966. Limestone pavements with special reference to West Ireland. *Trans. Inst. Brit. Geogr.*, 40, pp. 155-172.

PRELIMINARY THOUGHTS ON A STRUCTURAL-LITHOLOGICAL MODEL OF KARST LANDFORM DEVELOPMENT

George A. Brook
Department of Geography
University of Georgia, Athens, Georgia
U.S.A.

Introduction

Since the publication of H. Lehmann's detailed study of karst in the Sewu Mountains of Java (1936) and with the emergence of the general concepts of climatic morphology during the 1930's and 1940's, the climatic variable has been used more than any other to explain regional variations in the character of karst landform assemblages. In general, tropical assemblages are considered to contain a wider variety of landform types and to be more accentuated than assemblages in colder and drier alpine, arctic, and sub-arctic regions where there is often only limited karst development.

The concept of climatic morphology has so permeated the karst literature since the mid 1930's that the discovery of a complex, highly accentuated karst landscape in the sub-arctic Nahanni region of northern Canada in August 1971 (Brook and Ford, 1976; Ford and Brook, 1976; Brook, 1976) was completely unexpected. This karst which is considered to have formed by "normal" solutional processes during the last 200,000 years and is still actively developing today, more closely resembles present-day humid tropical karst terrains than it does sub-arctic or even warm temperate regions. The very existence of the Nahanni karst questions the idea that karst landform morphology and degree of development are climate-dependent.

The influence of structure and lithology upon karst landform morphology

A considerable body of evidence supports the view of Panoš and Štelcl (1968) that although climate influences the intensity and speed of processes that act upon a karst landscape, the limestones themselves give rise to basic fundamental forms. In Jamaica, Kegelkarst is restricted to areas of hard, highly fissile White Limestone and is not typical of the more chalky and less fissured Montpelier beds (Sweeting, 1958). Wilford and Wall (1965) content that the absence of conical karst in Sarawak is due to the fact that the bulk of the limestones have a low primary porosity. In Puerto Rico, Monroe (1964) has found that each lithologic type of limestone has given rise to a specific group of solution phenomena and few karst features

seem to be common to all lithologies. Verstappen (1964) feels that "neither age sequence, nor climatological differences alone can . . . . satisfactorily explain all phenomena observed and a third factor . . . . the lithology of the limestones, ... including their water absorbing capacity and their porosity, deserves more attention than it usually gets. Only the combination of all three factors can lead towards a better understanding of the origin and development of the diversified karst phenomena" (p. 40-41).

If karst landform morphology is intimately related to the properties of the host limestone, then it follows that similar limestones should spawn the same landforms even where there are differences in prevailing climate. One landform that is certainly not climate-dependent is the solutionally widened fracture, the karst street, which has been identified in sub-arctic (Brook, 1976; Brook and Ford, 1976), alpine (Croce, 1964), warm temperature (Cvijić, 1893; Waltham, 1970), tropical semiarid (Jennings and Sweeting, 1963) and humid tropical regions (Jennings and Bik, 1962; Wilford and Wall, 1965; Verstappen 1964; Monroe 1964). If karst landforms such as the karst street and the doline can develop under a wide range of climates, this is strong evidence to suggest that karst landform morphology in general may be related to the structural and lithological properties of the host limestone which impart to it a susceptibility to solution.

Modelling the solutional susceptibility of a limestone mass

Tija (1969) has argued that slopes in tropical karst regions are governed by the spacing of vertical joints and faults and horizontal bedding planes for these control rates of solution in these directions. He notes that mogotes develop where the horizontal planes of weakness are unimportant; while karst cones, which have gentler slopes, form in limestones which possess definite horizontal planes of weakness.

Tija (1969) has emphasized the role of structure, but lithology must also play a part in controlling slopes in carbonate regions. Consider the slopes that might be typical of the end members of a series of possible structural/lithological limestone types. At one extreme is a crystalline, non-porous, massively-bedded and heavily faulted limestone. It has a low primary permeability and bedding partings are so tightly closed that they permit virtually no groundwater movement along them. The karst landforms that would be expected in such a limestone would have a marked vertical component. Walls would tend to be steep to vertical because of fault control and because the rock is massive enough to retain vertical cliffs. The limestones of the Nahanni Karst of Canada have just these properties and here, intersecting networks of vertical-walled karst streets are ubiquitous.

At the other extreme, is a porous, thinly-bedded limestone crossed by several major fractures and dissected by a multitude of minor open joint systems. It has a relatively high primary permeability and water can move easily along the bedding planes. It is unlikely that vertical-walled solutional landforms would develop in such a rock, first because it is not mechanically strong enough to support vertical walls for long, and secondly because the more even distribution of solution as waters percolate into the numerous small cracks, would favour the formation of shallow, round karst forms rather than steep, sharp ones. There can be little doubt that the structural and lithological properties of a limestone influence the morphologies of surface landforms. Depending upon the limestone, the slopes of karst depressions and hills might be expected to vary between almost vertical to almost horizontal.

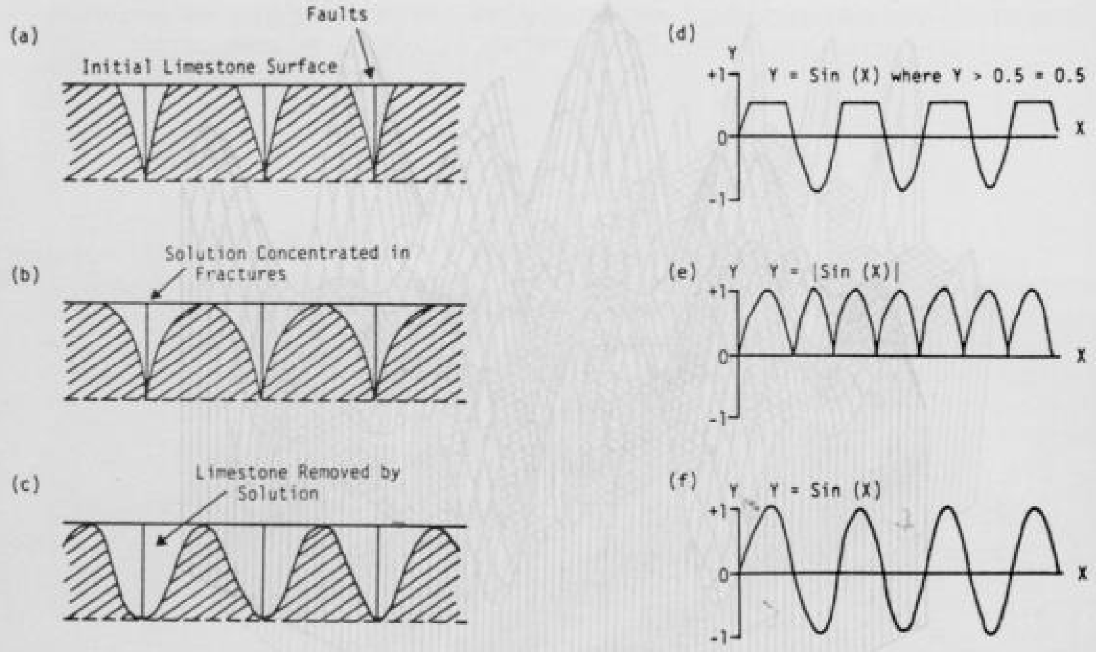
Many workers have attested to the fact that in a karst area solution proceeds most rapidly along lines of secondary permeability. Faults and master joints, therefore, represent the weakest portions of a carbonate mass and will locate the most intense solutional activity. At increasing distance from each fracture the limestone is less and less susceptible to solution from the surface down. When a limestone mass is subjected to erosion, fractures will become depressions as they are etched out by solution and the resistant blocks between will form hills. Slopes will vary in angle in relation to the physical properties of the host limestone. Three of many possibilities are illustrated in Fig. 1 along with simple wave forms which simulate these hypothetical landscape profiles.

The solutional susceptibility of any recently-uplifted, horizontally-bedded limestone mass that is crossed by one or more sets of fractures can be modelled if the properties of the limestone are known. For instance, the susceptibility of a limestone crossed by one set of equally-spaced fractures etched out in the manner depicted in Fig. 1 (c) is a sine wave surface with the wavelength equal to the spacing of the fractures. The overall weakness of a limestone mass, crossed by two sets of fractures which intersect at 90°, is the sum of the weaknesses due to each fracture set. That is, it is the summation of two sine waves (Fig. 2). Similarly, a picture of the solutional susceptibility of a limestone crossed by three sets of fractures, two intersecting at 90° and the third at 45°, can be obtained by superimposing three sine wave surfaces, one for each fracture set (Fig. 4). Both theoretical models (Fig. 2 and 4) bear a striking resemblance to present-day cone and mogote karsts (Fig. 3). The similarity is particularly marked in the case of Fig. 4 where hill summits and depression floors are distributed in a spatially irregular fashion and occur at a variety of elevations.

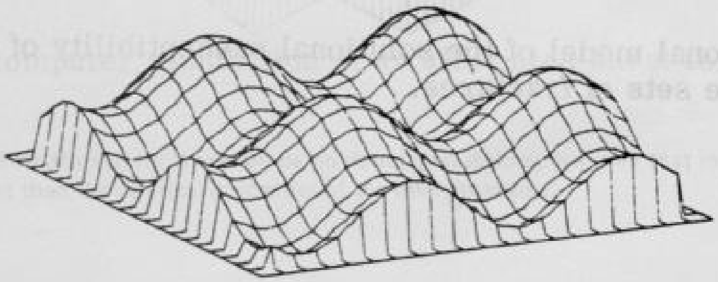
The theoretical solutional susceptibility of a more massive limestone crossed by three sets of fractures, that are etched out in the manner depicted in Fig. 1(b), (Fig. 5) is remarkably similar to spitzkarren Furthermore, if it is assumed that the depression floors in this model are alluviated, the result is a three-dimensional picture of tower karst (Silar, 1965).

Discussion

Although this paper is little more than an interim report of work in progress, early results have been encouraging. The simple structural-lithological model of karst landform development presented here appears to be a viable alternative to the morphoclimatic theory. That is not to say that climate does not play a part in

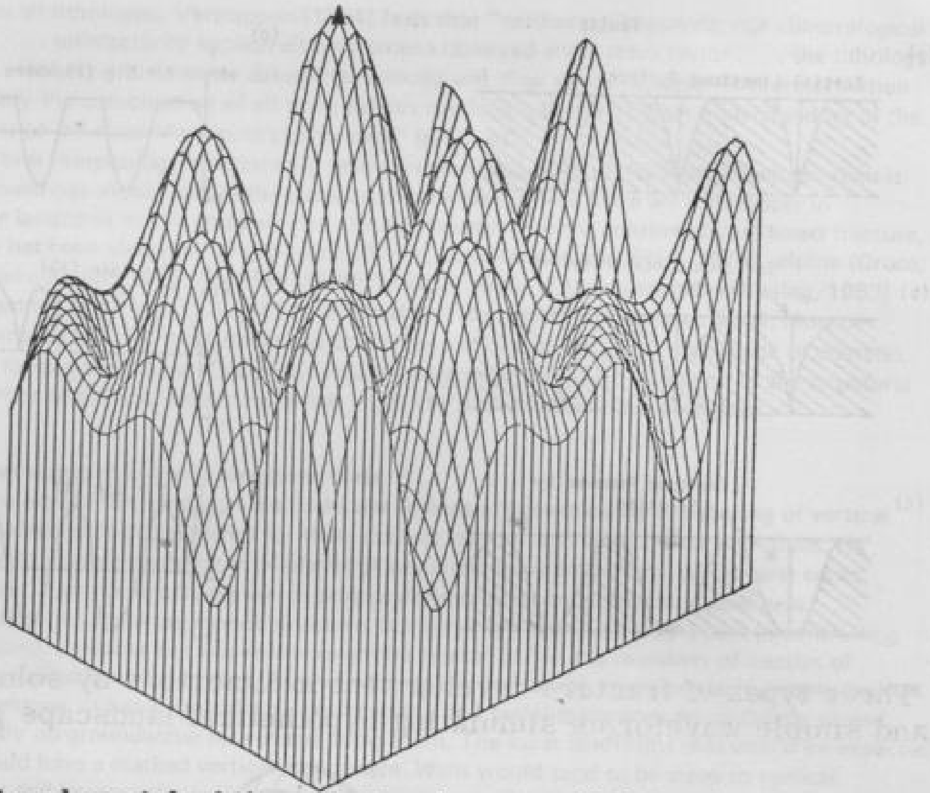


1. Three types of fracture development in limestone by solution (a, b, c). and simple waveforms simulating hypothetical landscape profiles (d, e, f)

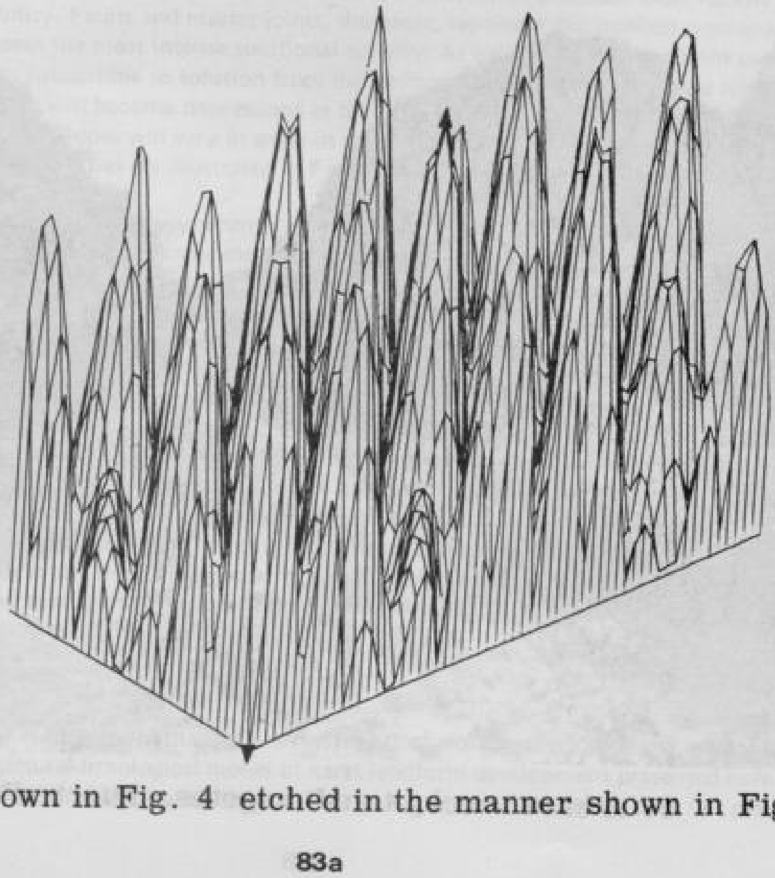


2. A model of solutional susceptibility of a limestone mass crossed by two sets of equally spaced fractures intersecting at right angles.

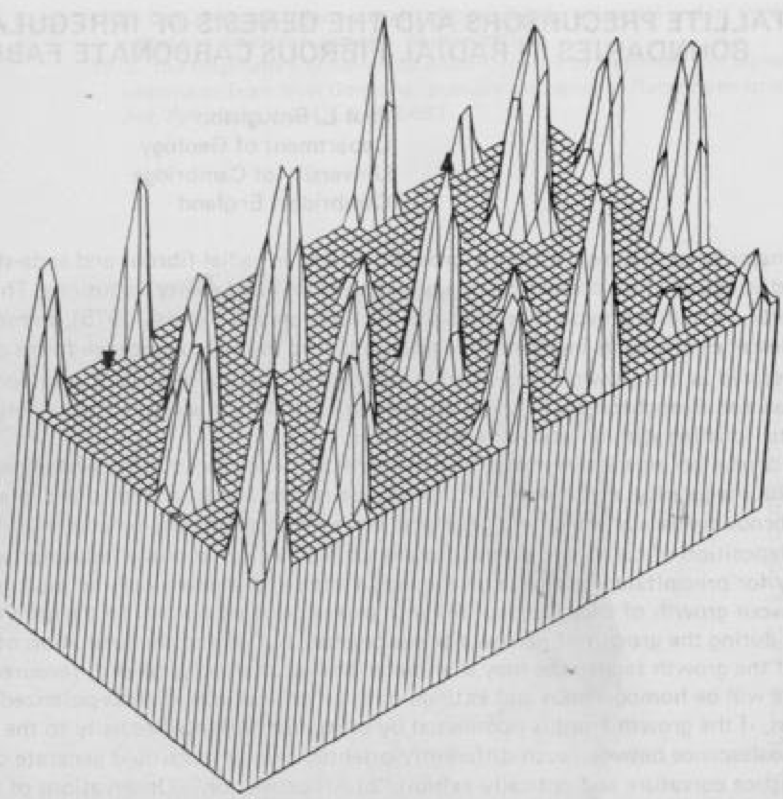
3. A karst cockpit and mogotes, Puerto Rico.



4. **A three dimensional model of the solutional susceptibility of a limestone mass crossed by three sets of fractures.**



5. **The model shown in Fig. 4 etched in the manner shown in Fig. 1 (b).**



6. A computer simulation of an alluviated karst terrain.

the moulding of karst landforms, for there can be no doubt that it does, but only that in many instances it may be less significant than the physical properties of the host limestone.

References

Brook, G.A. 1976. *Geomorphology of the North Karst, South Nahanni River region, Northwest Territories, Canada.* Unpubl. Ph.D. thesis, McMaster Univ., 627 pp.

Brook, G.A. & Ford, D.C. 1976. The Nahanni North Karst: A question-mark on the validity of the morphoclimatic concept of karst development. *Proc. 6th Intern. Congr. Speleol.*, Olomouc, Czechoslovakia, 1973, II, pp. 43-57.

Croce, D. 1964. Cryonival phenomena and karst phenomena in the plateau of the Sella group. *Erdkunde*, 18 (2), pp. 146-148.

Cvijić, J. 1893. Das Karstphänomen. *Geogr. Abhandl.*, 5 (3), pp. 218-329.

Ford, D.C. & Brook, G.A. 1976. The Nahanni North Karst; Northwest Territories, Canada. *Proc. 6th Intern. Congr. Speleol*, Olomouc, Czechoslovakia, 1973, II, pp. 157-168.

Jennings, J.N. & Bik, M.J. 1962. Karst morphology in Australian New Guinea. *Nature*, 194, pp. 1036-1038.

Jennings, J.N. & Sweeting, M.M. 1963. The Limestone Ranges of the Fitzroy Basin, Western Australia: a tropical semi-arid karst. *Bonner Geogr. Abhand.*, 32, 60 pp.

Lehmann, H. 1936. *Morphologische Studien auf Java.* Engelhorn, 114 pp.

Monroe, W.H. 1964. *The zanjon, a solution feature of karst topography in Puerto Rico.* U.S. Geol. Survey Prof. Paper, 501-B, pp. B126-B129.

Panoš, V. & Štelcl, O. 1968. Physiographic and geologic control in development of Cuban mogotes. *Zeit Geomorph.*, 12, pp. 117-165.

Silar, J. 1965. Development of tower karst of China and North Vietnam. *Bull. Nat. Speleol. Soc.*, 27 (2), pp. 35-46.

Sweeting, M.M. 1958. The karst lands of Jamaica. *Geogr. Jour.*, 124, pp. 184-199.

Sweeting, M.M. 1972. *Karst Landforms.* Macmillan, London, 362 pp.

Tjia, H.D. 1969. Slope development in tropical karst. *Zeit Geomorph*, 13, pp. 260-266.

Verstappen, H.Th. 1964. Karst morphology of the Star Mountains (central New Guinea) and its relation to lithology and climate. *Zeit. Geomorph.* 8, pp. 40-49.

Waltham, A.C. 1970. The karstlands of the Ioannina region, N.W. Greece. *J. Brit. Speleol. Assoc.*, 6 (45), pp. 1-11.

Wilford, G.E. & Wall, J.R.D. 1965. Karst topography in Sarawak. *Jour. Trop. Geogr.*, 21, pp. 44-70.

CRYSTALLITE PRECURSORS AND THE GENESIS OF IRREGULAR CRYSTAL BOUNDARIES IN RADIAL-FIBROUS CARBONATE FABRICS

Paul L. Broughton
Department of Geology
University of Cambridge
Cambridge, England

The majority of discernible former growth surfaces in radial-fibrous and soda-straw infilled carbonate stalactites are distinguished by concentrations of linear, fluid-filled cavity inclusions. These inclusion patterns record ephemeral crystallite growth morphologies (Broughton and Kendal, 1975). Immediate and complete crystallite coalescence generates inclusion-free growth layers. Partial coalescence forms crystals with linear inclusions, preserved as the growth lines, wherein the inter-crystallite spaces are enveloped fluid-filled cavities (Kendall and Broughton, 1977). The absence of crystallite coalescence, probably by ionic poisoning, generates crystal splitting with an acicular crystal habit.

Most crystal boundaries in stalactitic carbonate are generated during crystallite growth and coalescence. The irregularity, commonly with re-entrant angles, is not related to the interaction of the mega-scopic fibrous crystals at the growing surface, but to their crystallite precursors.

The deposition of carbonate on the growth surface is a compromise between two parameters. There is the tendency for precipitated calcite to be aligned in lattice continuity with its substrate. Also, there is a tendency to favour growth of those crystallites with c-axes oriented normal to the growth surface. These are not in conflict during the growth of narrow fibrous crystals, but during the formation of relatively wide crystals, one of the growth tendencies may dominate. The resultant crystal with favoured lattice continuity of the substrate will be homogeneous and extinguish as an optical unit in cross-polarized light. (Fig. 1A and 2C). In contrast, if the growth front is dominated by crystallites oriented radially to the curved growth surface, then coalescence between such differently oriented crystallites would generate crystals with considerable lattice curvature and optically exhibit "brush extinction". Observations of stalactitic carbonate with extreme lattice curvature are rare (see Folk and Assereto, 1976). Compromise between the two growth tendencies, or shifting equilibrium in the dominance of one type on the growth surface, is responsible for the formation of crystals with diminished lattice curvature. The compromise crystals on normal wide and curved growth surfaces are characterized by moderate (Fig. 2A) to extensive (Fig. 1B) subdivision into subcrystals having patchy optical extinction.

Crystal boundary irregularity may occur when adjacent crystals possess very similar crystallographic orientation. The crystallographic orientation of crystallites nearest the developing crystal boundaries will be influenced by their substrate as well as the orientation of crystallites of the neighbouring crystal. The calcite within such crystallite will belong to neither crystal exclusively at the time of precipitation, and it will be arbitrary as to whether the crystallites join the lattice of one crystal or the other. Very faint, generally discontinuous, irregular boundaries within a larger, more defined crystal, will result (Fig. 3). Some stalactites appear to be composed of very small elongate subcrystals (Fig. 2A). This suggests that sometimes the crystallites fail to coalesce completely and maintain their own slightly divergent orientation. Changes in the allegiance of crystallites adjacent to existing dominant mega-crystals would result in the formation of irregular boundaries.

A fibrous crystal will expand at the expense of its neighbour if its crystallite precursors, adjacent to the future crystal boundary, grow faster than those of its neighbours. The imbalance of crystallite growth may result from several causes, including larger crystallite size and differential poisoning of neighbouring crystallites by impurity absorption. Nutrient destined for neighbouring smaller or poisoned crystallites would be captured by the larger or unpoisoned crystallites, promoting differential growth. Changes in environmental conditions will result in a new sequence of stable configurations between adjacent crystallites, and subsequent changes in the orientation of crystal boundaries. Some jagged crystal boundaries may be relatively late phenomenon. Fracture planes in stalactites may divide a formerly strained and curved crystal lattice. A similar phenomenon has been described by Tucker and Kendall (1973) in limestone fabric.

Most crystals in some stalactite fabrics persist from their origin to the growing surface of the stalactite. In other mosaics, new crystals appear at almost every growth surface, and are either rapidly cut out by more favourably-oriented neighbours during competitive growth or are terminated at subsequent growth surfaces. Various intermediate forms may be observed between the two extremes.

Acknowledgements

This paper has been developed from a co-operative study with A. Kendall, Saskatchewan Geological Survey, on the genesis of stalactitic carbonate. It is an elaboration of an aspect of Kendall and Broughton (1977) and Broughton and Kendall (1975).

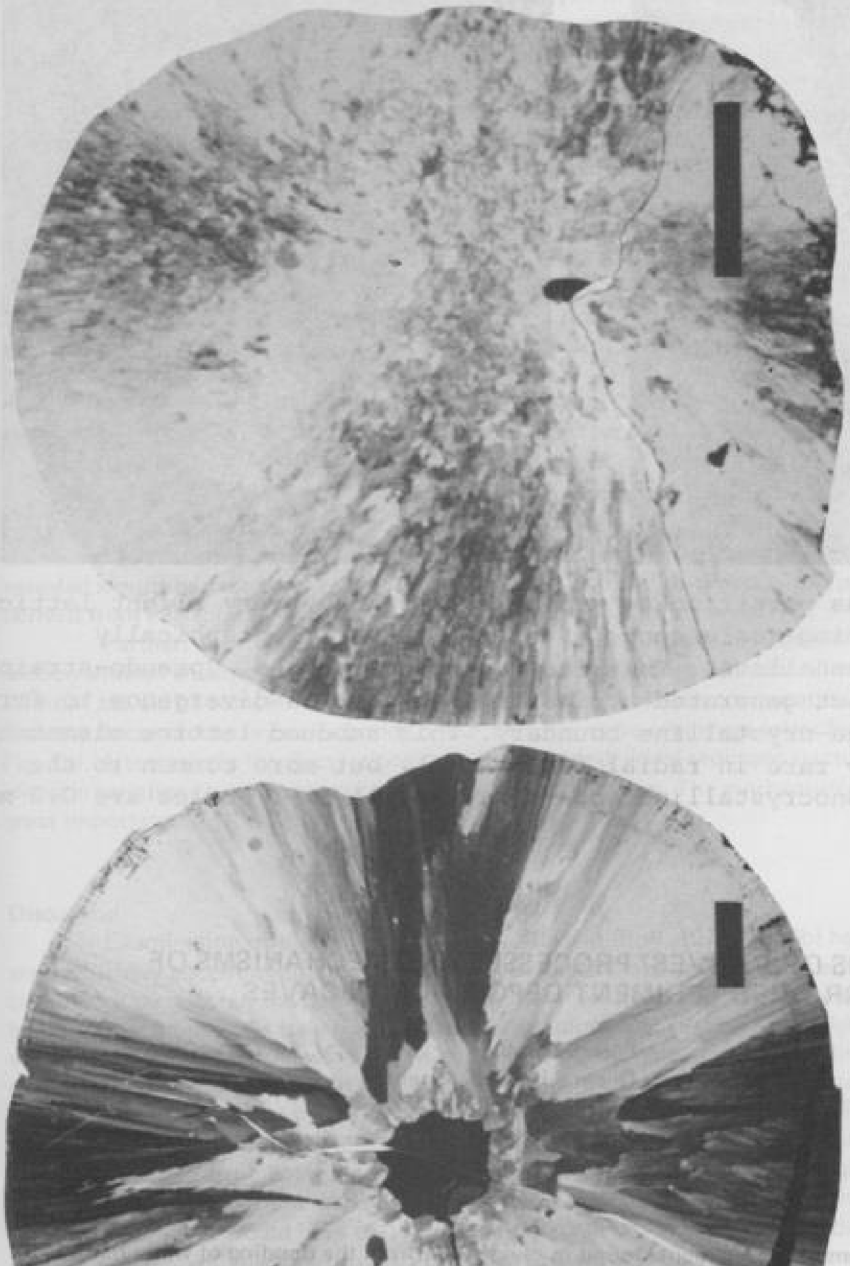
References

Broughton, P. & Kendall, A. 1975. The genesis of some stalactitic crystal fabrics and their relevance to the origin of limestone cements (Abs). *Geol. Soc. America, Abstracts with Programs,* vol. 7, p. 1010-1011.

Folk, R. & Assereto, R. 1976. Comparative fabrics of length-slow and length-fast calcite and calcitized aragonite in a Holocene speleothem, Carlsbad Caverns, New Mexico. *Jour. Sed. Petrology,* vol. 46, p. 486-496.

Kendall, A. & Broughton, P. 1977. Origin of radial-fibrous crystal fabrics within stalactites and its significance with respect to limestone cements. In preparation.

Tucker, M. & Kendall, A. 1973. The diagenesis and low-grade metamorphism of Devonian styliolinid-rich pelagic carbonates from West Germany: possible analogues of Recent pteropod oozes, *Jour. Sed. Petrology*, vol. 43, p. 672-687.



B

A

Figure 1.

(A) Cross-section of stalactite composed of wide crystals with relative lattice continuity, distinguishing as an optical unit in cross-polarized light.

(B) The curved growth surface and divergence of the c-apes promotes subcrystallization.

Scales are 2 mm.

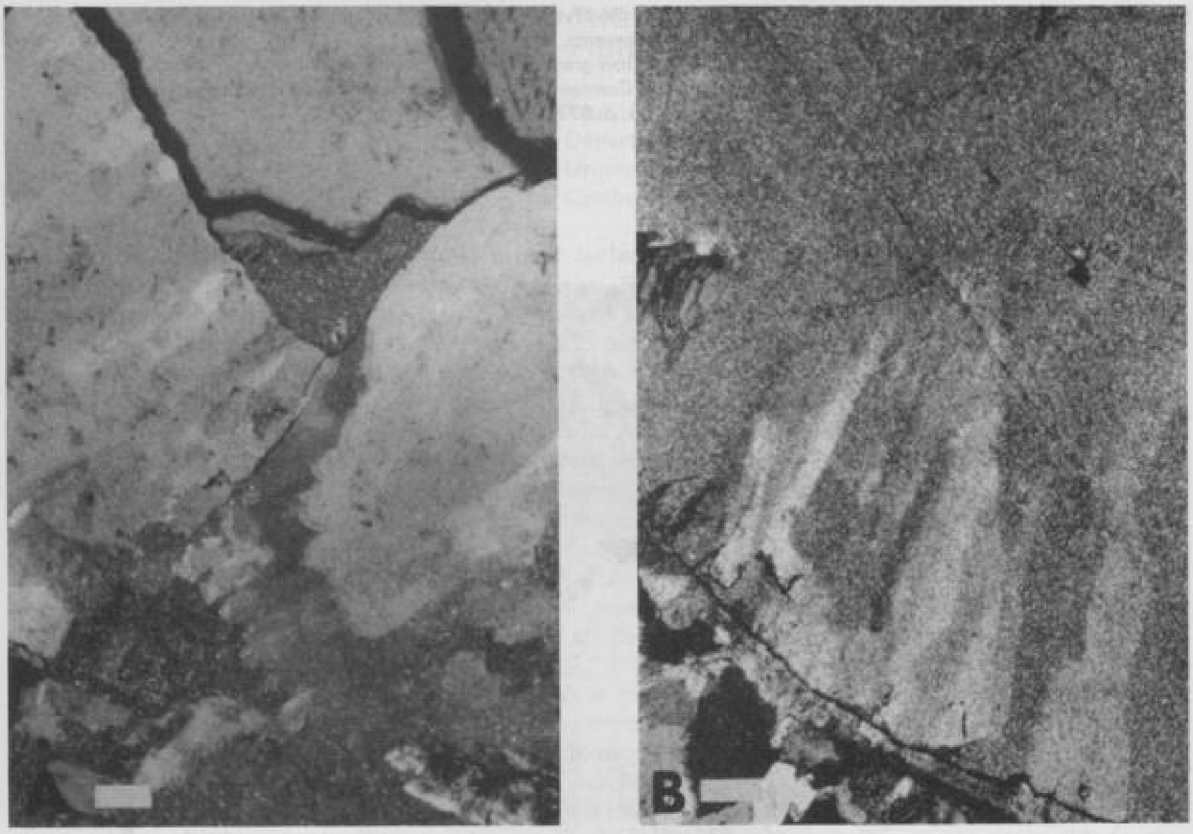


Figure 3. Discontinuous partitioning within a crystal by very slight lattice mismatch during coalescence of similar crystallographically oriented crystallites. This results in a serrated, "pseudo-strained" optical effect generated by insufficient c-axes divergence to form a normal mega-crystalline boundary. This subdued lattice mismatch is generally rare in radial fibrous (A), but more common to the formation monocrystalline soda-straw infill (B). Scales are 0.3 mm.

Scales are 0.3 mm.

LAMINATIONS OR VARVES? PROCESSES AND MECHANISMS OF FINE-GRAINED SEDIMENT DEPOSITION IN CAVES

Peter A. Bull
Geography Department
University College
Singleton Park
Swansea, Wales

Introduction

The idea that finely laminated sediments found in caves result from the ponding of water has long been advocated (Llopis Lladó, 1950; Bretz, 1956) and it has generally been considered that this ponding was due to climatically induced flooding of the cave. Sweeting (1950) ascribes ponding to high water tables of glacial and post-glacial times, whilst Llopis and Gomez (1949); Llopis and Thomas (1953) and Ullastre (1968) attribute it to a semi humid phase of the cave characterised by slow flow and eventual stalagmitization. As has been noted by Masriera (1970), the association of glacially derived sediments being deposited in quiet underground lakes has led to the idea that the resultant laminations were varves (Siffre, 1960; Fray, 1961). Further it has generally been considered that the laminations were laid down in a horizontal attitude in the conventional sedimentological manner. However, both principles, that of varve sedimentation *sensu stricto* and that of horizontal sedimentation, seem inapplicable in the case of the cave sediments studied.

Reams (1968) first advocated the principle of parallel accreting sediment layers on underlying surfaces. Further work (Bull, 1976a, 1976b) has shown that the laminated sediments can remain stable on slopes in excess of 70° and even, in some instances, on slopes in excess of 90°. These subsequent studies, together with other field observations, suggest that the process of parallel accretion is the predominant means of deposition of the laminated sediments in caves throughout South Wales and south-west England.

Masriera (1970) noted that the laminations in caves were not varves in the strict sense as they were

not necessarily reflective of annual climatic fluctuations, but he considered that the term varve should be used as it had a more explicit descriptive meaning than any alternative terminology. It is this final conclusion of Masriera (1970) that this study attempts to question, as it is considered herein, that the term lamination or even rhythmite is free of the underlying connotations of seasonal sedimentation normally associated with the term "varve".

A problem which further complicates this research field concerns the precise morphology of a varve. Conventionally, a varve comprises two layers of sediment, termed a couplet, consisting of a coarse spring-thaw sedimentation with an associated fine-grained winter-freeze deposit. Recent work (Peach and Perrie, 1975) has shown, however, that detailed analysis of a varve couplet can reveal a more complex pattern of sedimentation than has previously been assumed. Fluctuations upon the basic coarse/fine sequence (Fig. 1b) can be identified to be due to weekly or even daily variations in climate, and hence, of the glacier ablation rate. Fig. 1b, A represents the coarse material rapidly laid down after the initial thawing of an ice mass. B represents the gradation of coarse to fine material as summer deposition continues. C portrays the daily or weekly fluctuations in temperature and hence the variations in the rate of ablation. Finally, D portrays the cessation of deposition with the onset of winter freeze conditions.

By utilizing the same analysis techniques of Peach and Perrie (1975) (Quantimet 720 visual computer analysis) it was the aim of this research to investigate the micromorphological character of a distinctly laminated fine-grained sediment identified in Agen Allwedd, Powys (Bull, 1975). It is hoped that these results will shed light on the problem of classifying sediments either as varves (reflecting seasonal climatic variation) or as laminations (which can be indicative of energy fluctuations at any time-scale). This distinction will also have implications for further studies concerning sediment sources and the process of cave deposition.

Sediment studies in Agen Allwedd

Agen Allwedd (SO18761586) is a 21km. cave system in Powys, South Wales containing sediments that are capped by a finely laminated deposit throughout much of the cave. Inspection of this 'cap-mud' has revealed a sequence of dark and light coloured layers comprising 196 major beds within a 10cm. thickness (Plate 1). The layering appears to reflect differential sedimentation rates and grain shape (Bull, 1976b) rather than a variation in mineralogical content. Analysis of these cap-muds along a 1km. passage (Main Passage) has revealed almost perfect correlation of bed layers and also bed thickness with distance down-passage (+0.92, derived from Pearson's coefficient of correlation, see also Plates 1 and 2).

Further, examination of the individual grain sizes of the major sediment units within a cap-mud section showed an almost perfect correlation with corresponding sediment units some 5km. away (Fig. 1a). Without the aid of complex smoothing techniques and correlation computations, it appears from Figure 1a that the fluctuations may correspond to four complex varve sequences (after Peach and Perrie, 1975, herein Fig. 1b). Alternatively the fluctuations may represent individual sediment fluctuations with four major climatic variations superimposed on the general micro-pattern. The mechanism of sedimentation is, then, of great importance.

Discussion

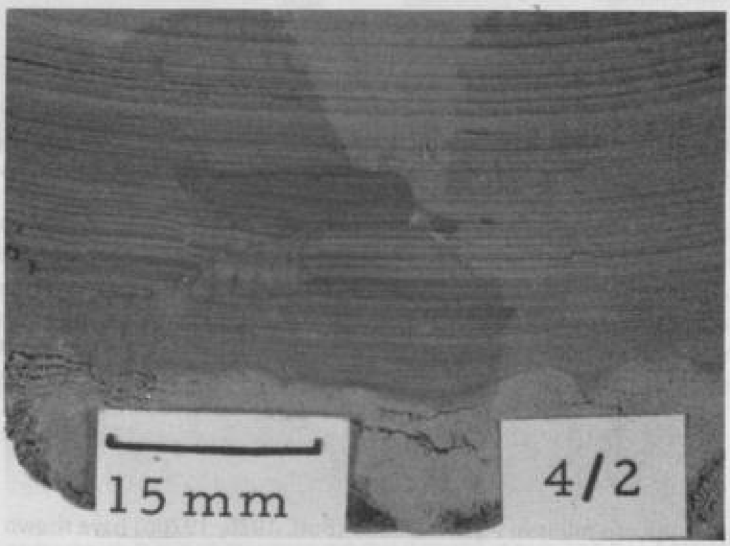
Examination of the cap-muds in Agen Allwedd (Bull, 1975, 1976b) have shown that the deposits are exclusively allochthonous, being laid down by parallel accretion in lacustrine conditions which were continuous throughout the period of sedimentation. Since no discrete sediment feeder could be found between the sample sites (taken at regular intervals along Main Passage) the high value of r computed above would infer one of the following modes of deposition. If single or discrete sediment pulse input were advocated, a mechanism of even distribution through the lake would be necessary to account for the persistence of laminations without a proximal/distal sedimentary assemblage. This must be considered unlikely as flow within the water body would scour and redeposit existing sediments. This is not seen to occur. If a diffuse sedimentation were advocated, a process of filtration through the overlying beds would account for the even sedimentation, in places to the roof (Bull, 1976b). External control of this rhythmic pulsing of sediment would have to be able to regulate micro-sediment inputs through 200 metres of Millstone Grit and Limestone! Intermediate control, via an overlying cave system, could, however, regulate micro-sedimentation within the underlying cave passage. No such cave system is known, nor can complementary sedimentological evidence be postulated for the existence of such a cave.

A more posing problem, however, concerns the mechanism controlling sedimentation rates. Initiation of the sedimentary pulse can be considered to be of external origin. The periglacial and loess-like nature of much of the sediment (Bull, 1976b) may further suggest contemporary surface conditions of a periglacial nature. Freeze-thaw cycles may then reasonably be advocated as a mechanism of sediment control and release, allied to a diffuse-filtration sedimentary process. Thunderstorm activity, together with the resultant flood pulses, would alternatively provide rhythmically pulsed sediment, although such a run-off would follow discrete channels into the cave. This would then result in flow structures throughout the cap-mud. These do not exist.

Whether the fluctuations in sediment pulses may be termed varves must for the present remain a moot point. The grain-size variations through the cap-mud (Fig. 1a) may represent four varves, or a multiple series of pulsed inputs. The overlying large-cycle trend must then be explained for the latter case.

The cap-mud may yet be varved, but not as is normally considered. Research continues to clarify these problems, but for the present the term 'varve' must be used with extreme caution.

1. Laminated sediments from Main Passage, Agen Allwedd. (x2).



2. Laminated sediments in Agen Allwedd, one kilometre from those in Fig. 1.

Acknowledgements

The author thanks D.M. Lawler for reviewing this script and also Chelsea Speleological Society for their help with field work. Particular thanks to Mr. R.K. Musgrove, Mr. I.G. Penney and Professor E.K. Tratman for their continual constructive discussions. Fieldwork was undertaken with permission of the Nature Conservancy and financial support was given by the Natural Environment Research Council. Their help is gratefully acknowledged.

References

Bretz, J.H. 1956. *Caves of Missouri,* 34, 2nd Series. Missouri Geol. Survey and Water Resources. 490p.

Bull, P.A. 1975. *An electron microscope study of clastic cave sediments.* Unpub. thesis. Univ. Wales, Swansea.

Bull, P.A. 1976a. Dendritic surge marks in caves. *Trans. Brit. Cave Research Assn.* 3 (1) 1-5.

Bull, P.A. 1976b. *Cave sediment studies in Agen Allwedd.* Unpub. thesis. Univ. Wales, Swansea.

Fray, A.F. 1961. A varved clay in Agen Allwedd. *Hereford Caving Club Jl.* 9, 7-9.

Llopis Lladó, N. 1950. Sobre algunos fenómenos de sedimentación fluviolacustre en las cavernas. *Speleon,* 1 (1) 23-37.

Llopis Lladó, N. & Gomez de Llarena, J. 1949. Estudio geológico de la caverna Troskaeta-ko-kobea. *Munibe,* 1 (4) 153-179.

Llopis Lladó, N. & Thomas Casajuana, J.M. 1953. Estudio hidrogeologico de la vertiente meridional de Montserrat. *Speleon.* 4 (3-4) 121-191.

Masriera, A. 1970. Contribución al estudio de los sedimentos varvados hipogeos. *Speleon.* 17, 27-39.

Peach, P.A. & Perrie, L.A. 1975. Grain-size distribution within glacial varves. *Geology* 3 (1) 43-46.

Reams, M.W. 1968. *Cave sediments and the geomorphic history of the Ozarks.* Unpub. thesis. Washington University.

Siffre, M. 1960. Sur un cas de fossilisation de varves souterraines craquelées. *Annales de Spéléologiè* 15. fasc 2, 415-420.

Sweeting, M.M. 1950. Erosion cycles and limestone caverns in the Ingleborough District. *Geog. J.*, 115, 63-78.

Ullastre Martorell, J. 1968. Cova Negra de Tragó de Noguera. Observaciones geomorfólogicas y espeleometeorológicas. *Geo y Bio Karst* (16, 17) 26-31.

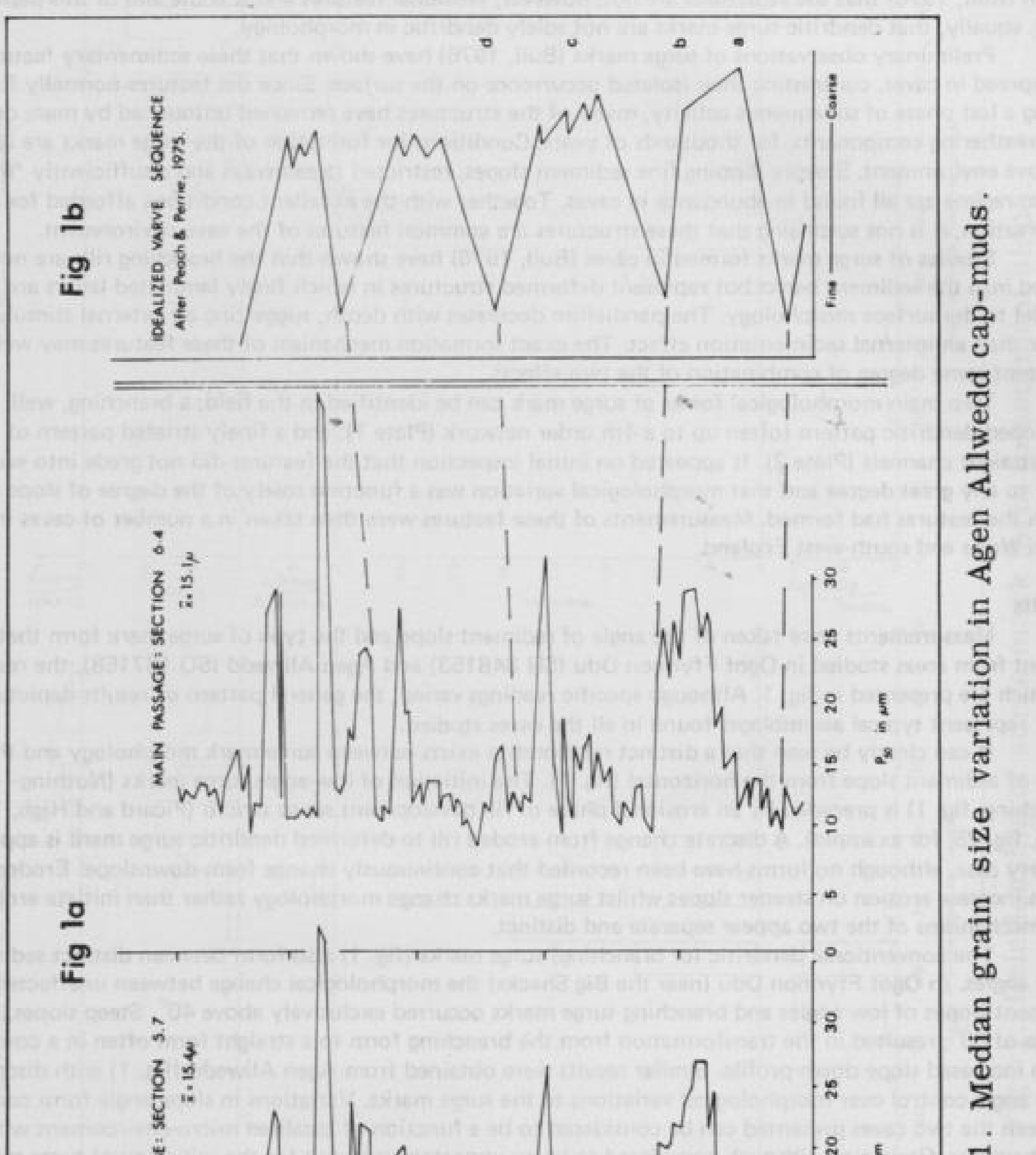


Fig. 1. Median grain size variation in Agen Allwedd cap-muds.

SURGE MARKS IN CAVES

Peter A. Bull
Geography Department
University College
Singleton Park
Swansea, Wales

Introduction

Originally considered to represent hieroglyphs or trace fossils (Lesquereux 1884; Newberry, 1888), surge marks have now been recognised as sedimentary structures formed as a result of the ponding back and

the slopping of water up over a steep sediment bank in response to restricted surging water currents (Boyd and Ore, 1963; High and Picard, 1968). Surge marks were first termed *dendritic surge marks* by High and Picard (1968) and considered to be erosional structures from then after (Picard and High, 1973). It has been shown (Bull, 1976) that the structures are not, however, erosional features and it is the aim of this paper to show, equally, that dendritic surge marks are not solely dendritic in morphology.

Preliminary observations of surge marks (Bull, 1976) have shown that these sedimentary features are widespread in caves, contrasting their isolated occurrence on the surface. Since the features normally form during a last phase of subaqueous activity, many of the structures have remained untouched by man, or by any weathering components, for thousands of years. Conditions for formation of the surge marks are ideal in the cave environment. Steeply dipping fine sediment slopes, restricted streamways and a sufficiently 'flashy' stream regime are all found in abundance in caves. Together with the excellent conditions afforded for preservation, it is not surprising that these structures are common features of the cave environment.

Studies of surge marks formed in caves (Bull, 1976) have shown that the branching rills are not eroded into the sediment banks but represent deformed structures in which finely laminated layers are parallel to the surface morphology. The parallelism decreases with depth, suggesting an external stimulus rather than an internal sedimentation effect. The exact formation mechanism of these features may well represent some degree of combination of the two effects.

Two main morphological forms of surge mark can be identified in the field; a branching, well developed dendritic pattern (often up to a 4th order network (Plate 1); and a finely striated pattern of near-straight channels (Plate 2). It appeared on initial inspection that the features did not grade into each other to any great degree and that morphological variation was a function solely of the degree of slope on which the features had formed. Measurements of these features were then taken in a number of caves in South Wales and south-west England.

Results

Measurements were taken of the angle of sediment slope and the type of surge mark form that was present from areas studied in Ogof Ffynnon Ddu (SN 848153) and Agen Allwedd (SO 187158), the results of which are presented in fig. 1. Although specific readings varied, the general pattern of results depicted in fig. 1 represent typical assemblages found in all the caves studied.

It can clearly be seen that a distinct relationship exists between surge mark morphology and the angle of sediment slope from the horizontal (fig. 1). The initiation of low-angle surge marks (Nothing–Branching, fig. 1) is preceded by an erosional phase of rill development *sensu stricto* (Picard and High, 1973, p. 35, fig. 25, for example). A discrete change from eroded rill to deformed dendritic surge mark is apparent in every case, although no forms have been recorded that continuously change form downslope. Eroded forms increase erosion on steeper slopes whilst surge marks change morphology rather than initiate erosion. The mechanisms of the two appear separate and distinct.

The conventional dendritic (or branching) surge marks (fig. 1) also form between distinct sediment slope angles. In Ogof Ffynnon Ddu (near the Big Shacks) the morphological change between unaffected sediment slopes of low angles and branching surge marks occurred exclusively above 40°. Steep slopes, in excess of 60°, resulted in the transformation from the branching form to a straight form often in a continuum on an increased slope down-profile. Similar results were obtained from Agen Allwedd (fig. 1) with discrete slope angle control over morphological variations to the surge marks. Variations in slope angle-form control between the two caves presented can be considered to be a function of localised micro-environment within the chambers. Grain size, although considered to be an important restraint for the initiation of surge mark development (High and Picard, 1968), appeared to have no apparent effect upon the resultant surge mark type.

Discussion

Since the early work of Boyd and Ore (1963) it has generally been accepted, by the few workers who have reported surge mark structures, that the features have originated along margins of water bodies and that continual transgression and regressions of water over the sediment surfaces *erodes* the structures into dendritic surge marks. It has been shown before (Bull, 1976) that the features are not eroded, and that now, morphology is a direct function of sediment slope. Whether a viable concept can be invoked concerning stable sediment slopes (necessarily over 40° and up to 90°), which are affected by repeated flooding of water, inducing only deformation of the sediment surface, remains to be proved. Only isolated instances of sediment slumping have been identified (draw-down effects excluded, see Waltham, 1974, p. 160), and these can be shown to be of limited extent considering the magnitude of sediment surface involved.

Elsewhere (Bull, 1976) it has been shown that horizontally laminated sediments are depressed rather than deformed in areas of surge mark, down-profile initiation. This would tend to suggest external distorting pressures rather than penecontemporaneous deposition. Further, it has also been shown (Bull, 1976) that micro-horst faulting has occurred in the troughs of the surge mark forms also suggesting applied stress conditions of 'external' origin. It would appear, therefore, that a major mechanism in the formation of a surge mark is the deformation of the sediment body by external currents, although this may well be complemented to a degree by a supply of silt grains settling out of suspension on the dividers between the grooves after each transgressive flood. At present work is underway to ascertain the micro-sediment characteristics within a structure in order to discover the degree of deposition or deformation process that is initiating the surge mark.

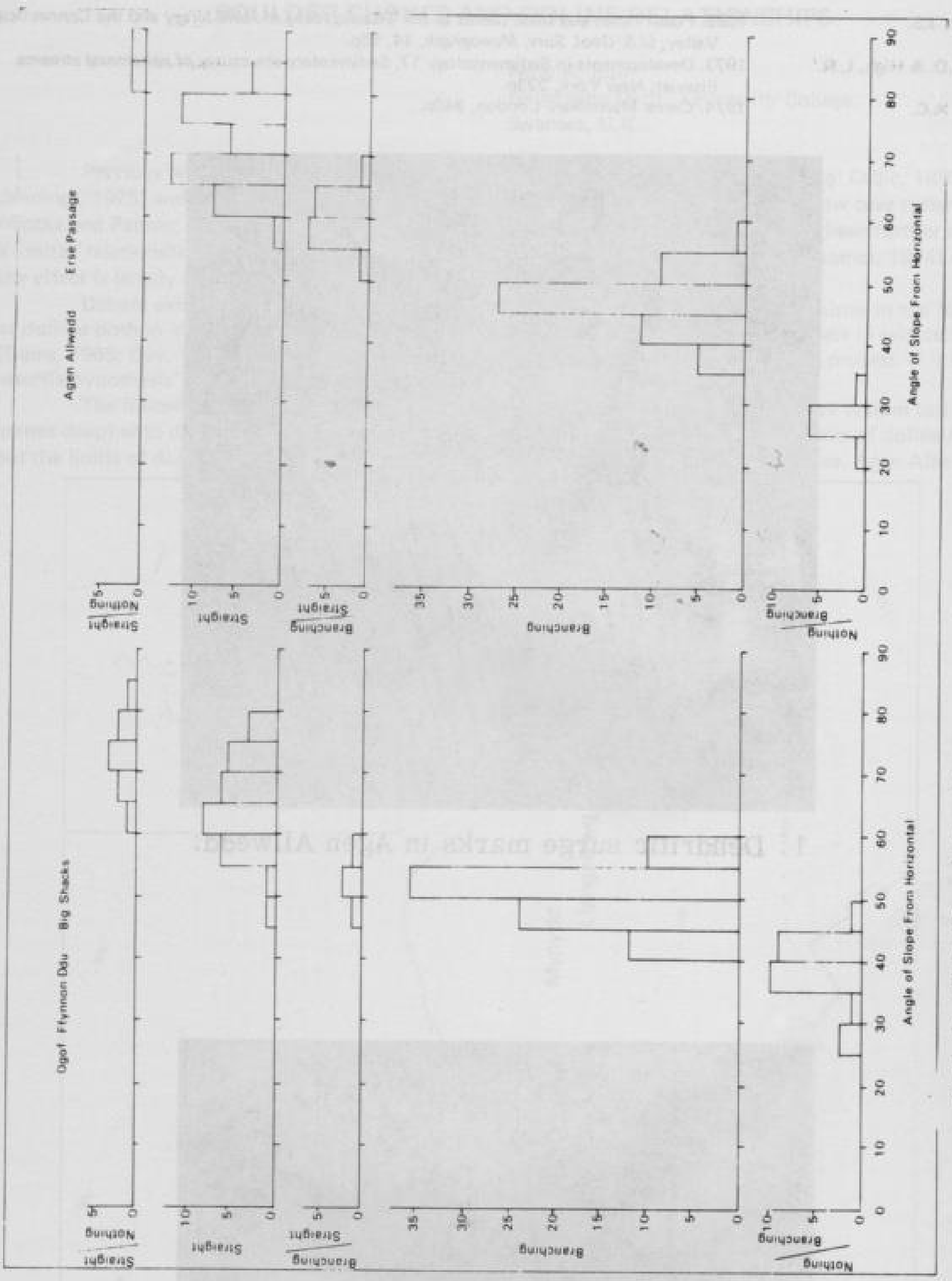


Fig. 1. Relationship of surge mark form to sediment slope.

Surge marks have been observed by the author immediately after formation in Little Neath River Cave, (SN912142) and during formation in a tidal sump Otter Hole, (ST527967), but it is considered that they represent largely fossil structures, preserved, in Britain at least, as a final testament to the high water conditions in caves during the waning period of the last glacial period.

Acknowledgements

The author would like to thank N.E.R.C. for sponsorship during the period of research for this paper and Chelsea Speleological Society for their help. Thanks are also due to the Nature Conservancy for permission to work in Ogof Ffynnon Ddu and Agen Allwedd. Final thanks to Mr. C. Davies, Dr. S.J. Culver and Mr. C. Edmunds for their help in the field and their intuitive discussion.

References

Boyd, D.W. & Ore, H.T. 1963. A Wyoming specimen of *Dendrophycus. Contrib. Geol. 2*, 63-68.

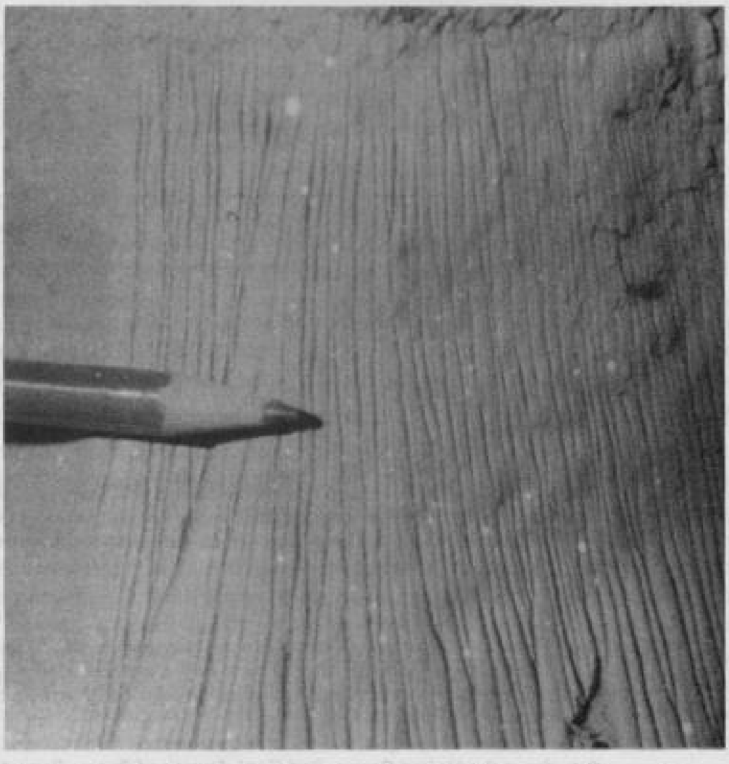
Bull, P.A. 1976. Dendritic surge marks in caves. *Trans. Brit. Cave Research Assn.*, 3 (1), 1-5.

High, L.R. & Picard, M.D. 1968. Dendritic surge marks *(Dendrophycus)* along modern stream banks. *Contrib. Geol.* 7, 1-6.

Lesquereux, L. 1884. Description of the coal flora of the Carboniferous formation in Pennsylvania and thoughout the United States, *2nd Geol. Survey of Penn., Report of Progress,* "P", 3, 695-977.

Newberry, J.S. 1888. Fossil fishes and fossil plants of the Triassic rocks of New Jersey and the Connecticut Valley, *U.S. Geol. Surv. Monograph*, 14, 95p.
Picard, M.D. & High, L.R. 1973. Developments in Sedimentology 17, *Sedimentary structures of ephemeral streams.* Elsevier, New York, 223p.
Waltham, A.C. 1974. *Caves.* Macmillan, London, 240p.

1. Dendritic surge marks in Agen Allwedd.



2. Straight surge marks in Agen Allwedd.

BOULDER CHOKES AND DOLINE RELATIONSHIPS

Peter A. Bull
Geography Dept., University College,
Swansea, U.K.

Previous research has related the form to the process of doline development (e.g. Cvijic, 1893; Jennings, 1975) and shown that there is a genetic connection between dolines and shallow cave systems, (e.g. Miotke and Palmer, 1973; Palmer and Palmer, 1975). Studies in Welsh interstratal karst have further suggested a limited relationship between different doline forms and shallow cave development (Thomas, 1974) where the effect is largely of collapse of the overlying insoluble cap-rock, the Millstone Grit.

Debate exists as to the relative importance of solution and, or, collapse mechanisms in the formation of dolines both in interstratal karst and in areas of 'naked' karst. Both mechanisms operate in selected instances (Gams, 1965; Day, 1976) and a solution-collapse 'shuffle' may well be the predominant process. It is this 'shuffle-hypothesis' that is, in part, considered below.

The following model attempts to introduce the relationship between a deep cave system (up to 250 metres deep) with doline forms on the surface. This research has investigated not the limits of doline *formation*, but the limits of doline *effect* upon the evolution and development of the underlying cave, Agen Allwedd, a

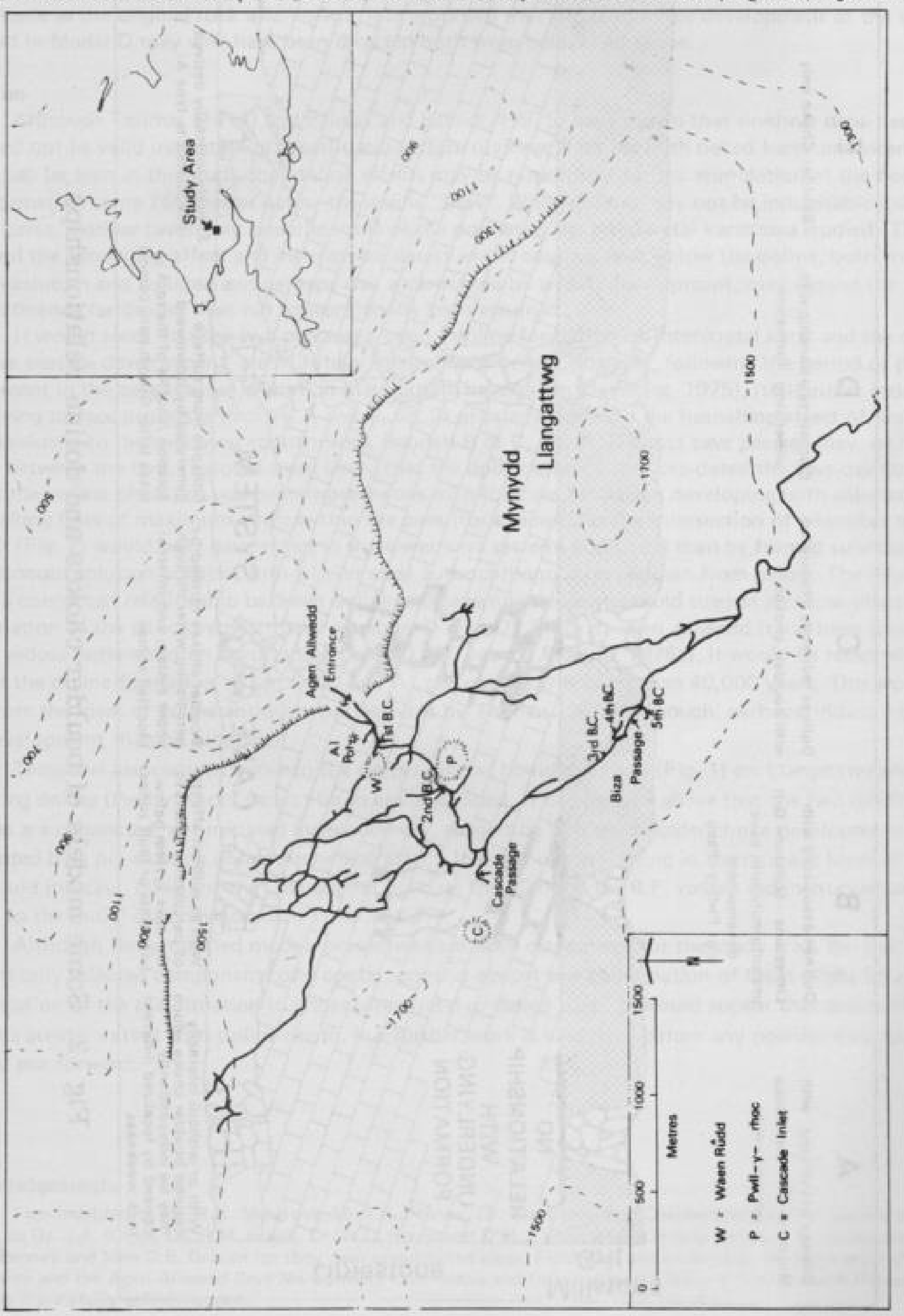


Fig. 1 Agen Allwedd in relation to Mynydd Llangattwg.

21 km. system in South Wales (Fig. 1).

Some Models of Boulder Chokes and Doline Relationships in Agen Allwedd

A model of boulder chokes and doline relationships has been formulated (Fig. 2) as a result of extensive sedimentological investigations undertaken in Agen Allwedd (Bull, 1976a). The model, however, does not represent the only relationships that may exist between dolines and areas of cavern collapse in interstratal karst areas, but may serve to show five types which are only selected members of a continuum. The model is simplistic in design, considering only vertical developments, although in nature a more dislocated relationship may exist between the surface and the underlying cave, resulting in a stepped profile.

The model accepts that dolines, internally derived boulder chokes and cavern breakdown may develop independently (Davies, 1949, 1951; Brucker, 1966), although it allows for a development of these two processes contemporaneously or temporally distinct but genetically connected. Often the very presence of a doline may concentrate percolating water to a specific area which, in turn, may stimulate breakdown in the underlying cave, with or without a previous breakdown internally initiated. Sedimentological investigations in Agen Allwedd (Bull, 1976a, 1976b) indicate that sand-sized particles have been deposited in the cave originating from the overlying basal grits of Mynydd Llangattwg. These have been transported via a connection between the first and second boulder chokes and their respective surface expressions. Figure 1 shows the relationship between the

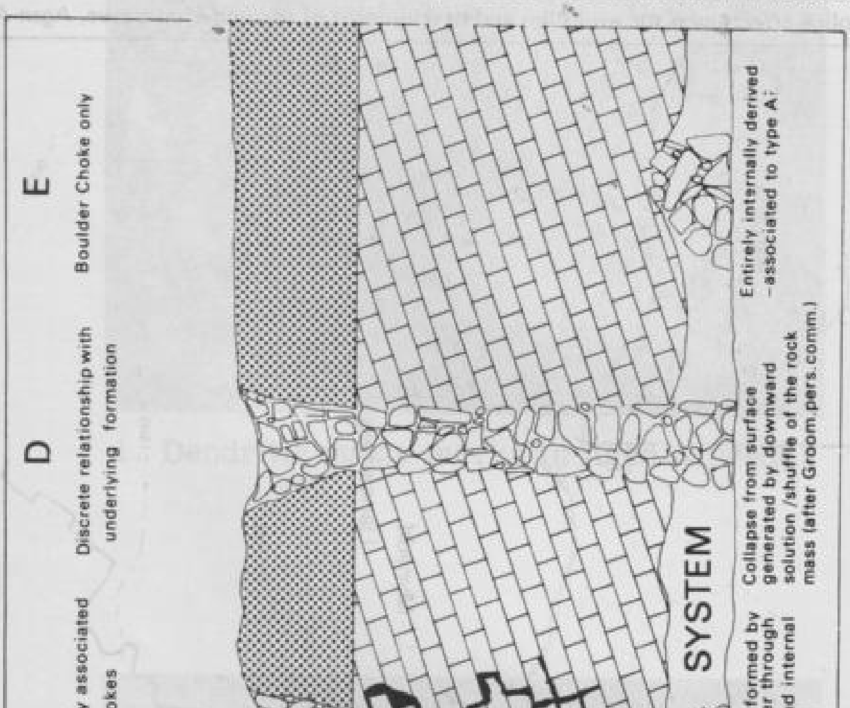


Fig 2 Some models of boulder chokes and doline relationships.

Pwll-y-Rhoc doline and the second boulder choke (200m. vertically), and A1 pot and Waen Rûdd and the first boulder choke (100m. vertically). Similar sediment paths can be identified between Cascade Sink and Cascade Passage (Fig. 1, 150m vertically), an area of positive water connection at the present and also Biza Passage with an unknown surface connection (Fig. 1). Although no known cave system exists between Agen Allwedd and the surface, except for a very small cave development at the base of the unconformity between the Millstone Grits and the underlying limestone (e.g., Pwll-y-Pasg, fig. 2, model B), the existence of unknown passages may dislocate the connections between the surface and the cave.

Models A and E represent end members, stressing the possible interdependency of a doline and cave breakdown formation. It is likely that the model A (Fig. 2) represents the situation for those dolines which appear only to relate to local shallow subsidence (Thomas, 1974), or relate only to localised internally stimulated breakdown (Fig. 1, the third, fourth and fifth boulder chokes). These model forms may also represent the initial stage of a doline/boulder choke relationship and the intermediate models B and C may develop from them. The second boulder choke and the Pwll-y-Rhoc doline suggests such a development.

Model D (Fig. 2) represents the total development of the 'shuffle-hypothesis', but it is thought that this type of surface-cave relationship can only result from a shallow development (as in the cave of the first boulder choke and Waen Rûdd — A1 Pot, fig. 1). Furthermore, the development of such a solution-collapse model may necessitate the presence of an active stream below (Palmer and Palmer, 1975) to remove enough material to allow collapsed boulders (although in some part dissolved) and their void spaces to occupy the same volume as the original rock assemblage. It is proposed that stimulation for development of the situation portrayed in Model D may well have been directed both from below and above.

Discussion

Although Thomas (1974) and Palmer and Palmer, (1975) have shown that sinkhole densities and patterns need not be valid indicators of specific sub-surface drainage lines for both naked karst and interstratal karst, it can be seen in this study that doline effects may be responsible for the stimulation of the boulder choke formation some 250 metres below the doline "base". While dolines may not be indubitable indicators of deep caves, shallow caves may underlie some of the dolines in the interstratal karst area studied (Thomas, 1974) and the funnelling effect and inherent weakness of the country rock below the doline, both from percolation-solution and collapse and perhaps also accentuated by a fault development, may extend the zone of doline influence far deeper than has conventionally been assumed.

It would seem that the two processes, one of doline formation on interstratal karst and the other of deep cave passage development, are of totally independent origin. However, following the period of phreatic development in the cave, vadose alteration may initiate breakdown (Jennings, 1975), itself either independent of overlying surface processes (models A and E, fig. 2) or as a response to the funnelling effect of fault or doline weakness to the overlying country rock (models B or C, fig. 2). Distinct cave passage may, or may not, develop between the two. It would seem likely that the doline effect either pre-dated the cave development (at least the vadose phase) or was contemporaneous with the cave formation developing both solution-collapse dolines along lines of maximum stress within the cave (for example, at the intersection of a number of passages), Model D (Fig. 2) would only have effect in shallower cave systems and could then be formed substantially from autochthonous solution-collapse with smaller scale authochthonous breakdown from below. The development of such a connected relationship between doline and cavern breakdown would suggest a vadose phase during the formation of the structure postulated in model D (Fig. 2). Since in Agen Allwedd it has been shown that a major vadose sedimentation occurred perhaps 40,000 years B.P. (Bull, 1976a), it would be reasonable to suggest that the doline formation (Waen Rûdd and A1 pot complex) is older than 40,000 years. This would further collaborate the ideas of doline antiquity put forward by Thomas (1974) although, perhaps, indicating an even older development than he proposed.

Temporal associations between the deeper second boulder chokes (Fig. 1) on Llangattwg and the connecting doline (Pwll-y-Rhoc) cannot be so easily decided. It can be seen above that the two development processes are connected, yet initiated independently, suggesting that the boulder choke development may be accentuated by a pre-existing doline-funnelling effect. Internal relative dating in the relevant boulder choke areas would indicate, however, that these areas pre-date the 40,000 year B.P. vadose sedimentation and relate perhaps to the initial cave development (+1m.y. B.P.).

Although the simplified models presented have been categorised for the study area, the five variations represent only selected components of a continuum and almost any combination of them might be a valid representation of the real situation in either interstratal or naked karst. It would appear that doline effect extends to a greater extent than doline depth, but further work is necessary before any positive conclusions can be safely put forward.

Acknowledgements

I am indebted to Mr. R.K. Musgrove, Mr. I.G. Penhey, Dr. S.J. Culver and Chelsea Speleological Society for help in the field, to Dr. J.A. Briggs, Dr. R.M. Frank, Dr. W.C. Rouse and D.M. Lawler who critically reviewed an earlier draft and to Mr. I.G. Penney and Miss G.E. Groom for their own unpublished ideas. Fieldwork was undertaken by permission of the Nature Conservancy and the Agen Allwedd Cave Management Committee and financed by the Natural Environment Research Council. Their help is gratefully acknowledged.

References

Brucker, R.W. 1966. Truncated cave passages and terminal breakdown in the Central Kentucky Karst. *Bull. Nat. Speleol. Soc.* 28 (4) 171-178.

Bull, P.A. 1976a. *Cave Sediment Studies in Agen Allwedd.* Unpub. Ph.D. Univ. Wales.

1976b. An electron microscope study of sediments from Agen Allwedd, Powys. *Trans. British Cave Research Assn.*, 3 (1) 7-14.

Cvijic, J. 1893. *Das Karstphänomen.* Geographische Abhandlungen herausgegeben von A. Penck, 5, 217-330.

Davies, W.E. 1949. Features of cave breakdown. *Bull. Nat. Speleol. Soc.* 11, 34-35.

1951. Mechanics of cavern breakdown. *Bull. Nat. Speleol. Soc.* 13, 36-42.

Day, M. 1976. The morphology and hydrology of some Jamaican karst depressions. *Earth Surface Processes*, 1, 111-129.

Gams, I. 1965. Types of accelerated corrosion. In *Problems of the Speleological Research*, (ed. O. Steld) 1, 133-139.

Jennings, J.N. 1975. Doline morphometry as a morphogenetic tool: New Zealand examples. *New Zealand Geographer*, 31, 6-28.

Miotke, F.D. & Palmer, A.N. 1973. *Genetic relationships between caves and landforms in the Mammoth Cave National Park area. A preliminary report.* Druck: Böhler, Würzburg. 69p.

Palmer, M.V. & Palmer, A.N. 1975. Landform development in the Mitchell Plain of southern Indiana: origin of a partially karsted plain. *Zeit Geomorph.* 19 (1) 1-39.

Thomas, T.M. 1974. The South-Wales interstratal karst. *Trans. British Cave Research Assn.* 1(3) 131-152.

THE FOSSIL FAUNAS OF KARST CAVES ON THE EASTERN SHORE OF THE BLACK SEA IN PALEOLITHIC, MESOLITHIC AND MORE RECENT TIME

N.I. Burchak-Abramovich
Vipoloj Prospekt Waza Pshavela 51, Kospics 4 Quartiez
(Apt) 7, Tbilisi 380077, U.S.S.R.

The Karst Caves of the Eastern shore of the Black Sea (Abhazia, Uegrelia, Krasnodar District) contain rich faunas of fossil Vertebrates of paleolithic, mesolithic and more recent times. In six caves (Navalishin cave, Ahshtyrsk cave of Krasnodar District and in cave Hupynypshahva, Kva-Chara, Kĕp-Bagaz, Okumi of Abhazia) were found 35 species of Mammals, 18 species of Birds, 2 species of Amphibia and *Homo sapiens* L. The total list of this fauna includes 57 species.

Gulo gulo subsp. is found in the upper Paleolithic- Mesolithic cave Hupynypshahva and in Eoneolithic cave Kĕp Bagaz, both in South Abhazia. *Spelaearctos spelaeus* Rosm. in Abhazia apparently lived at the beginning of the mesolithic, *Glis glis* was first found in Russia in Okumi (South Abhazia) in 1975.

CONSERVATION DES CAVERNES AMENAGEES RESULTATS OBTENUS DANS QUELQUES PAYS D' EUROPE OCCIDENTALE

V. Caumartin
Laboratoire d'hydrologie appliquée
Dijon, France.

The general principles have been put forward in a booklet presented in Olomouc. The present paper deals with the results obtained from the treatment of chlorophyllian and microbial corrosion, the modification of equipment and the experimental determination of the visitor flow.

Les principes généraux de conservation des cavernes aménagées ont été présentés à Olomouc, en 1973, dans une brochure intitulée: "La conservation des cavernes aménagées", éditée par l' A.N.E.C.A.T. (Association nationale des exploitants de cavernes aménagées pour le tourisme — France); cette brochure contenait les résultats d'études fondamentales.

Les applications ont donné lieu à un certain nombre de remarques pratiques dont nous allons résumer ci-dessous l'essentiel. Elles concernent les corrosions chlorophylliennes et microbiennes éliminées ou stoppées avec succès, les modifications d'installations destinées à favoriser la conservation, enfin la détermination du flux de visiteurs à admettre.

LA CORROSION CHLOROPHYLLIENNE

Il s'agit de l'implantation de végétaux chlorophylliens aux endroits éclairés. Cette flore dégrade les supports sur lesquels elle s'implante; elle est constituée, au départ, d'algues et de mousses qui apparaissent presque simultanément, enfin, en situation extrême, de fougères. Ill est toujours intéressant, d'un point de vue purement écologique, de distinguer les espèces, variables d'une région à l'autre, mais le problème capital pour nous c'est l'élimination.

Les mousses sont les organismes les plus faciles à détruire. On peut appliquer en poudrage, à très faible dose (2 g à 4 g au m2), des produits à base de diuron.

Dans ces conditions, sur supports calcaires, les algues disparaissent également mais en cas de persistance

on peut avoir recours, très efficacement, à des solutions de formol neutralisé à 1-4%, en pulvérisation ou lavage et brossage avec une brosse douce en nylon; contre les fougères, l'application de désherbants ne se justifie pas; on est, dans la majorité des cas, en présence de peuplements très clairsemés dont on vient aisément à bout par un arrachage à la main.

Ces techniques sont valables, à l'exception du formol, aussi bien pour les grottes à peintures que pour les grottes à concrétions. Pour les grottes à peintures et à gravures, les produits à base de diuron peuvent être utilisés efficacement, même à la dose de 6-8 au m2, en dehors des représentations.

Nous avons, avec succès, procédé aux mêmes traitements, à titre préventif, sur les surfaces éclairées, avant l'ouverture de la saison touristique.

On peut avoir recours à d'autres produits mais il est recommandé de s'adresser à ceux qui sont peu solubles et difficilement biodégradables; dans ces conditions, l'action est persistante aux doses employées et les risques de pollution des résurgences et nappes phréatiques sont nuls. La mise en suspension dans l'eau n'est pas contre-indiquée mais le poudrage à sec est toujours préférable.

Les végétaux tués brunissent rapidement et doivent être, pour l'esthétique, éliminés par lavage avec une brosse douce. L'eau de grotte ou de résurgence karstique, qu'il s'agisse de dilution, de mise en suspensions, de lavage est la seule qui convienne.

Ces traitements ne nécessitent aucun matériel spécialisé toutefois, pour les grandes cavités et les applications au plafond, nous expérimentons actuellement un matériel portatif à moteur électrique en usage en arboriculture.

On peut se trouver également en présence de développements algaux sur des pièces d'eau souterraines (lacs, gours, etc. . .) très fortement éclairées; pour les limiter ou les supprimer, nous utilisons avec succès le brome ou les dérivés bromés; ces produits sont efficaces et parviennent, lorsque c'est le cas, aux résurgences sous forme de bromures à concentrations pratiquement indécelables.

La présence de la végétation chlorophyllienne est bien entendu liée à l'éclairage mais deux facteurs, la longueur d'onde de la lumière utilisée et le dégagement de chaleur, entrent en ligne de compte.

En ce qui concerne la longueur d'onde, le problème demeure pour l'instant insoluble car les exploitants préfèrant la lumière blanche mais dans certains cas, représentations rupestres et vestiges préhistoriques ou historiques, on peut se contenter d'un éclairage intermittent. Pour limiter des dégagements de chaleur nous avons adopté, avec plein succès, dans certaines conditions, des lampes dites froides en usage pour éclairer les expositions de denrées alimentaires fragiles (ex : PAR COOL 38 PHILIPS) mais il ne faut pas oublier qu'elles doivent être montées sur culots spéciaux.

La Corrosion Microbienne

Nous avons rangé, dans cette catégorie, les dégâts causés par les bactéries (y compris les actinomycètes) et les moisissures.

Ces dégâts apparaissent toujours en milieux privilégiés: concrétions touchées régulièrement par les touriste, zones de condensation avec dépôts de matière organique (systèmes en V — zones tampon haute et basse — voir brochure citée ci-dessus en référence). L'implantation de cette microflore est moins spectaculaire mais on peut facilement la localiser soit par l'odeur dégagée, soit par un examen aux U.V. (V. Caumartin — 1971 — Excursion sur les corrosions microbiennes en grottes. Note sommaire sur les techniques de recherche — Spelunca — Mémoires no. 7 — p. 31-37). Au toucher, on repère une odeur caractéristique due à la géosmine synthétisée par un actinomyces. Aux ultra-violets, on met en évidence, sur fond en général violet, des pustules fluorescentes liées à la présence de colonies microbiennes encroûtées de calcite.

On peut envisager un traitement au formol à 1-3% mais il est plus rationnel de stopper l'évolution de la corrosion:

- en empêchant les visiteurs de toucherà tout,
- en bloquant le fonctionnement des systèmes en V et des zones tampon par l'adjonction de sas à l'entrée et à la sortie ou en canalisant les condensations sur une surface rocheuse non concrétionnée.

En ce qui concerne le premier point, il convient surtout de discipliner le public qui a la fâcheuse habitude de toucher à tout; certaines exploitations ont réussi à empêcher de fumer, de jeter des papiers, des gommes à mâcher etc. . . les visiteurs, sensibilisés par les problèmes d'environnement, ne sont pas indifférents aux observations quand elles leur sont convenablement présentées.

Pour le second point, une étude climatologique et microscopique s'impose pour bien localiser les condensations accompagnées de matière organique (les plus dangereuses).

Mais avant toute intervention, il est indispensable de s'assurer qu'on est bien en présence, sur les surfaces fragiles (concrétions — représentations rupestres), d'une corrosion en évolution. Le meilleur moyen consiste à prendre des diapositives en couleur à intervalles de temps réguliers (deux fois l'an par exemple). En positionnant rigoureusement l'appareil photographique, en réglant convenablement l'éclairage au moment de la prise de vue, on obtient des images significatives; leur examen comparé par projection permet de diagnostiquer, à coup sûr, les dégradations évolutives donc actives.

Les Modifications D' Installations

L'adjonction de sas permet de limiter les condensations et les apports organiques qui les accompagnent mais il convient également de bannir de la grotte toute matière fermentescible et surtout la présence de W.C. car ils entretiennent, sur place, un peuplement microbien dangereux et dégagent gaz carbonique et ammoniaque.

Le bois n'y a pas non plus sa place car en pourrissant il propage des moisissures.

Les mains courantes des pistes aménagées pour les touristes sont souvent en fer et ce métal, au contact des mains, s'oxyde. L'oxyde ferrique ne présente, par lui-même, aucun danger mais l'entretien des équipements rouillés exige fréquemment l'usage de décapants ou autres ingrédients corrosifs. Il est plus rationnel d'utiliser pour les mains courantes, un matériau inaltérable, par exemple, un matériau plastique; celui-ci est par ailleurs plus agréable au toucher et les visiteurs ne se salissent pas les mains. Pour la piste elle-même, le ciment est tout indiqué car il se prête mieux à l'entretien ce qui permet d'éviter, en particulier, la propagation des souillures par les visiteurs.

Enfin, il arrive fréquemment que les concrétions, trop brutalement chauffées par suite d'un éclairage mal adapté, sèchent, perdent leur éclat et deviennent plus fragiles. En présence d'une telle situation, l'usage des lampes froides s'impose.

La Determination du Flux de Visiteurs

Un des facteurs les plus favorables à la dégradation des cavernes aménagées est l'abondance des visites quand la capacité d'échange avec le milieu extérieur ou la roche est réduite; on assiste alors à un réchauffement rapide, une chute d'hygrométrie relative, une accumulation de CO_2 etc. . . ; il faut à tout prix, dans ce cas, éviter les surcharges.

Comment peut-on déceler le phénomène, donc déterminer le flux de visiteurs à admettre ou du moins la limite à ne pas dépasser?

On y parvient par une étude climatologique simple, au moyen d'appareils enregistreurs d'hygrométrie et de température. Dans la plupart des cavités, les courbes d'hygrométrie et de température reflètent, avec un décalage de plusieurs heures parfois 24 heures et une large amplitude, les perturbations extérieures. Dans la cas qui nous préoccupe, si l'afflux de visiteurs est trop important, les variations sont concordantes pour l'hygrométrie et la température mais d'amplitude inverse et l'équilibre se rétablit plus ou moins vite, indépendamment des perturbations extérieures. Ill tombe sous le sens qu'une grotte qui récupère lentement son propre équilibre ne peut être chargée en visiteurs, qu'une grotte qui ne subit pas de variations brutales est apte à accueillir des groupes plus importants.

Conclusion

Tous les problèmes posés par la conservation des grottes aménagées sont loin d'être résolus mais un certain nombre d'entre eux, les plus graves, ont déjà trouvé, au moins en partie, une solution satisfaisante.

Nous n'avons plus d'excuses de laisser se détériorer les cavernes aménagées pour le tourisme.

SURFACE KARST LANDFORMS ON THE MOROCCAN HAMADA OF GUIR

V. Castellani
Cattedra di Astrofisica
dell' Universita di Roma
Casella Postale 67
00044 Frascati, Italy.

W. Dragoni
Societa Speleologica Italiana
and G.D. "Urri"

The occurrence of closed drainage basins on the surface of limestone hamadas has been often interpreted in terms of karstification. The hamadas in the Saharan regions of Morocco are largely intersected by more or less large depressions (roughly equivalent to dolines in more humid climates) whose central regions are covered by sands and pebbles. We shall refer to similar structures adopting the term "daya" from the work by Mitchell and Willimot (1974) which gave a general review of the problem as well as an interesting analysis of some dayas in the South of Morocco (see also Reading University Reports 1969, 1971).

Mitchell (1970) suggested the aerial photography could be a useful device in studying the occurrence of dayas in arid regions. In the following we shall report some results of such an investigation carried out on the so called "Hamada du Guir" in the Ksar-es-Souk district in the South of Morocco.

The Hamada of Guir

The hamada of Guir is a wide table-land, made up by undisturbed Oligo-Miocene limestone sediments. It is bounded by a sharp and almost vertical scarp (kreb) about 100 m deep. The morphology of dayas along a portion of the hamada has been recently studied by one of us (Castellani 1977); here we will deal with a general analysis of the presence of dayas along the hamada. The aerial cover (1:100,000) by the Moroccan Institute Geographique National allows us to elaborate a careful documentation of a portion of the hamada du Guir 2,500 km^2 wide. On the basis of such material we constructed a map of the distribution of dayas along the surface of the hamada. It is understood we are using the term daya to indicate the central region of the hollows where the surface is covered by sands, silts and, sometimes, by pebbles.

We registered on the surface of the hamada the presence of 2345 dayas with sizes between a few tens of metres and more than 1 Km, and depth generally not exceeding 10 m. We can roughly separate three types of dayas:

(i) "Para"-dayas: dayas connected to form a continuous drainage line, with N-S direction, sometimes reaching the south edge of the hamada, otherwise connected with a final large closed basin.

(ii) Large dayas: with sizes up to more than 1 km, largely irregular in shape, with evident inflow channels.

(iii) Small dayas: with a diameter of some tens of metres, a sub-circular form and rare tracks of inflow disturbances.

The systems of para-dayas are likely linked with structural alignments and original tectonic disturbances.

Large dayas appear to be mainly concentrated close to the edge of the hamada, whereas small circular dayas appear to be grouped in peculiar internal regions.

There is no clear evidence for the origin of differences between large and small dayas. In the assumption of homogeneous rainfall (from a quantitative as well as chemical point of view) on the hamada surface, we can suppose such differences are simply derived by original heterogeneity on the plateau. Otherwise we could speculate on possible edge-effects in the distribution of rainfall and wind transported sands. As a matter of discussion we finally report the exotic possibility that along the edge of the hamada the underground flow of water is favoured by the valley below: in this case the recrystalisation of carbonates could be prevented and efficiency of karstification could rise just along the edges.

The map in fig. 1 has been explored by means of a computerized image-scanning device (the "Quantimet" QDM720 produced in U.K. by IMANCO) at the Institute of Geology of the University Rome..

The east side of the map was first explored, measuring the ratio of surface covered by daya floors in squares of 225 km^2. By shifting the square in direction N-S by half its vertical dimension we found

TABLE 1.

% of area covered by dayas	5.1	4.6	2.9	3.8	4.6	5.8	3.7	5.3	4.6
	N → S								mean

That the ratio of surface covered by the dayas does not vary drastically along the 80 km of hamada explored, supporting the idea that dayas are a necessary consequence of climate as well as of rocks.

A similar analysis performed in direction W-E, i.e. from the edge of the hamada toward the interior, gives the following results:

TABLE II.

% of area covered by dayas	10.2	6.5	5.3	5.5	4.3
	W → E				

It follows that large dayas cover a relatively larger fraction of their drainage basins. Such a result discloses dayas do not represent a series of "homologous" structures, in the sense that the space filled by the daya soil is strictly proportional to the catchment area; in this case the ratio of surface covered by dayas should decrease with increasing size of the dayas. Also if we suppose that a daya is just a surface-phenomenon, we would expect a constant value for this ratio, so that it is difficult to escape the conclusion that peripheral dayas show evidence for a higher efficiency of an undetermined mechanism of formation.

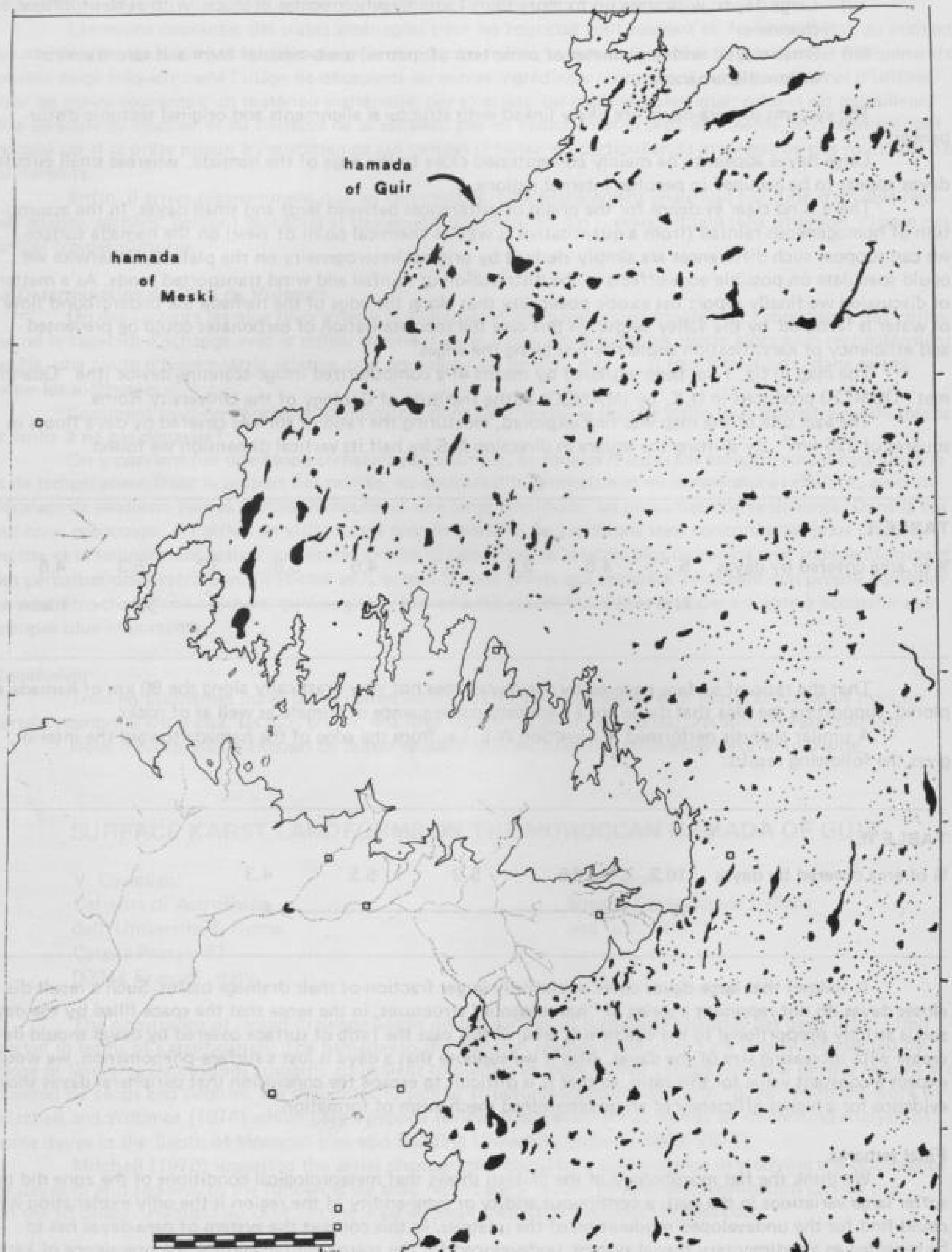
Final remarks

We think the flat morphology of the plateau shows that meteorological conditions of the zone did not suffer large variations in the past; a continuous aridity or semi-aridity of the region is the only explanation we could find for the undeveloped moderation of the plateau. In this context the system of para-dayas has to be regarded as a rudimentary fluvial system, undeveloped for the scarce rainfall and for the prevalence of karstification on fluvial erosion.

As regards the present conditions of the hamada, the annual mean temperature at Boudenib (at the North side of the Hamada) is 19.6°C, whereas the annual rainfall in the region surrounding the hamada is varying between 50 and 100 mm/year.

Also, taking into account the altitude of the plateau can lower the mean temperature down to 18.0°C, we find, according to Turc (1954), practically all the rainfall is expected to evaporate. This is confirmed by the absence at the foot of the hamada of any spring.

The high mean temperature and the absence of vegetation are both factors depressing the aggressiveness of water. Assuming only that atmospheric CO_2 was dissolved in the water, we expect about 60 mg of carbonate can be dissolved by a litre of water (Roques 1972), so that $0.06 \times 0.05 \times 10^8 = 3 \times 10^6$ gr/km^2 of limestone can be dissolved each year under the present conditions, and for the minimum rainfall (50 mm). Allowing $\sim 1.5 \times 10^7$ years have been elapsed from the uplift of the plateau, we find $\sim 4 \times 10^7$ ton ($\sim 2 \times 10^7$ m^3/km^2) of limestone could have been dissolved. That corresponds to a 20 m thick layer of limestone. Such a value likely represents a large underestimate of possible karstification, as there are, on other grounds, some evi-


hamada
of Guir
hamada
of Meski
0 1
5
km

dences for an increased humidity in the past and, may be, of a steppe-like vegetation.

Nevertheless this value seems high with respect to the volume and depth of actual depressions, and can be interpreted in terms of a very reduced efficiency of karstification, likely to be connected with the almost total evaporation of water. On the other hand, it seems difficult to believe in the development of large underground cavities: there is no evidence of these along the kreb wall, and the morphology of dayas looks peculiar as a prevailing horizontal karst.

References

Castellani, V. 1977. "Grotte d'Italia" (in print)

Mitchell, C.W. 1970. "The interpretation of dayas on aerial photographs of arid areas" III Symp. Inter. Photointerpretation, Dresden.

Mitchell, C.W. & Willimot, S.G. 1974. "Dayas of the moroccan sahara and other arid regions, *Geograph. Journ. 140,* 441. *Reading University Expedition to moroccan Sahara* 1969, Dept. of Geography, University of Reading. *Reading University Expedition to moroccan Sahara* 1971, Dept. of Geography, University of Reading.

Roques, H. 1972. "Chimica dei carbonati ed idrogeologia carsica" *Atti Seminario Speleogenesi di Varenna, Grotte d'Italia 4,* 48.

Turc. L. 1954. "Le bilan d'eau des sols; relations entre les precipitations, l'evaporation et l'ecoulement" La Houille Blanche, 3 journees de l'hydraulique de la Societe Hydrotechnique de France, Paris, pp. 89-99.

CAVE RESCUE IN THE UNITED KINGDOM

E.C. Catherine
Chairman, Cave Research Council.
4 Christine Close, Ash, Aldershot,
Hampshire GU12 6QL. U.K.

In the United Kingdom the Police are responsible for the safety of people and property, as part of their duties and therefore they are responsible for cave rescues. For more than 40 years this service has been provided in liaison with the Local Police by cavers living or active in the popular caving areas in view of their knowledge and experience of the local caves, potholes and mines.

The cave rescue organisations in each area are completely independent, drawing members of the rescue team from local cavers, arranging their training, electing their officers, providing the necessary equipment and arranging their own finances. As Public Funds are not provided for the cave rescue service most Cave Rescue Organisations rely on donations from people they have rescued or from local cavers. Liaison is maintained with the local Police, who, in view of their responsibility, receive all calls for cave rescue and then contact the Cave Rescue Organisation in accordance with a prearranged scheme.

By 1966 the increased interest in caving as an activity resulted in more people, particularly younger people exploring caves, potholes and old mines and as many of them were not members of local clubs they lacked experienced guidance and the number of accidents increased. One incident resulted in delay in calling the Cave Rescue Organisation and confusion with Local Police and in view of this some Cave Rescue Organisations considered it was time for a National Body to be formed to obtain national recognition.

On 24th June, 1967 the Inaugural Meeting of the Cave Rescue Council was held and it was decided that this would be the National Body which would obtain recognition from the Home Office and the Association of Chief Police Officers for regional Cave Rescue Organisations but would not control these organisations which would remain completely independent. Recognition was received providing the Cave Rescue Council would arrange for a service to be available for any Police Authority Areas where underground accidents could arise.

A study of the 45 Police Authority Areas, which would be brought into operation in England and Wales on 1st April, 1968, showed that cave rescue calls could be received from 24 of them. Arrangements were made for some of the existing Cave Rescue Organisations to extend their areas and for new organisations to be established by experienced members of the existing organisations. Cave rescue for all Scottish Police Authorities continued to be provided by the Scottish Cave Rescue Organisation and for Northern Ireland and the Republic of Ireland by the Irish Cave Rescue Organisation.

In 1971 the Home Office advised all Police Authorities to arrange accident insurance cover for all members of the public assisting them in their emergency services, and all cave rescue teams, providing the Police had requested their assistance, were given the benefit of this insurance. The terms of this cover are:

Death	£10,000
Loss of both eyes and limbs	£10,000
Loss of one eye or one limb	£5,000
Temporary total disablement	£30 per week for a maximum of 104 weeks
Temporary partial disablement from engaging in any occupation	£12 per week for a maximum of 104 weeks
Permanent total and absolute disablement from engaging in any occupation	£1,000 per annum for 10 years

Damage to clothing and personal effects £25 in all but since this cover was provided it has not been necessary to make any claims and we hope this will always be the position.

The Police are able to refund out-of-pocket expenses to all cavers involved in a rescue call but this is only usually claimed when considerable expenditure is involved.

Since the formation of the Cave Rescue Council it has been agreed that this body exists to provide a cave rescue service and is not concerned with cave safety as it is considered this is a duty of the caving clubs and the National Caving Association. Member Organisations publish an Annual Report and this gives factual details of rescues and is circulated to all caving clubs in the area in the hope that they will read and avoid similar caving accidents. These reports are also circulated to the Local Police Authority and other Cave Rescue Organisations.

In addition to arranging the cave rescue service the Cave Rescue Council also arranges for one of its member organisations to organise the National Cave Rescue Conference in its area every other year. The Council also maintains contact with the Mountain Rescue Committee and details of the cave rescue organisations are published in their Annual Handbook.

During 1976 it was reported that a minor cave rescue had occurred in an old mine shaft outside the Police Authority Areas covered by the cave rescue service. In view of this the Cave Rescue Council decided that the existing service should be extended to cover all Police Authority Areas in England and Wales; following consultations with the Association of Chief Police Officer; arrangements were made for the 13 member organisations to provide cover for all the 42 Police Authorities now existing.

On the formation of the National Caving Association the Cave Rescue Council became a member organisation on the basis that it was only concerned with its object of providing a cave rescue service but arrangements have now been made for member organisations to provide details of accidents involving equipment to their Equipment Committee in order that investigations can be made and cavers informed of the results through the Equipment Failure Report service.

Some of our member organisations combine cave rescue with mountain rescue and calls are received from Farmers to assist in rescuing cattle which have fallen into potholes; at times requests are received from the Police to assist in searching for missing people.

BEDDING PLANE ANASTOMOSES AS EVIDENCE OF EROSION IN DIFFERENT ROCKS

Vittorio Castellani and Arrigo A. Cigna
(Società Speleologica Italiana)
Viale Medaglie d'Oro, 285, 1-100136 Roma, Italy.

It was early recognised that bedding planes can play an important role in cave morphology and, in speleogenesis. Bretz (1942, 1956), in studying the so-called ceiling channels, first drew attention to the occurrence of networks of small tubes etched into the ceilings of some caves along old bedding planes: the "bedding plane anastomoses". More recently Pasini (1967) revised the argument, giving a careful analysis of ceiling channels in caves near Bologna (Italy).

Following Bretz's hypothesis, bedding plane anastomoses (BPAs) are expected to be the remnants of incipient speleogenesis along a bedding plane which comes to the light when two adjacent rock beds have been separated by collapse. Unlike other channels occurring along bedding planes, the typical cross sections of BPAs are circular with the bottom just in correspondence to the bedding plane. This has been interpreted in terms of phreatic conditions as well as of insoluble components of limestones (Bretz) or water-carried clays (Pasini) deposited in the lower portion of the duct, stopping downward erosion. Recently Ford (1976) drew attention to possible confusion between BPAs and stylolites, suggesting in some cases anastomoses originate as large scale stylolites.

The limestone of Bisceglie (Italy)

The large calcareous platform of "Murge" in South Italy, facing the Adriatic Sea, supports a large variety of karstic forms (Zezza 1975) including the well known "Grotte di Castellana", among the largest in Italy. Near the small town of Bisceglie (Bari), marine erosion on a large bank of fine limestone gives a cross-section of a series of thin limestone beds, no thicker than 30-40 cm containing networks of well defined BPAs.

It can be noted that the BPAs are scattered along the various beds, so that no preferential beds appear to occur, and that they are strictly confined above the bedding plane, the upper face of the lower bed being practically unaffected by the formation of the tube. Also along the whole cliff (nearly 1 km long) the only flow-channels are the BPAs.

As pointed out by Warwick (1975) the formation of such tubes may take most of the water-flow, inhibiting any further development of the system. In this context the network of BPAs in Bisceglie rocks could be regarded as equivalent to the "fragmentation" of a large cave into a series of parallel tubes acting as a whole as a well developed system of drainage. Some collapse reveals meandering ducts like those found in the roof of some caves. It is worthwhile noticing that Zezza (1975) quotes similar structures in the "Pulo di Molfetta", a large depression of karstic origin, some 10 km inland from Bisceglie; BPAs are characteristic of a large region of the Murge Plain.

It is difficult to have a clear idea of the factors controlling such a typology: epiphreatic or very gentle flow conditions have been suggested, though Martini (1960) wondered if a mechanism of condensation could contribute to similar forms. Microscopic examination showed solution of the rock and deposition of calcite crystals in the duct deiling, while the smoother surface of the duct floor appeared to be covered by a crust composed by small quartz crystals with some calcite.

The marl of Habbaniya (Iraq)

The Iraqui plain is mainly formed of sandstone, conglomerate, evaporites and alluvium near the Tigris and Euphrates rivers. Some 75 km W of Bagdad, between the Euphrates and the Hannaniya Lake, small beds of marl occur in sandstone. Some BPA-like channels were found in the marl (Fig. 4). Their size and appearance is similar to the BPA channels described in the limestone of South Italy. Owing to the paucity of channels it was not possible to ascertain their development within the bedrock; but they were developed above the bedding planes and in each case the upper face of the lower bed was practically unaffected by the formation of the tube as in the Italian BPA channels mentioned earlier.

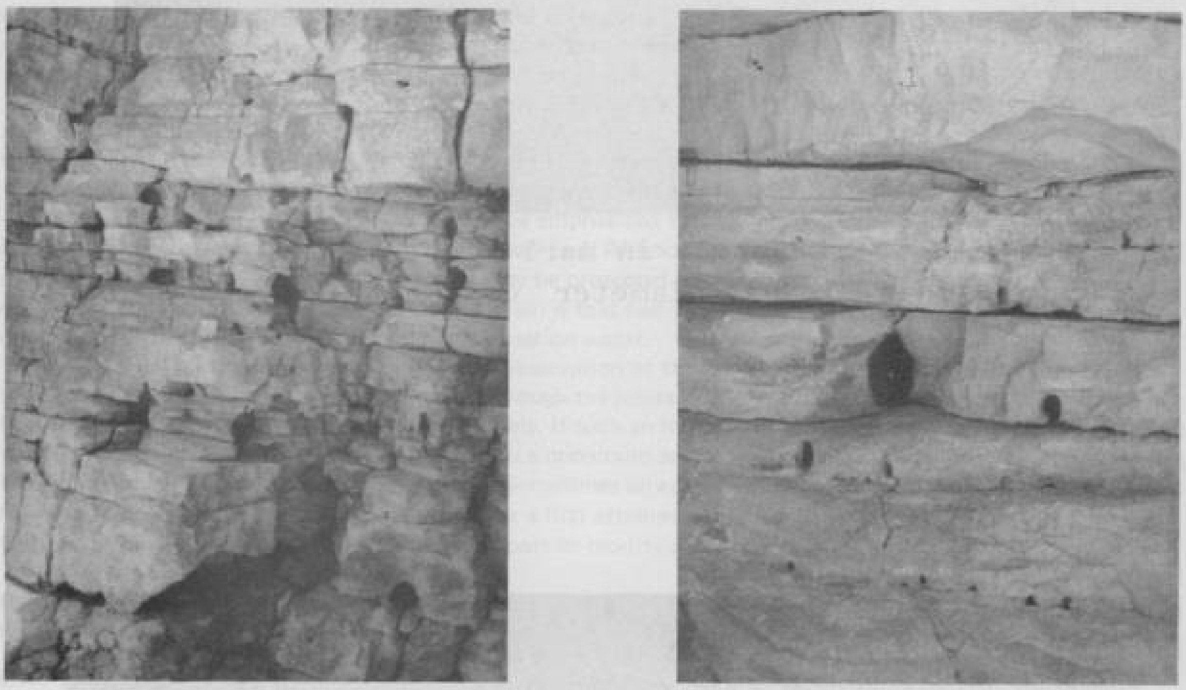


Fig. 1,2 - Bedding plane anastomoses in limestone near Bisceglie (Bari, South Italy).

Fig. 3 - Lower face of a bed in the same limestone of Fig. 1 and 2.

Fig. 4 - Channels in marl near Habbaniya (Bagdad, Iraq). Diameter of the coin: 28 mm.

Fig. 5 - Channels in volcanic tuff near S.Maria di Galeria (Roma, Italy).

The tuffs of Sabatini volcanoes (Italy)

Finally, it may be worth noticing the occurrence of BPA-like channels in volcanic rocks. The Sabatini volcanic group is roughly centered around the Bracciano lake, about 30 km NW of Rome, and fluvial erosion has cut a network of small valleys in Pleistocene pyroclastic flows, tuffs and volcano-sedimentary deposits. Such volcanic rocks have likely experienced a period of phreatic activity, so that along the walls of the volcanic hills one can find small channels following the bedding planes, which often closely resemble BPAs.

In the sides of a tuff formation south of the village of S. Maria di Galeria (Roma), many flow channels appear along the various beds. Morphology of BPAs is sometimes completely simulated though other ducts are etched just in the middle of bed rocks (Fig. 5) or as classic phreatic tubes along rock fractures. The channels are present only in stratified tuffs as well as in a layer of friable sandstone (with the same minerals of the tuffs) of fluvial-lacustrine origin. In homogeneous tuff (lower part of fig. 5) channels are absent. The walls of some channels are covered by an iron oxide flowstone as a consequence of deposition by ferruginous waters.

Conclusions

The channels here described were found in different kinds of rocks and this phenomenon fits the form convergence theory proposed by Eraso (1976). He pointed out that different factors are interrelated during the whole karstification process and the action of these factors must be considered simultaneously. Therefore the variation of a single factor (e.g. the nature of rock) is generally not sufficient to modify the end result.

In the examples here considered, the lithological contrasts did not affect the morphology of the channels, probably allowing only some minor difference in the location of the ducts relative to the bedding plane. Changing from the most soluble rock (limestone) to the intermediate one (marl) and to the less soluble tuff, the location of the ducts moves from the bedding plane to the middle of the bed. On the other hand the channels were absent in non-stratified rock. It must be emphasized that the cross section of the channels is situated above a bedding plane leaving unaffected the lower bed. Although the reasons for this fact are not fully determined, it seems that the floor of the channel may be protected against erosion by a film of clay (or similar material) deposited by the water. Another problem is that two kinds of waters appear to be capable of producing the observed forms: epiphreatic, and condensation water.

A preliminary hypothesis founded on observation of the limestone of Bisceglie suggests that condensation water, from the air flowing in summer through the joints or the pores of the rock, could play an important role in the genesis and growth of the channels. If such an hypothesis is correct the channels should develop with an increasing intensity inside the rock up to a maximum where the condensation process has its maximum, to decrease thereafter and cease still farther in. Sometimes an epiphreatic flow may be established in the channel network. These ideas should be considered as a first attempt to explain some interesting erosion features. Only additional observations will be able to support or modify such a conclusion.

References

Bretz, J.H. — 1942. Vadose and Phreatic Feature of limestone caverns. *Jour. Geol.*, 50(6).
1956. Caves of Missouri, *Geol. Surv. and Water Res.*, 39 (2).

Eraso Romera, A. — 1976. Nuevo metodo en la investigacion del karst, los models naturales y la convergencia de formas. *Proc. 6th Int. Congr. Speleology*, Olomouc 1973, 2: 89-108.

Ford, T.D. — 1976. *The geology of caves*, in: Ford & Cullingford (Eds.) *The Science of Speleology*. Academic Press, London, 34.

Martini, J. — 1960. Note sur l'erosion inversée. *Stalactite, Soc. Svizzera Spel.*, 4 (5).

Pasini, G. — 1967. Osservazioni sui canali di volta della grotte bolognesi. *Le Grotte d'Italia*, Serie 4, 1: 17.

Warwick, G.T. — 1975. *Geomorphology and caves*, in Ford & Cullingford (Eds.) *The Science of Speleology*. Academic Press, London, 61-125.

Zezza, F. — 1975. Le facies carbonatiche della Puglia e il fenomeno carsico ipogeo. *Geol. Appl. e Idrogeol.*, 10: 1-31.

SUR TROIS SYSTEMES KARSTIQUES DE GRANDE AMPLEUR: EYNIF, KEMBOS ET DUMANLI (Taurus Occidental, Turkey)

Claude Chabert

Speleo - Club de Paris - 7 rue La Boétie - 75008 - Paris

Abstract: Three big hydrological systems are briefly described. All of them are connected with Manavgat river in the Taurus mountains, Turkey. The first, in Cretaceous limestone, the Kembos system, is located on the left bank of the river. It is the downstream part of Beyşehir lake—Yedi Miyarlar/Düdensuyu system (L = 75 km, D = 730 m) with twelve springs (Q = 40 m^3/s ca). Also on the right bank, the Eynif system, in Cretaceous and Miocene limestones, proved by dye-test (L = 35 km, D = 910 m) begins at Eynif polje. The resurgences are 21 springs (Q = 5 m^3/s ca). There is a strip of flysch between the systems, which means no connection is possible.

On the left bank lies the big spring of Dumanlí (Q = 50 m^3/s). The sources of this system are unknown yet. Suğla polje (L = 55 km ca) is supposed to be one of them.

A blind cave, in conglomerate, Tilkiler düdeni, leads into Eynif system. Its speleological exploration was begun in 1976 by French cavers.

Cette note n'a pas d'autre prétention que de donner un aperçu des possibilités spéléologiques du Taurus Occidental. Des colorations effectuées il y a neuf et dix ans ont mis en évidence des percées

hydrologiques parmi les plus longues du monde. Elles intéressent toutes le bassin d'alimentation d'une rivière: la Manavgat qui, longue de 80 km environ, a un débit important. Lors d'une forte crue, il a été évalué à 1200 m^3/s, alors que sa moyenne annuelle est de 156,8 m^3/s, son étiage 80 m^3/s avec des minima à 35-40 m^3/s. En hautes eaux, son débit passe à 700 m^3/s avec des maxima à 1000 m^3/s.

La Manavgat reçoit l'apport de plusieurs émergences karstiques, rive droite et rive gauche, qui lui assurent un débit d'étiage tel qu'il a motivé la décision de bâtir un barrage, aujourd'hui en cours de construction, dans les dernières gorges que traverse la rivière: le barrage d'Oymapínar.

Le cours de la rivière se confond localement avec le tracé d'une faille visible en amont de Sinanhoca. Les grandes unités géologiques sont orientées différement selon qu'elles appartiennent à l'une ou à l'autre de ses rives.

Rive droite, l'unité tectonique d'Eynif est représentée par des calcaires et des conglomérats miocènes surmontés par des calcaires crétacés. Elle est compartimentée par des bandes de flysch qui séparent les deux grands systèmes hydrologiques de cette rive: Kembos et Eynif. Elle est suivie de l'unité du Yelek dağ, enserrée entre deux couches de flysch, où prédominent les calcaires du crétacé. Les calcaires miocènes et les conglomérats apparaissent au sud de l'unité d'Eynif où parfois ils s'enchevêtrent de façon complexe pour disparaitre totalement sous les calcaires crétacés au fur et à mesure qu'on s'avance vers le nord.

I Kembos

Le système de Kembos est la partie aval d'un système encore plus grand qui commence au lac de Beyşehir pour se terminer dans les gorges de la Manavgat aux Yedi Miyarlar et à Düdensuyu.

Les Yedi Miyarlar sont de puissantes sources (alt 430 m; Q = 40 m^3/s environ en août 1968, mais seulement 3 m^3/s environ en juillet 1974) alimentées par les pertes du polje de Kembos (alt 1140 m) et vraisemblablement par celles du polje de Sobuca (alt 1000 m environ) d'une part et par les pertes du lac de Beysehir, Homat Bürnü düdenleri (alt 1130 m) de l'autre. Les émergences sont groupées sur 250 m et sont au nombre de 12 exactement. Les deux dernières sont de véritables rivières qui donnent à elles seules un apport de 35 m^3/s environ (étiage de 1968) à la Manavgat.

Plus vers l'aval, mais située dans une reculée, la grotte semi-active de Düdensuyu (alt 406 m) forme avec les Yedi Miyarlar un vaste "delta" hypogé. Le réseau souterrain reliant les pertes du polje de Kembos (Büyük düden et Feyzullah düdeni) à Düdensuyu, non prouvé par coloration, est long de 30 km pour une dénivellation de 730 m environ. C'est la seconde partie du grand réseau lac de Beysehir (Homat Bürnü düdenleri)—Yedi Miyarlar long de 75 km pour une dénivellation identique (720 m).

Sur ce système, nous ne connaissons jusqu'à présent, que les deux pertes du polje de Kembos, Büyük Düden (D = 178 m) et Feyzullah düdeni (D = 400 m), la grotte de Düdensuyu, remarquable par ses dimensions et ses grands lacs étagés (D ≠ 2000 m), puis un certain nombre de petits gouffres dont le plus profond, Karabacak düdeni, atteint 122 m de profondeur. La carte ci-jointe donne l'emplacement des autres cavités connues (n° 11 à 16).

II Eynif

La percée hydrologique d'Eynif présente les mêmes caractéristiques que celle de Kembos: pertes de polje alimentant un réseau d'émergences impénétrables. Leurs cours supposés sont sensiblement parallèles. Elles appartiennent à la même rive. A Eynif, vers l'aval, nous avons une prédominance des congléмérats sur le calcaire.

Les sources d'Oymapínar, M 1 à M 24, forment comme les Yedi Miyarlar un "delta" souterrain. Elles donnent un apport moyen de 5 m^3/s environ à la rivière de Manavgat. Pour leur alimentation, elles dépendent de la partie nord du polje d'Eynif, avec une cavité pénétrable, Akpinar (alt 940 m) qui a été colorée en 1967 et à révélé un réseau de 35 km de longueur pour 910 m de dénivellation (les sources M1-M24 sont à 30-32 m d'altitude).

Mais le polje d'Eynif distribue un autre réseau hydrologique. La coloration, en janvier 1976, des pertes de sa partie sud, les Beyçayírí düdenleri, a montré une liaison polje d'Eynif — Düdensuyu, soit un réseau de 12300 m de longueur pour 534 m de dénivellation. D'autres sources comprises entre Düdensuyu et les Oymapínar ont en même temps été colorées: Kemik Döklü (alt 310 m), Sevinç Moisi (alt 184 m) et aussi une source de la rive gauche, Yarpuzlu kaynaǧí (alt 186 m, D = 14000 m).

Ainsi le polje d'Eynif occupe une position privilégiée dans le bassin d'alimentation de la Manavgat, puisqu'il distribue deux réseaux hydrologiques parallèles. Ceci se comprend si on admet une discordance de ce phénomène karstique avec la structure géologique puisqu'il est coupé en son milieu par le flysch assurant l'indépendance des systèmes de Kembos et d'Eynif.

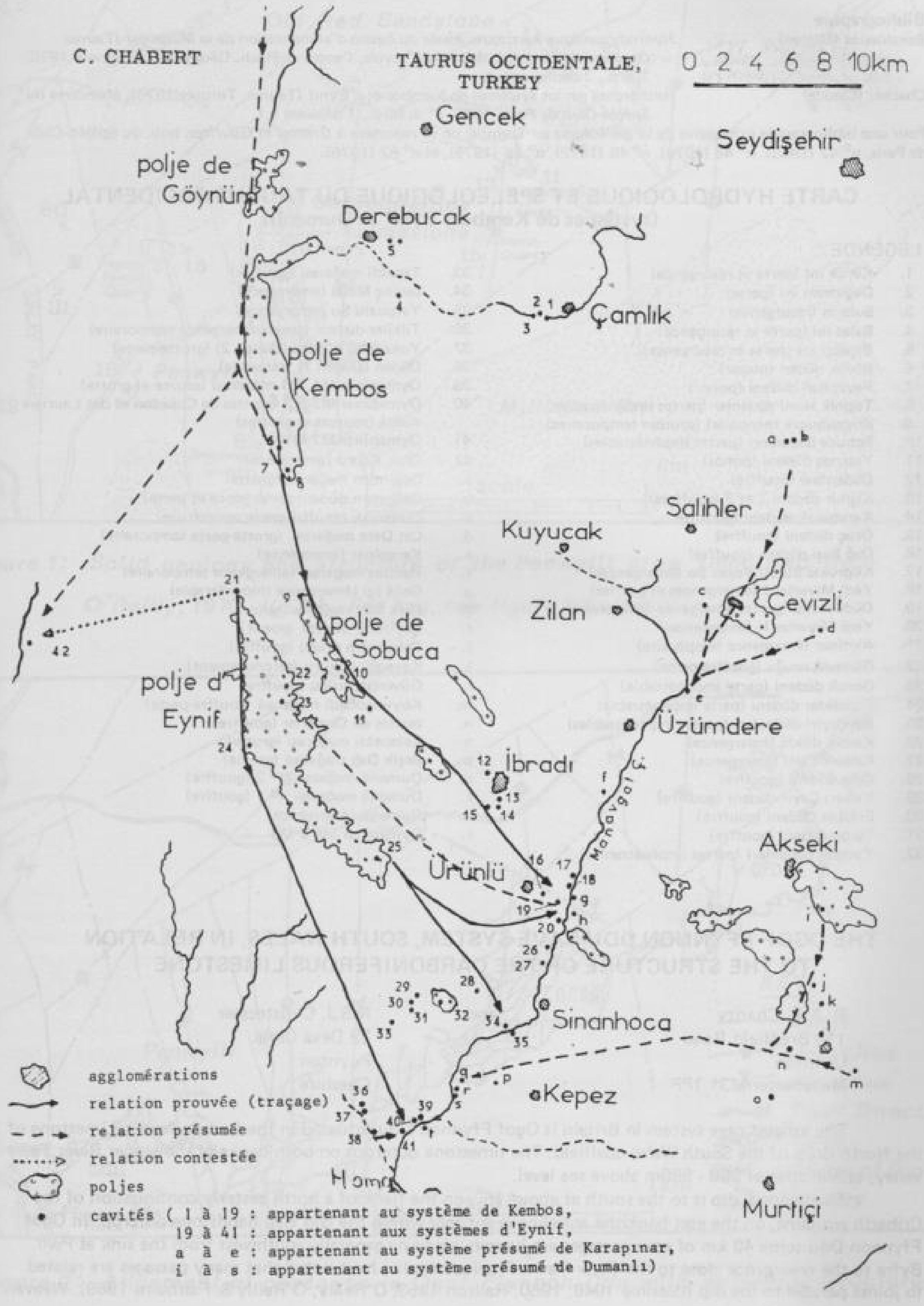
Rattachés au système d'Eynif, nous connaissons, outre Akpínar qui est un trop-plein et laisse supposer en amont un réseau souterrain encore inconnu qui donnerait au système d'Eynif une longueur supérieure, le ponor de Gürlevik oruğu, Tepekli mağarasí (P = −147 m), l'estavelle de Düden (P = −64 m), ces deux dernières cavités étant creusées dans le conglomérat, plus une série de petites grottes et de gouffres profonds de 20 à 50 m (ce sont les n° 28 à 32 de notre carte).

Les explorations de 1976 du Club Alpin Français (Spéléo-Club de Paris et Club Martel) ont reconnu sur 2755 m une cavité aveugle, Tilkiler düdeni, qui a été découverte lors du creusement d'une galerie de reconnaissance dont l'entrée se situe au contact des mollasses imperméables et des conglomérats (formation de Tepekli). Cette cavité a le double privilège de se développer dans le conglomérat (P = 159 (−66, +93) m) et d'être parcourue par un fort courant d'air. Elle est la première grande cavité découverte dans cette partie du Taurus, à l'exception de Düdensuyu, et permet d'augurer favorablement des possibilités spéléologiques du

Taurus: on y distingue une zone noyée, pour le moment inaccessible, une zone semi-active (celle qui a été explorée en 1976) et une zone fossile.

III Dumanli

Avec Dumanlí, nous nous trouvons en présence d'une émergence de prestige. Elle se jette rive gauche de la Manavgat (alt 60 m) et elle est la seule grande source de cette rive, du moins éclipse-t-elle toutes celles qui la précèdent. Son débit moyen annuel est de 50 m^3/s. En hautes eaux, il passe à 100 m^3/s, à l'étiage il est toujours supérieur à 15 m^3/s (valeur observée en novembre 1964). On connaît théoriquement son bassin d'alimentation, estimé à 2800 km^2 (Bakalowicz, 1970). On suppose qu'elle est alimentée par les poljes d'Akseki, de Sadíklar et surtout par le lac-polje de Suğla (D = 55 km environ). L'existence d'une



barrière de flysch à la hauteur de Sinanhoca ne ruine pas cette hypothèse car il est probable que sa faible épaisseur n'interdise pas le passage des eaux par l'intermédiaire d'un karst noyé. Pratiquement, le mystère reste entier: aucune coloration n'est ressortie à Dumanlí.

Les expéditions de 1966 (Spéléo-Club de Paris, Spéléo-Club de la Faculté des Sciences d'Orsay, British Speleological Expedition to Turkey 1966) se sont efforcées d'atteindre le cours souterrain qui n'a été entrevu qu'à deux reprises et fort près de l'émergence elle-même, dans les Dumanlí mağarasí n°1 et n°2. Les autres cavités intéressantes, Koyungöbedi mağarasí (P = −210 m) et Çayirönü düdeni (P = −153 m) mériteraient d'être colorées.

Remerciements: cette note n'aurait jamais vu le jour sans l'amabilité de la Société Spéléologique de Turquie présidée par le docteur Temuçin Aygen.

Bibliographie

Bakalowicz (Michel) *Hydrodynamique karstique: étude du bassin d'alimentation de la Manavgat (Taurus Occidental, Turquie)*, thèse du 3° cycle, Centre de Rech. Géodynam., Thonon, 1970, 106 p., 3 dépliants h.t.

Chabert (Claude) Recherches sur les systèmes de Kembos et d'Eynif (Taurus, Turquie 1976), *Mémoires du Spéléo-Club de Paris*, 1976, n° 4, 68 p., 1 dépliant h.t.

Pour une bibliographie exhaustive de la spéléologie en Turquie, on se reportera à *Grottes et Gouffres*, bull. du Spéléo-Club de Paris, n° 42 (1968), n° 45 (1970), n° 48 (1972), n° 55 (1975), et n° 62 (1976).

CARTE HYDROLOGIQUE ET SPELEOLOGIQUE DU TAURUS OCCIDENTAL
(systèmes de Kembos, Eynif et Dumanli)

LEGENDE

1. Körük ini (perte et résurgence)
2. Değirmen ini (perte)
3. Sulu in (résurgence)
4. Balat ini (perte et résurgence)
5. Biçakçi ini (perte et résurgence)
6. Büyük düden (ponor)
7. Feyzullah düdeni (ponor)
8. Toprak Huni düdenler (pertes impénétrables)
9. Boyalibucak menbalari (sources temporaires)
10. Sobuca düdenleri (pertes impénétrables)
11. Yatirtaş düdeni (ponor)
12. Düdenönü (gouffre)
13. Kişmir düdeni 1 et 2 (gouffres)
14. Karabacak düdeni (gouffre)
15. Oruç düdeni (gouffre)
16. Dağ Başi düdeni (gouffre)
17. Köprüklü Su ou Beyaz Su (émergences)
18. Yedi Miyarlar I (émergences et grottes)
19. Düdensuyu (grotte-émergence temporaire)
20. Yedi Miyarlar II (émergences)
21. Akpínar (émergence temporaire)
22. Gürlevik oruğu (gouffre-perte)
23. Obruk düdeni (perte impénétrable)
24. Tomaklar düdeni (perte impénétrable)
25. Beyçayiri düdenleri (pertes impénétrables)
26. Kemik döklü (émergence)
27. Kelbakit alti (émergence)
28. Cula düdeni (gouffre)
29. Yukari Çayir düdeni (gouffre)
30. Erkibet düdeni (gouffre)
31. Türbe düdeni (gouffre)
32. Yongali düdenleri (pertes impénétrables)
33. Tepekli mağarasi (gouffre)
34. Sevinç Mòisi (émergence)
35. Yarpuzlu Su (émergence)
36. Tilkiler düdeni (grotte-émergence temporaire)
37. Yukaridağ düdeni (Düden 2) (grotte-perte)
38. Düden (Düden 1) (estavelle)
39. Oymapínar M1, M1 mağarasi (source et grotte)
40. Oymapínar M2-M3 (grottes de Cupidon et des Lauriers roses) (sources et grottes)
41. Oymapínar M7-M12
42. Oluk Köprü (émergence)

a. Değirmen mağarasi (grotte)
b. Değirmen düdeni (émergence et perte)
c. Düdencik (gouffre-perte temporaire)
d. Cat Dere mağarasi (grotte-perte temporaire)
e. Karapínar (émergence)
f. Handos mağarasi (émergence temporaire)
g. Gelif Içi (émergence impénétrable)
h. Kirk Göz mağarasi (grotte)
i. Çayirönü düdeni (ponor)
j. Cehennem oruğu (gouffre)
k. Kayaağil cukuru (effondrement)
l. Güvercin oruğu (gouffre)
m. Koyungöbedi mağarasi (gouffre-perte)
n. cavités de Cemerler (gouffres)
o. Kelebekli mağarasi (grotte)
p. Beşik Dağ mağarasi (grotte)
q. Dumanli mağarasi n° 2 (gouffre)
r. Dumanli mağarasi n° 1 (gouffre)
s. Dumanli (émergence)
t. Oymapínar M4 à M6

THE OGOF FFYNNON DDU CAVE SYSTEM, SOUTH WALES, IN RELATION TO THE STRUCTURE OF THE CARBONIFEROUS LIMESTONE

R.A.P. Charity
118 Bradfield Road
Urmston
Manchester M31 1PP

and

N.S.J. Christopher
22 Deva Close
Poynton
Cheshire

The longest cave system in Britain is Ogof Ffynnon Ddu, situated in the Carboniferous Limestone of the North Crop of the South Wales coalfield. The limestone outcrops on both banks of the Upper River Tawe valley, at altitudes of 300 - 580m above sea level.

The regional dip is to the south at about 15°, on the flank of a north easterly continuation of the Cribarth anticline, on the east bank the anticline is entirely within the Old Red Sandstone outcrop. In Ogof Ffynnon Ddu some 40 km of cave passages are known, trending generally southwest from the sink at Pwll Byfre to the resurgence close to the River Tawe. Previous studies have noted that many passages are related to joints parallel to the dip (Glennie 1948, 1950; Railton 1953; O'Reilly, O'Reilly & Fairbairn 1969). Weaver

(1973 and 1975) attempted to analyse the structural pattern of joints, faults and folding in relation to the cave. O'Reilly (1973) provided a general structural account including a map which formed the basis of the present study.

Observations of the attitude of the limestone bedding in the various quarries and other exposures around Penwyllt have shown that the limestone outcrop is traversed by a pattern of North-south folds, which plunge more or less down the dip, to the south. In the Twyn Disgwylfa and Cwm Dwr quarries these are accompanied by numerous small faults, some normal, others reversed. Though of small displacement they are frequently accompanied by crush or shear zones of brecciated or slickensided limestone. Geological mapping

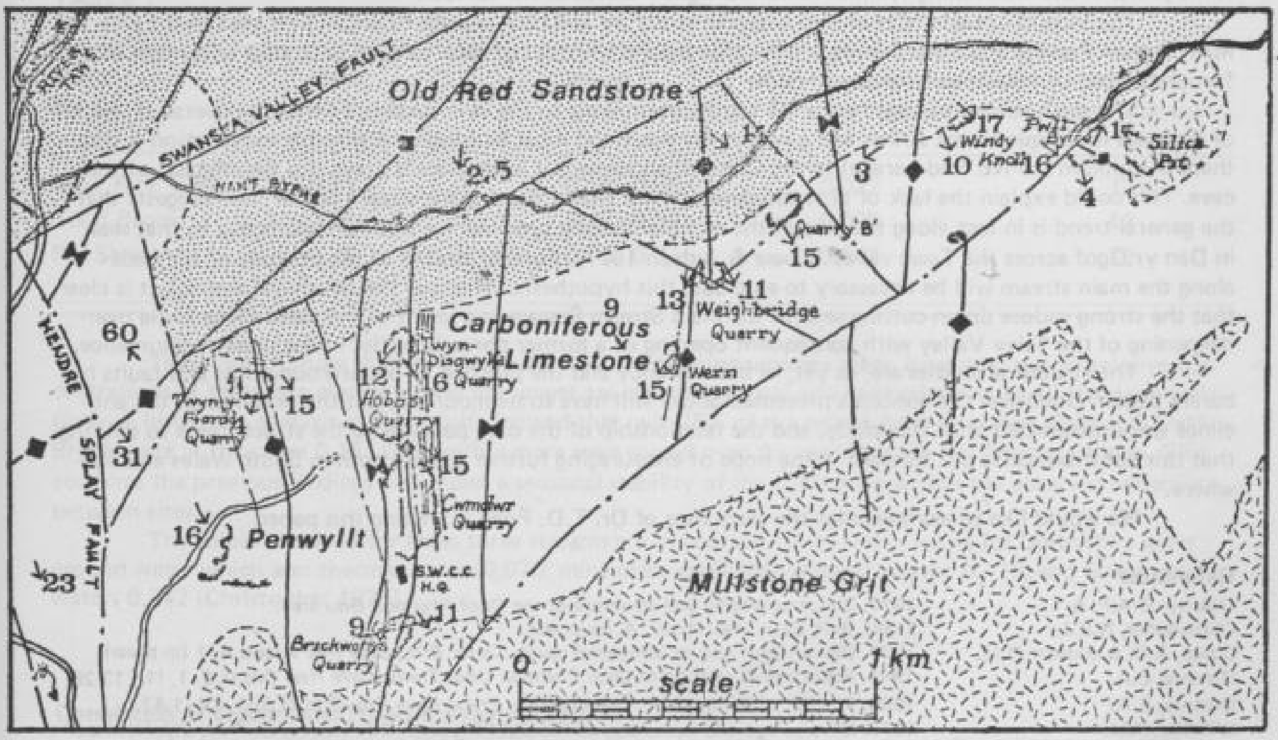


Figure 1: Solid geology and structure of the Penwyllt area (modified from O'Reilly, 1973 fig.2). For key, see figure 2 below.

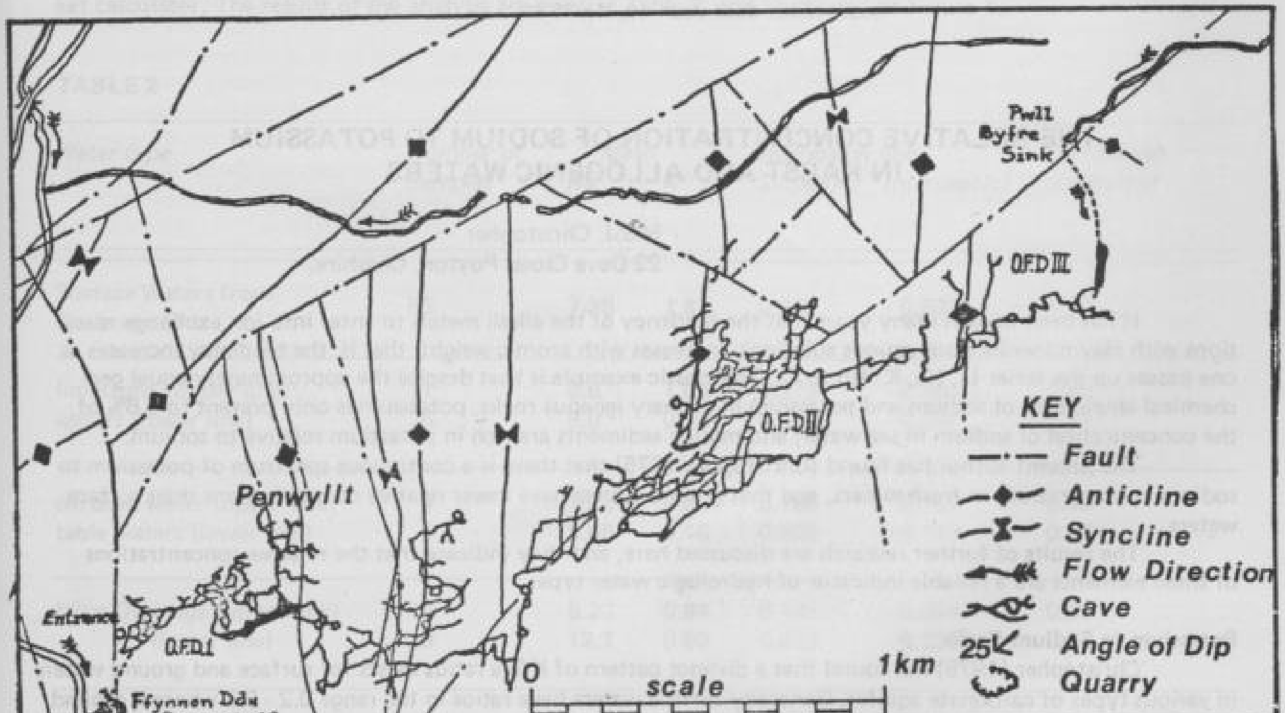


Figure 2: Alignment of passages in Ogof Ffynnon Ddu with anticlinal structures

has confirmed many of the previously recognised faults; in particular a strong fault trending S.W. from the sink at Pwll Byfre more or less along the main line of the cave south of Penwyllt (Figs 1 and 2). The detailed observations are being published elsewhere (Charity & Christopher 1977).

When the plan of Ogof Ffynnon Ddu (O'Reilly, O'Reilly and Fairbairn 1969) is superimposed on to the authors' structural map, a striking relationship between the density of passages and the main orientation to the structure is revealed. Passage density is greatest in the region of the crests of the plunging anticlines, and negligible in the synclines. The strong north-south orientation of these dense patterns of passages on anticlinal crests suggests that they were probably developed in joints opened there by tension normal to the fold trend, while joints in the intervening syclines remained tightly closed at the surface.

The second notable relationship between structure and cave passage orientation is seen in the way the Main Stream Passage and others swing southwards around the nose of each fold, so as to take advantage of a favourable bed of limestone or group of beds.

The main stream passage forms the southeastern limit to the cave system, so that the overall direction of drainage is oblique to the strike, and a reason for this trend must be sought. A possible explanation is that there is a hidden SW-NE fold parallel to the Cribarth anticline but immediately down dip (Southeast) of the cave. This could explain the lack of phreatic development below the present stream course, and suggests that the general trend is in fact along the axis of the complementary syncline – a position analogous to that seen in Dan yr Ogof across the Tawe valley (Coase & Judson 1977). Further studies of the attitude of the beds along the main stream will be necessary to elucidate this hypothesis. Whatever the structural control, it is clear that the strong vadose down-cutting seen in the Main Stream Passage is a result of the rapid Pleistocene over-deepening of the Tawe Valley with consequent opening of a former phreatic outlet in the present resurgence.

The structural studies are, as yet, in their infancy and the plotting of underground dips and faults has barely begun. Doubtless the concepts presented above will have to be modified, but the presence of the anticlines was unsuspected until this study, and the relationship of the cave passages to the structures is so striking that this contribution is put forward in the hope of encouraging further studies both in South Wales and elsewhere.

We would like to acknowledge the assistance of Dr. T.D. Ford in writing this paper.

References

Charity, R.A.P. & Christopher, N.S.J. 1977. The stratigraphy and structure of the Ogof Ffynnon Ddu area. *Trans. Brit. Cave. Res. Assoc.* 4. (in press).

Coase, A.C. & Judson, D.M. 1977. Dan yr Ogof and its associated caves. *Trans. Brit. Cave Res. Assoc.* 4, 1 (in press).

Glennie, E.A. 1948. Some points relating to Ogof Ffynnon Ddu. *Trans. Cave Res. Grp G.B.* 1, (1), 13-25.

Glennie, E.A. 1950. Further notes on Ogof Ffynnon Ddu. *Trans. Cave Res. Grp. G.B.* 1, (3), 1-47.

O'Reilly, P.M. 1973. Morphology and hydrology of the Ogof Ffynnon Ddu karst area. *Proc. 6th Internat. Speleol. Cong.* Olomouc, Czecho. (reprinted in South Wales Caving Club Newsl. 1973).

O'Reilly, P.M., O'Reilly, S.E., & Fairbairn, C.M. 1969. *Ogof Ffynnon Ddu.* South Wales Caving Club publn. Penwyllt.

Railton, C.L. 1953. The Ogof Ffynnon Ddu system. *Cave Res. Grp. G.B.* Publn. No. 6.

Weaver, J.D. 1973. The relationship between jointing and cave passage frequency at the head of the Tawe Valley, South Wales. *Trans. Cave Res. Grip. G.B.* 15 (3), 169-173.

Weaver, J.D. 1975. The structure of the Swansea Valley disturbance between Clydach and Hay-on-Wye, South Wales. *Geol. Jour.* 10, (1), 75-86.

THE RELATIVE CONCENTRATION OF SODIUM TO POTASSIUM IN KARST AND ALLOGENIC WATERS

N.S.J. Christopher
22 Deva Close, Poyton, Cheshire.

It has been known many years that the tendency of the alkali metals to enter into ion exchange reactions with clay minerals from aquous solutions, increases with atomic weight, that is, the tendency increases as one passes up the series Li, Na, K, Rb to Cs. The classic example is that despite the approximately equal geochemical abundance of sodium and potassium in primary igneous rocks, potassium is only present to 3.6% of the concentration of sodium in sea water, and marine sediments are rich in potassium relative to sodium.

The present author has found (Christopher 1975) that there is a continuous spectrum of potassium to sodium concentrations in fresh waters, and that ground waters have lower relative concentrations than surface waters.

The results of further research are discussed here, and they indicate that the relative concentrations of these elements are a reliable indicator of hydrologic water type.

Potassium to Sodium Ratio

Christopher (1975) has found that a distinct pattern of K/Na ratios exists for surface and ground waters in various types of carbonate aquifer. Generally surface waters have ratios in the range 0.2 - 0.3 whereas ground waters are in the range 0.05 - 0.25 although higher ratios have been recorded for both water classes. A recognisable bimodel distribution also exists for ground waters with the majority having ratios in the range 0.05 - 0.1 or 0.2 - 0.35; the latter range is similar to surface waters.

This distribution is what would be expected for resurgences discharging slow percolation water or conduit water with a high proportion of allogenic water, respectively.

To evaluate the seasonal variability of the K/Na ratio for surface waters, three small streams draining Upper Carboniferous shales and sandstones were sampled regularly over a year. (These rocks are similar to those which form the catchments for the allogenic recharge streams of the Derbyshire karst).

The mean, range, and standard deviation values of the ratios are given in Table 1, excluding values during flood events, which will be discussed later.

TABLE 1

Table 1 Stream	Mean K/Na	Range	St. Deviation	No. of Analyses
West Park Gate	0.21	0.18 - 0.38	0.022	17¾
Todd Brook	0.21	0.12 - 0.38	0.030	13
Pot Shrigley	0.25	0.18 - 0.37	0.043	20

These results show that three separate streams, draining separate areas, have very similar relative concentrations of these two elements, and the ranges are almost identical and have relatively small standard deviations. A histogram analysis of the results showed that over 75% of the results from West Park Gate and Todd Brook were in the range 0.15 - 0.25 with a more even spread over the range for the Pot Shrigley stream. This confirms the previous findings and shows a seasonal stability of the K/Na ratio within the observed variability between sites.

The values observed for these three streams are in contrast to the mean values for Derbyshire karst ground water which are: thermal waters 0.070; mine drainage 0.090; perched waters' 0.178; and limestone waters 0.242 (Christopher 1975).

Correlation of Sodium and Potassium Concentrations

The trend recognised on the basis of average data described above suggests that a linear relationship between sodium and potassium concentration should exist, and so a mathematical analysis of available data was performed, the data available being the author's and that of Edmunds (1971).

The data was grouped into broad hydrologic groups, the groups being those of Edmunds namely: thermal, mine drainage, perched waters, limestone waters, and surface streams off shale and grit.

The data was then processed using standard regression analysis, with the aid of a preprogrammed pocket calculator. The results of the analysis are given in Table 2, and illustrated in Figure 1.

TABLE 2

Water type	*Number of Samples*	*Mean Na*	*Mean K*	*Regression line Slope (m)*	*Regression line intercept (c)*	*Correlation coefficient r*
Surface Waters from Shale and Grit	55	7.38	1.87	0.367	- 0.832	0.73
limestone (upper line) waters	31	6.6	1.06	0.379	- 0.654	0.85
limestone waters (lower line)	26	8.0	0.74	0.089	- 0.030	0.77
perched water (upper line)	4	15.3	4.9	0.166	0.167	0.96
table waters (lower line)	8	8.06	0.48	0.038	0.172	0.95
Mine Drainage (upper line)	16	6.22	0.84	0.151	- 0.094	0.90
Mine Drainage (lower line)	10	12.7	0.69	0.073	- 0.236	0.93
Thermals	8	18.6	1.40	0.070	0.101	0.71

All lines defined by $K = mNa - c$

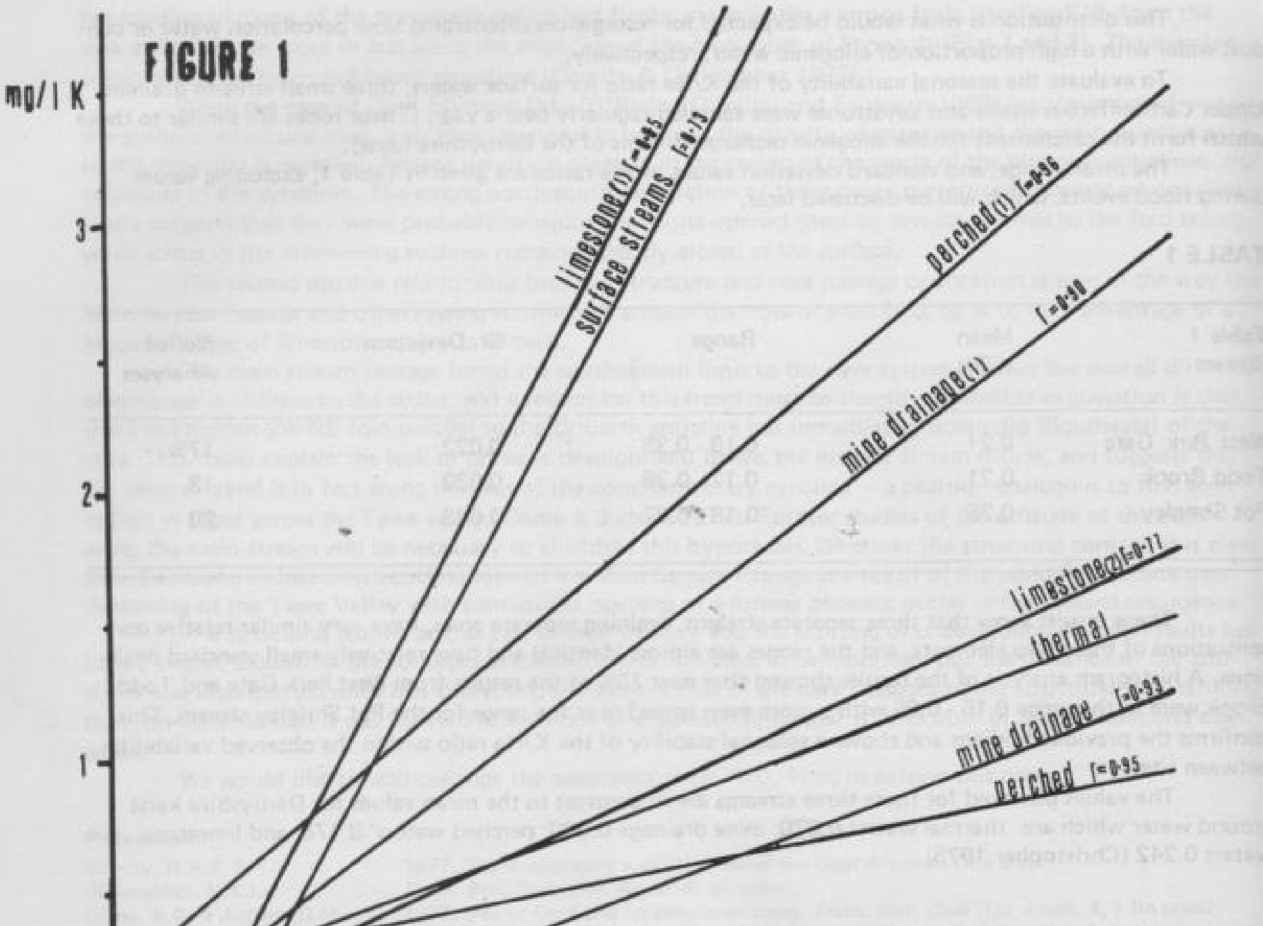


Fig. 1. Correlation of sodium and potassium concentrations in five karst water

This analysis has produced correlation lines with acceptable correlation coefficients for all water type that fit into a single uniform picture.

Figure 1 shows that mine drainage waters, limestone waters, and perched water-table waters have two lines. The upper line of the limestone waters is very similar in slope to that of the surface streams, indicating that these resurgences discharge conduit water with a rapid flow-through time. The lower limestone water line falls into a bracket with the lower lines for mine drainage, perched water-table waters and thermal waters. It would appear that this group of lines characterised the slow percolation water of Derbyshire. The intermediate lines (the upper mine drainage and perched water-table waters lines), appear to indicate that these waters have a significantly longer flow-through time than the limestone waters of the upper line, and possibly represent rapid percolation waters.

The original information for these graphs was compiled from a variety of data, mainly single samples from numerous resurgences, but also a lesser number of repeat samples from one resurgence at different stages of flow.

From these data points a number of examples arise which show the kind of movement of potassium relative to sodium that is to be expected from Figure 1 if, at low flow, the resurgence is discharging percolatic water and, in the case of conduit systems, discharges allogenic or rapid percolation water at high flow.

TABLE 3

Resurgence	*Flow Stage*	*Hydrolologic Type*	*Sodium mg/1*	*Potassium mg/1*
Wormhill Springs	Low	Conduit	13.4	1.78
	High		15.2	3.2
Well Head	Low	Conduit	4.5	0.45
	Medium		5.1	1.2
Ilam Well	Low	Diffuse	8.7	1.0
	Medium		8.4	1.25

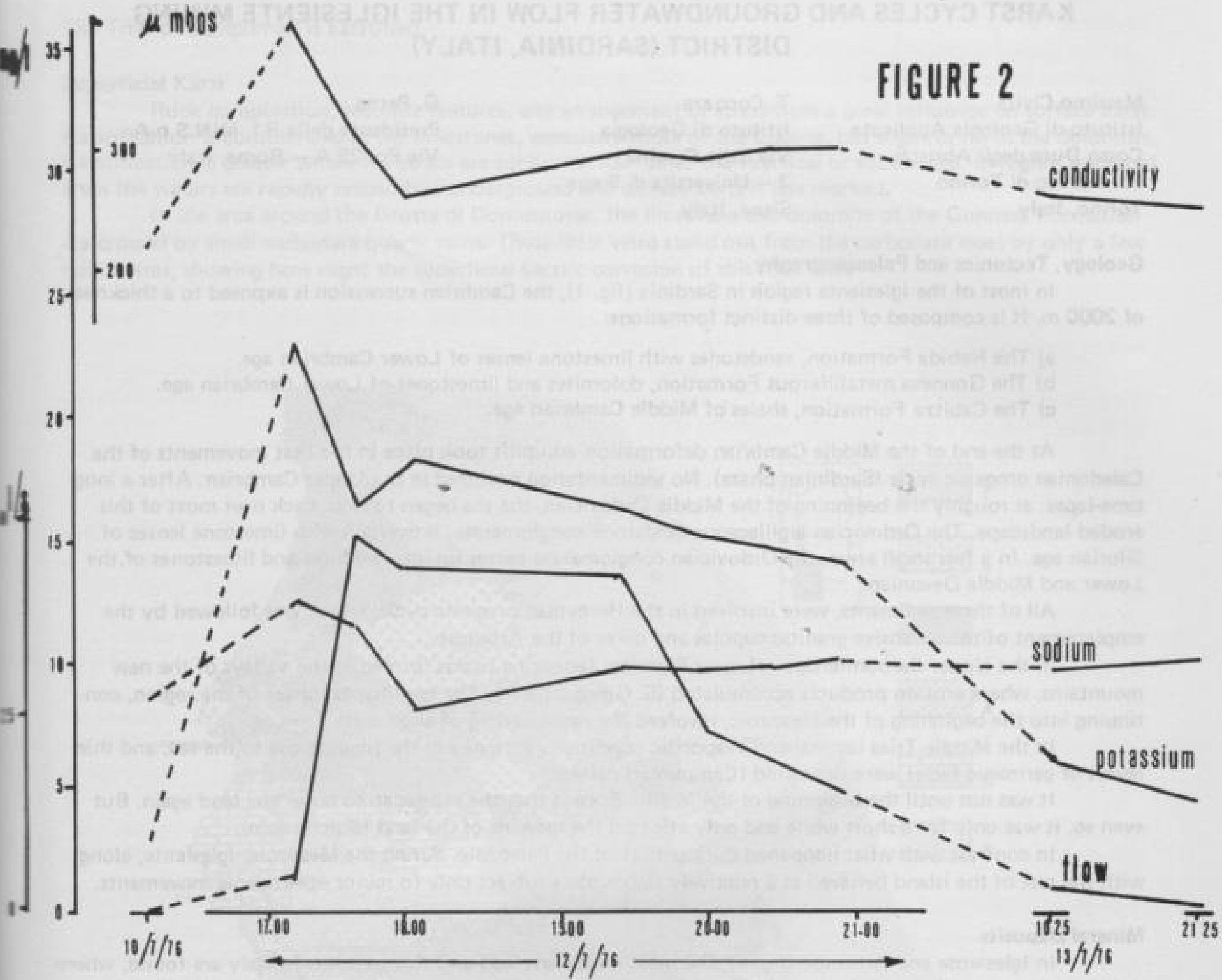


Fig. 2. Variation of conductivity, Na and K concentrations during a flood event.

These support the classification of these resurgences based on observations of the turbidity change with increasing flow, and other subjective evidence.

The Variation in Sodium and Potassium Concentration of Allogenic Water During a Flood Event

From the study of a surface stream results were obtained during an intense summer storm, when 50mm of rain fell within an hour, and the flow of the stream being studied increased almost 200-fold from 0.25 l/s. to 48 l/s. in 1¼ hrs. and returned to 0.32 l/s. in 19 hrs.

A comprehensive analysis of the samples was made, but only the potassium and sodium results will be considered here. These are illustrated in figure 2, which shows that a 50% increase in the sodium concentration occurs as the flood wave passes, from 8.6 mg/l to 12.5 mg/l, declining to 9.8 mg/l after 19 hrs. The potassium concentrations are, however, a complete contrast. A low flow value of 2.7 mg/l increases to 22.5 mg/l and declines proportionately more rapidly to 6.1 mg/l after 19 hrs. It is also important to note that the peak values of total dissolved solids, sodium, potassium etc. slightly precede the peak flow, so the initial effect of precipitation is far from simple dilution, and a complex response to precipitation is shown by even a simple stream.

The effect of these changes on the K/Na ratio is spectacular; the ratio increases from 0.31 to a maximum of 2.23 (close to the observed K/Na ratio found in shales) and declines to 0.71 in 19 hrs.

Conclusions

This study is part of a longer term study of the hydrogeochemistry of the Derbyshire karst waters, in an attempt to use chemical parameters as indicators of speleological potential in resurgence systems. The results reported here show that the K/Na ratio and relative concentration of the two elements are useful and potentially accurate indicators.

References

Edmunds, W.M. 1971. The Hydrogeochemistry of the Derbyshire Dome, with Special Reference to Trace Elements. *Ins. Geol. Sci. Rept.*, 71/7.

Christopher, N.S.J. 1975. The use of saturation index and potassium to sodium ratio as indicators of speleological potential, with special reference to Derbyshire. *Trans. Brit. Cave Res. Assoc.* Vol. 2 No. 1, pp. 29-34.

KARST CYCLES AND GROUNDWATER FLOW IN THE IGLESIENTE MINING DISTRICT (SARDINIA, ITALY)

Massimo Civita
Istituto di Geologia Applicata
Corso Duca degli Abruzzi
Politecnico di Torino
Torino, Italy

T. Cocozza
Istituto di Geologia
Via delle Cerchia
3 – Universita di Siena
Siena, Italy

G. Perna
Presidente della R1. MIN S.p.A.
Via Po, 25 A – Roma, Italy

Geology, Tectonics and Paleogeography

In most of the Iglesiente region in Sardinia (fig. 1), the Cambrian succession is exposed to a thickness of 2000 m. It is composed of three distinct formations:

a) The Nebida Formation, sandstones with limestone lenses of Lower Cambrian age.
b) The Gonnesa metalliferous Formation, dolomites and limestones of Lower Cambrian age.
c) The Cabitza Formation, shales of Middle Cambrian age.

At the end of the Middle Cambrian deformation an uplift took place in the first movements of the Caledonian orogenic cycle (Sardinian phase). No sedimentation occurred in the Upper Cambrian. After a long time-lapse, at roughly the beginning of the Middle Ordovician, the sea began to flow back over most of this eroded landscape. The Ordovician argillaceous sandstone conglomerate, is overlain with limestone lenses of Silurian age. In a few small areas, the Ordovician conglomerate passes up into argillites and limestones of the Lower and Middle Devonian.

All of these sediments, were involved in the Hercynian orogenic cycle, which was followed by the emplacement of the extensive granitic cupolas and dikes of the Arburese.

In the Upper Carboniferous – Lower Permian, lacustrine basins formed in the valleys of the new mountains, where erosion products accumulated (S. Giorgio basin). The continental phase of the region, continuing into the beginning of the Mesozoic, involved the peneplaining of large areas.

In the Middle Trias lagunal and evaporitic conditions obtained in the plains close to the sea, and thin layers of germanic facies were deposited (Campumari plateau).

It was not until the beginning of the Middle Eocene that the sea began to cover the land again. But even so, it was only for a short while and only affected the margins of the land (Sulcis basin).

In contrast with what happened during most of the Paleozoic, during the Mesozoic, Iglesiente, along with the rest of the island behaved as a relatively stable plate subject only to minor epeirogenic movements.

Mineral Deposits

In Iglesiente and Arburese (fig. 1), the most important lead and zinc deposits in Italy are found, where the Hercynian granitic batholith in Arburese is intersected by the hydrothermal dykes of Montevecchio and Ingurtosu which are rich in mineral deposits. The ore deposits of the Cambrian carbonate sequence of Iglesiente vary greatly in mineral assemblage and arrangement. Sphalerite and galena abound, the latter sometimes in silver-rich deposits, and there are smaller deposits of Smithsonite and barite. The mode of occurrence is in conformable lens-shaped bodies, in veins, in disseminated irregular bodies, and in karst cavities.

The great complexity of these orebodies has always made it difficult to understand their origins: In the past they were thought to be genetically related to the Hercynian granitic batholith of Arbus and considered hydrothermal. However, nowadays the opinion obtains that after a sedimentary origin, they were reworked during the various phases of emergence affecting the limestone and dolomites. This reworking involved the formation of karst features in which metalliferous minerals, transported by surface waters, both as ions and debris, were later deposited. Lastly, a remobilization of the minerals by low-temperature hydrothermal solutions led to the formation of unconformable veins.

Karstic cycles

During its long geological history, Iglesiente was involved in various karstic cycles, brought to light both by geological studies of the surface and by mining activities.

1st Cycle (Caledonian) corresponds to a period of local emersion that took place between the deposition of the "metalliferous" limestone and that of the Cabitza shale.

During the deposition of the nodules in some places (e.g. in the new +8 drainage tunnel at Monteponi mine), an emergence occurred with the formation of small cavities and breccia.

2nd Cycle (Caledonian) is related to the movements of the Sardinian tectonic phase preceding the Ordovician transgression. It is characterized by cavities of various sizes that are almost always filled by supergene sulphides and barite deposits (Barega Mine) and fossilized by "quarzites" (Arenas Mine).

3rd Cycle (Hercyno-Alpine) corresponds to the peneplanation of the Hercynian (Sa Bagattu Mine) in the Permo-Triassic. It continues during the Middle Trias (Muschelkalk) with the karstic cavities filled to a greater or lesser extent by alternating barite and silica deposits with sulphides. The secondary dolomitization of the limestone zones covered by shallow seas led to the formation of "yellow dolomite".

4th Cycle (Pre-Eocene): Crevasses opened and were then filled by conglomerates, coarse-grained sand and Eocene "coal" ("Mohen state" at the -100 level of Monteponi mine).

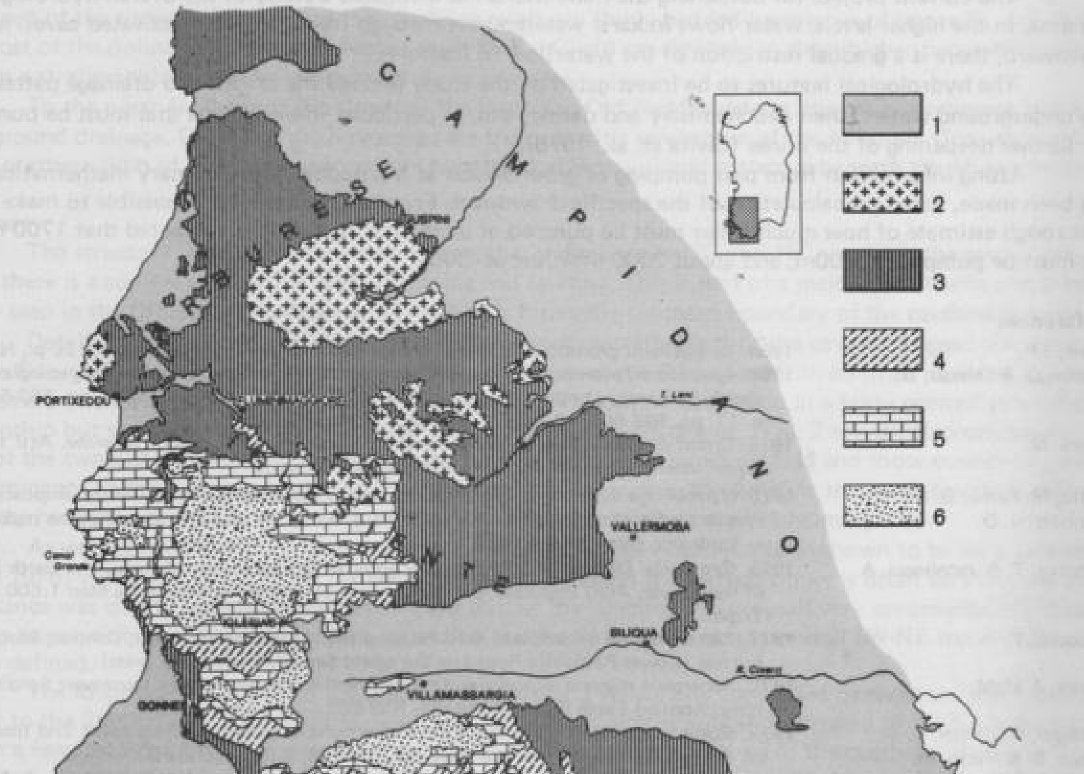
5th Cycle (Present-day) Reactivation of the old karst features of the preceding cycle. Karstification is most marked at the upper levels and at sea level (Gran Sargente), and seems to diminish gradually downward.

The Trias of Campumari is karstified.

Superficial Karst

Rock composition, tectonic features, and arrangement of strata have a great influence on surface karst. Karstification is considerable in the limestones, especially those of the Eocene, but slight or nil in the dolomites. Karstification is greater where the strata are subhorizontal rather than vertical or subvertical. In highly fractured areas the waters are rapidly reabsorbed underground and surface karst is less marked.

In the area around the Grotta di Domusnovas, the limestone and dolomite of the Gonnesa Formation are crossed by small carbonate quartz veins. These little veins stand out from the carbonate mass by only a few millimetres, showing how slight the superficial karstic corrosion of this rock was.



Geological map of the Paleozoic rocks of the Iglesiente and Sulcis regions of Sardinia. 1) post- Cambrian sediments and volcanics; 2) granite cupolas; 3) post-Devonian; 4-5-6 Cambrian: 4) Cabitza Formation; 5) Gonnesa (metalliferous) formation; 6) Nebida Formation.

Groundwater Flow

By the 19th Century mining activities reached the water-table, which was then 70 m a.s.l.

In order to lower the water table, in 1882 the excavation of a drainage tunnel at sea level was begun, starting from the impermeable Paleozoic shale and running towards Monteponi mine. When the tunnel reached the phreatic water of the Cambrian carbonatic sequence a moderate flow of water ensued, and when it intersected the "Gran Sorgente" karst shaft, the water flow increased to 3.6 cubic meters/sec. After five months the water flow decreased to 1.4 cubic meters/sec and the water table had been lowered in the entire metalliferous area.

Subsequently the water level was further lowered by the installation of pumps below sea level: -15m in 1927, – 60m in 1935 and -100m in 1955.

The underground waters have always shown some salinity, slight in the case of the water drained by the tunnel, and greater as it was pumped from the depths, up to the present amount, which is about 40% of that of sea water.

The current project for deepening the mine shafts has instigated a study of the overall hydrology of the area. In the higher levels, water flows in karst watercourses through fractures and reactivated caves. Moving downward, there is a gradual restriction of the waterflow to fractures.

The hydrological features to be investigated by the study include the origins and drainage pattern of the underground waters, their geochemistry and dating, and, in particular, the amounts that must be pumped for further deepening of the mines (Civita et. al., 1976).

Using information from past pumping of groundwater at Monteponi, a preliminary mathematical model has been made, based on calculation of the specific drawdown. From such a model it is possible to make a first rough estimate of how much water must be pumped at increasing depths. It is estimated that 1700 litres/sec must be pumped at -200m, and about 2000 litres/sec at -300m.

References

Benz, J.P. 1964. Le gisement plombo-zincifère d'Arenas (Sardaigne). Thèse Doct. Ing. 126 p., Nancy.

Brusca, C. & Dessau, G. 1968. *I giacimenti piombo-zinciferi di S. Giovanni (Iglesias) nel quadro della geologia del Cambrico sardo,* L'industria Mineraria, a. XIX, n. 9, pp. 470-494; n. 10, pp. 553-556; n. 11, pp. 597-609, 19 figs., 1 carta geol. 1:10.000, Roma.

Civita, M. 1975. *Criteri di valutazione della risorse idriche sotterranee in regione carsiche.* Atti 111° Conv. Intern. Acque sotterranee, Palermo (in stampa).

Civita, M. Perna, G. & Tamburrini, D. 1976. *Il problema delle acque profonde nel bacino metallifero dell'Iglesiente: impostazione di uno studio idrogeologico a fini multipli.* 1° Conv. Minerario e Metallurgico Italo-Societico in Sardegna, preprint, Cagliari.

Cocozza, T. & Jacobacci, A. 1975. *Geological Outline of Sardinia. Coy Squyres* (ed): Geology of Italy. The Earth Sc. Soc. of the Libyan Arab Republic, pp. 49-81, with Stratigraphic-Structural Map 1:500.000, Tripoli.

Cocozza, T. 1977. *The Cambrian of Sardinia,* C.H. Holland (ed.): Cambrian of West, Central, East and South Europe (Lower Paleozoic Rocks of the world Series). Elsevier (in press).

Moore, J. McM. 1972. Supergene mineral deposits and physiographic development in southwest Sardinia, Italy. Applied Earth Science, Vol. 81, B59-B66.

Padalino, G., Pretti, S. Tocco, S. & Violo, M. 1972. *Some examples of lead-sinc-barite depositions in karstic environments.* 2nd Inter. Symp. on the Mineral Deposits of the Alps, pp. 195-205, 9 figs, Ljubljana.

Padalino G., Pretti, S. Tocco, S. & Violo, M. 1972. *Carsismo e mineralizzazioni.* Rend. Soc. It. Min. e Petre., Vol. XXVIII, pp. 215-230, 7 figs., Pavia.

Perna, G. 1973. *Fenomeni carsici e giacimenti minerari.* Le Grotte d'Italia, ser. 4, vol. IV, pp. 77-158, figs. 29, tavv. 2, Bologna.

Perna, G. 1973. *Giacimenti minerari carsici.* Proceed. 6th Inter. Congr. of Speleology, vol. II, pp. 535-543, figs. 1, Olomuc.

Tamburrini, D. Zuffardi, P. 1967. *Ulteriori sviluppi delle conoscenze e delle ipotesi sulla metallogenesi sarda.* Giornata di Studi Geominerari, 7 ottobre, pp. 3-22, 22 figs. Agordo.

Vardabasso, S. 1975. *Sardegna speleologica,* Rass. Speleologica It., a. VII (3), pp. 119-136, 20 figs. 1 carta geol. Sardegna, Como.

THE STRUCTURE AND EVOLUTION OF THE DAN YR OGOF CAVES, SOUTH WALES

Alan C. Coase
Thornbridge Hall, Great Longstone,
Bakewell, Derbyshire, U.K.

This paper is concerned with two aspects of the caves' geomorphology: their relationship with their structural environment and, more tentatively, their evolutionary chronology.

The caves in question are located on the western side of the Tawe Valley in South Wales and consist of two large caves, Dan yr Ogof itself and Tunnel Cave, as well as numerous smaller ones. The two principal ones have been surveyed to approximately 15 and 2 kilometres respectively and both have been commercialised in their more accessible sections. (Tunnel Cave is now known as Cathedral Cave).

Exploration commenced in 1912, was resumed very successfully between 1937 and 1939 and further major discoveries were made between 1966 and 1970. The latter discoveries inspired intensive studies and detailed surveys which have recently been published by the British Cave Research Association (Coase and Judson, 1977).

Location

The caves covered in these studies are all related to Dan yr Ogof catchment area which is located in the Carboniferous Limestone of the Northern Crop of the South Wales Coalfield. Figure 1 places the caves within their hydrological and structural framework. Apart from the principal caves which are closely associated, though not now physically connected, other important sites are at Sink y Giedd, Waen Fignen Felen, and Pwll Dwfn. These have all been proved to connect with the Dan yr Ogof resurgence, the first named being the principal input stream. The second, which is fed from a large peat bog, provides a considerable input at times of heavy rainfall but otherwise Tunnel Cave only contains a small mis-fit stream. The evolution and chronology of these contributor systems is considered in more detail below.

Stratigraphic relationships

The greater part of the Dan yr Ogof passages are situated in the lower part of the Main Limestone of S_2 age, 106 m thick, though marker beds are few and correlation is rarely possible for more than a few tens of metres. Some of the avens penetrate upwards as far as the overlying Honeycomb Sandstone of lower D_1 age. Much of the surface outcrop is of the overlying relatively thinly bedded limestones of upper D_1 and D_2 age. Most of the dolines and the main swallet cave, Sink y Giedd are similarly in these higher beds which seem to form a stratigraphic barrier to exploration if not to water.

To the north lie the long dip-slopes of the Devonian Old Red Sandstone, the main catchment area for underground drainage. Overlying the limestones are the quartzitic sandstones of the Millstone Grit, and part of the northern limb of the greater part of the hypothetical Sink y Giedd system is beneath the Millstone Grit.

Structure

The structure is generally simple with a southerly dip between 5° and 15° except in the south east, where there is a complex, if narrow, belt of folding and faulting. This is part of a major disturbance and is most clearly seen in the Cribarth ridge (Weaver 1972) which forms the southern boundary of the catchment area.

Detailed underground analysis reveals that the south easterly parts of the cave are aligned along the shallow Dan yr Ogof syncline which is sub-parallel to the line of the Disturbance. In contrast much of the cave passages are orientated in a markedly north-south pattern. These have developed in a fairly normal down-dip relationship but they are also strongly related to joint and fault orientations. (Fig. 2 and 3). Recognition is given of the two distinct geomorphological units (passages within the synclinal fold and those outside it), and the dominance of this primary fracturing is very apparent. Even within the syncline the north-south passages are in the majority whereas in the principal 'input limbs' the dominance is overwhelming.

As well as folding and jointing, faulting within Dan yr Ogof itself has been shown to be very extensive (Coase 1975) with over 100 separate instances recorded. Although the vertical throw is often very limited their importance was clearly revealed when plotting the axis of the syncline. This reveals very considerable fluctuations in orientation, due largely to offsets caused by tear-faulting, although the overall SW-NE trend is generally clearly defined.

The longitudinal profiles of the main input limbs and synclinally controlled passages are also closely related to the lithology of the limestone. Speleogenesis appears almost entirely restricted to the S_2 beds and only in a few instances has any evidence of cavernous development been found in the overlying D_1 zone. One other important exception does exist for the known passages in Sink y Giedd are limited to the D_2 horizons. Access through the underlying D_1 beds is one of the major exploratory objectives outstanding for this should permit entry to the S_2 limestone, and the "missing" Giedd passages.

Close examination of the profiles shows that the relationship within the S_2 zone of passages to lithology is comparatively limited. The dominant characteristic is a remarkably even passage gradient which appears to be much more closely related to hydrological factors, instead of to specific beds.

Evolution and Chronology of the Cave System

As relatively little work has been done on the surface denudation chronology of the area only a speculative outline speleogenetic sequence can be proposed. Nonetheless, there is a series of stages recognisable in the development of the caves (or, perhaps more accurately, in the termination of the development) and these have been tentatively related to possible stages in the downcutting of the Tawe and its tributary the Haffes.

The basic assumption made is to accept Brown's view (1960) that the Tawe was initiated into its present course during one of the earliest interglacials of the Pleistocene. At this time the Haffes is thought to have been a very minor stream and the general pattern to have been a simple one of a series of subparallel consequent streams flowing roughly southwards (Fig. 2a).

These streams probably entered the limestone at an early point for their aggressive waters would soon have initiated cave development. As this proceeded it would have been accompanied by the input of considerable quantities of coarse debris with a fairly high incidence of corrosion. The probable pattern, and its relation to ice advance and retreats, interstadials and periglacial conditions, is best seen from Fig. 3.

As underground development advanced so too did the downcutting of the Tawe and the Haffes. The latter appears to have been accompanied by quite rapid headward erosion and river capture. Ultimately this capture led to the beheading of several of the principal input streams and limbs, such as the Tunnel Cave network and these were very rapidly abandoned. The present pattern reveals that this process has been almost completed, indeed the watershed between the Haffes and the Cig/Giedd is now a very low one. Backcutting is continuing with a marked nick point at Sgwd Ddu and a less well defined one higher to the west.

The largely unknown Giedd limb is likely to prove of great interest to both explorers and scientists in

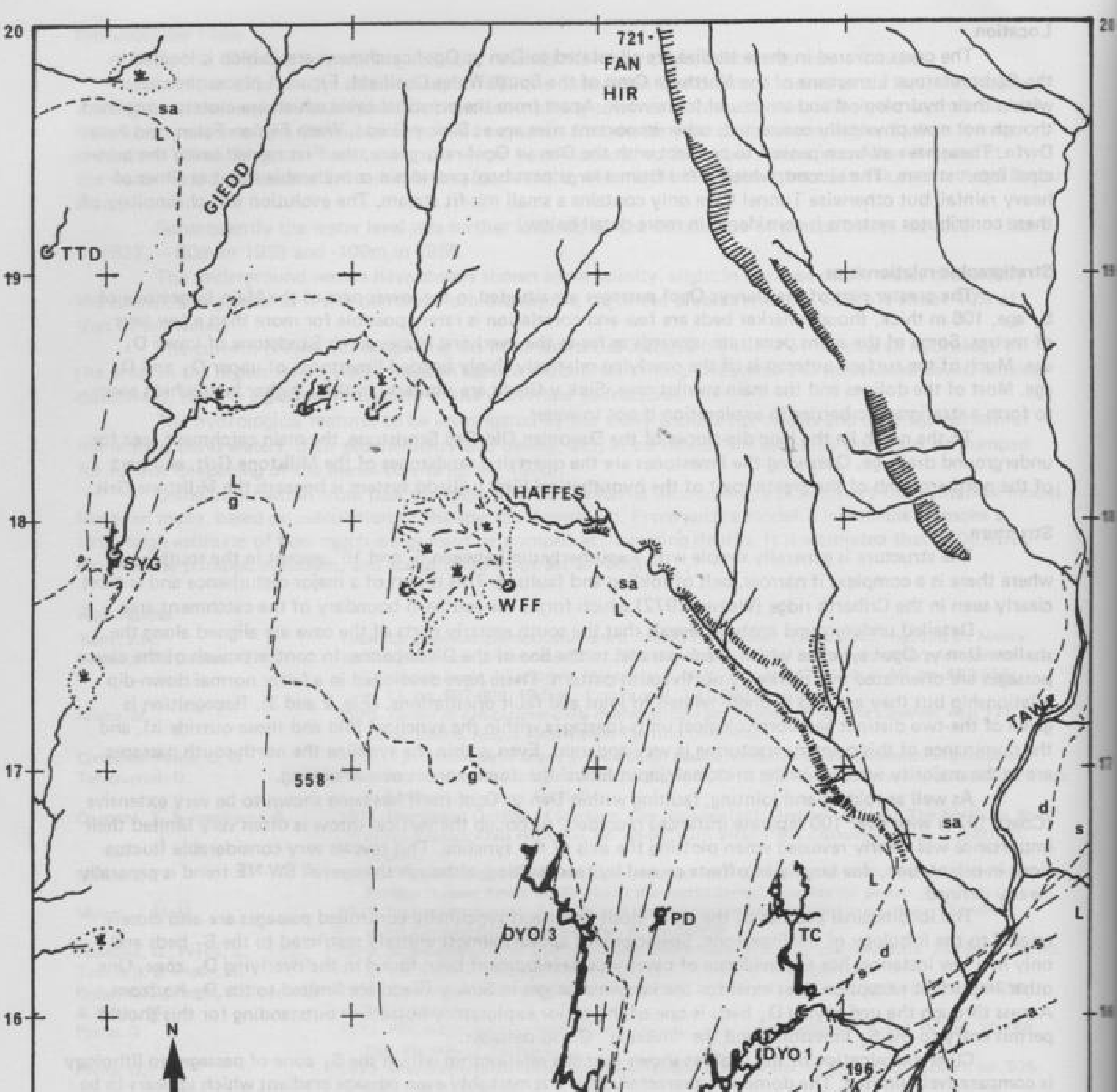


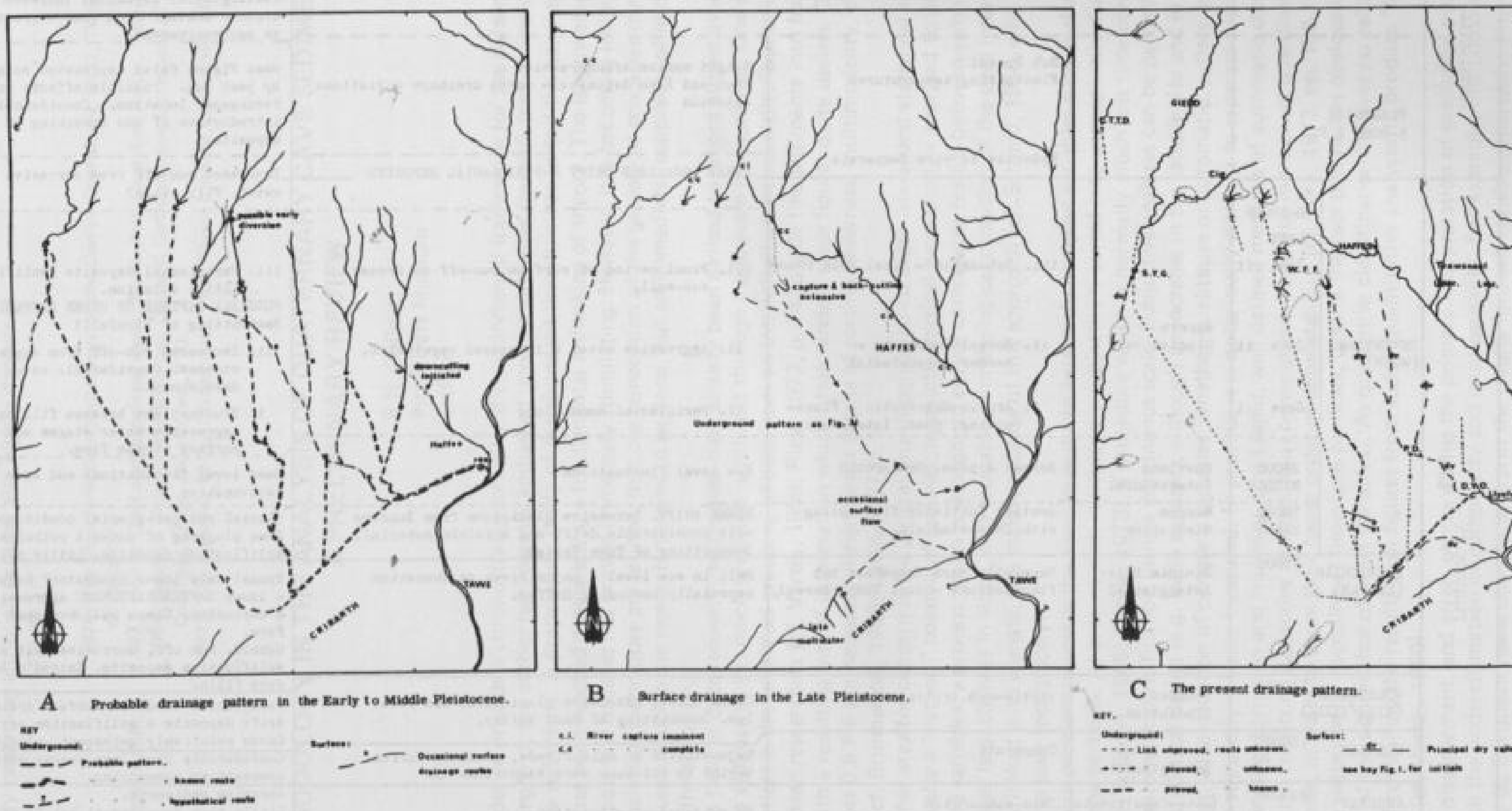
FIG.1 CAVES, DRAINAGE AND GEOLOGY IN THE DAN YR OGOF CATCHMENT AREA.

DYO – DAN YR OGOF
TC – TUNNEL CAVE
PD – PWLL DWFN
WFF – WAEN FIGNEN FELEN
SYG – SINK Y GIEDD
TTD – TWYN TAL DRAENEN

GEOLOGICAL BOUNDARY
FAULT
FOLD: anticline (---a---), syncline (---s---)
PEAT BOG
721· SPOT HEIGHT (metres)

L – LIMESTONE
sa – SANDSTONE
g – GRIT
sh – SHALES
d – DELTAIC & OTHER DEPOSITS

Fig. 2. Suggested stages in the evolution of the caves and the surface drainage pattern.



A Probable drainage pattern in the Early to Middle Pleistocene.

B Surface drainage in the Late Pleistocene.

C The present drainage pattern.

Fig. 3. Tentative correlations between the development of the cave system and Middle to Late Pleistocene stages.

PERIOD	STAGE Period in years before present		LOCAL NAME OR CHARACTER	CLIMATIC CONDITIONS	MAIN DEVELOPMENTS IN AREA	POSSIBLE EFFECTS ON CAVE DEVELOPMENT
POSTGLACIAL	PRESENT			Fluctuating but broadly Cool Temperate and wet	Continued downcutting. Peat deposits eroding.	Mainly misfit streams reworking fluvioglacial deposits. Increased organic content from peat - growth in aggressiveness.
	FLANDRIAN 5–8000 B.P.			Sub Boreal : Fluctuating temparatures	Slight marine transgression Peat and lake deposits - poss. drainage deviations Alluvium	Waen Fignen Felen depression 'occupied' by peat bog. Possible effects on resurgence location. Considerable introduction of and reworking of deposits.
				Moderate to Warm Temperate	FINAL LOCALISED DRIFT & PERIGLACIAL DEPOSITS	Increased run-off from corrasive melt water. Fill stage?
PLEISTOCENE Late	DEVENSIAN (WURM)	10–12000 LATE Zone iii		iii. Sub-Arctic → Final Cold Phase	iii. Final period of surface run-off on frozen sub-soil.	iii. Periglacial deposits (solifluction) Little solution. POSSIBLE CAPTURE OF UPPER HAFFES? Backcutting of Llynfell?
		Zone ii	Corrie Glaciations	ii. Boreal-Temperate → Warmer Interstadial	ii. Aggressive water - increased vegetation.	ii. Increased run-off from aggressive streams. Considerable cave development.
		Zone i		i. Arctic-Sub-Arctic → Fluctuating, poss. Interstadial	i. Periglacial conditions	i. Fluctuations between fill and aggressive water stages and surface stream flow.
		26000 MIDDLE	Paviland Interstadial	Boreal → poss. Sub.Arctic	Sea level fluctuations	Base level fluctuations and some rejuvenation
		50000 EARLY	Margam Glaciation	Arctic: Initially fluctuating with Interstadials.	NEWER DRIFT. Extensive glaciation from Beacons with considerable drift and morainic material. Downcutting of Tawe Valley.	Glacial and peri-glacial conditions, Some plugging of caves & potholes & solifluction deposits. Little solution.
	IPSWICHIAN (EEMIAN)	75000	Minchin Hole Interglacial	Generally Warm Temperate but fluctuations - Cool Temp.-Boreal	Fall in sea level - major river rejuvenation especially including Haffes.	Tunnel Cave loses headwater? Rejuvenation - lower HAFFES CAPTURED? Aggressive water & corrasion. Caves well developed in basic form. Consid. run off, corrasive melt water & solifluction deposits. Introd'n of early cave fills.
Middle	WOLSTONIAN (RISS/SAALE)	130000	Pencoed Glaciation	Arctic-sub Arctic	OLDER DRIFT. Extensive glaciation, sea level low. Downcutting of Tawe Valley.	Periglacial condits. surface drainage, drift deposits & solifluction active. Caves relatively quiescent, possib. plugged
	HOXNIAN	150000	Gower Beach Interglacial	Temperate	Rejuvenation of main rivers, possibly Haffes begins to cut back more significantly.	Considerable Cave Development with downcutting commencing.
	ANGLIAN (MINDEL)	240000	(Ante-Penultimate ? Glaciation on Continent)	Cold-sub-Arctic	No evidence of glaciation.	Abrasive sediments. Little cave development/solifluction deposits etc.
	CROMERIAN	310000	Interglacial	Temperate	Possible fluctuations in base level and rejuvenation	Presumed period of cave development
	BEESTONIAN (Gunz)	340 000	? (Early glaciation on Continent)	Cold	No evidence of glaciation.	Presumed period of only minor cave development.

terms not only of passage length and scale (Thomas suggested in 1954 that some of the surface collapse features implied "initiating caverns of greater width than the main chamber of Gaping Gill") but also of differing degrees of development. Thus Tunnel Cave shows features of an early stage with small phreatic roof tubes and deep but narrow and relatively under-developed vadose gorges dominating most areas beyond the commercialised entrance chamber (known as Cathedral Cave). However, the main known input limbs of Dan yr Ogof, i.e., the Great North Road/Far North which are fed only by misfit streams and flood waters from Waen Fignen Felen, are quite different. Here the scale of passage size is far more massive and the phreatic origins are

for the most part lost in major meanderings, undercutting and roof collapse. Faulting, not obvious in Tunnel Cave, is a major contributor here but undoubtedly of greatest importance has been the greater duration of attack by highly aggressive and corrasive waters. For this reason entry to the Giedd should be exciting and geomorphologically rewarding although perhaps also highly dangerous.

References

Coase, A.C.	1975. *The Structural Geomorphology of the Dan yr Ogof Caves,* Ph.D. Thesis, University of Leicester.
Coase, A.C. & Judson, D.M.	1977. Dan yr Ogof and associated caves. *Trans. Brit. Cave Res. Assoc.,* Vol. 4, No. 1.pp.245-344.
Thomas, T.M.	1954. Swallow Holes on the Millstone Grit and Carboniferous Limestone of the S. Wales Coalfield. *Geog. Journal,* vol. 120.
Weaver, J.D.	1972. *The Swansea Valley Disturbance,* Ph.D Thesis (unpubl.) University of Wales.

METHODOLOGY IN THE ANALYSIS OF QUATERNARY CAVE SEDIMENTS: A PRELIMINARY REVIEW

S.N. Collcutt
Pitt Rivers Museum
Oxford

In order to provide a chronostratigraphical and environmental framework for the palaeolithic industries of S.W. England, the author has recently embarked upon an extensive research programme concerning the analysis of cave sediments. A preparatory study of the abundant literature has forced the conclusion that a turning point has been reached necessitating a fundamental rethinking of theory. The largely empirical approach of the past few decades has proved immensely stimulating. However, it is becoming increasingly evident, as the analytical techniques are refined, that our conception of the geological processes involved is superficial and confused. Much basic research remains to be done, but an immediate reappraisal of methodology should clarify the situation.

In the field of data recovery, techniques have already been devised to record almost every tangible variable in cave sediments, yet much precision is still lost through inadequate mensuration. One of the most damaging practices is the uncritical grouping of data from an intrinsically continous distribution. For example, most N. European researchers (cf. Vertés, 1959; Riek, 1973, p. 74) divide fine sediments into four size categories only, with a resulting loss of information which often renders these figures quite useless. Divisions of at the very most 0.5 Phi are necessary if significant details of sorting, skewness, multimodality, etc., are to be recovered (cf. Brunnacker, 1966; Laville, 1973).

Another area for concern is the general unwillingness to consider lateral and statistical variation in sediments. Usually a "typical" column of samples, in strictly vertical succession, is analysed to provide point estimates of the variables, a process which is thought to ensure comparable results between samples. Topographical changes (e.g. changes in slope, cliff recession, morphological evolution of the cave interior, etc.), only indirectly linked with climate, can make nonsense of this approach (cf. Schmid, 1958, who gives some consideration to cave topography).

A major problem concerns the need to evaluate extremely complex variables such as shape and corrosion of limestone particles. At present such variables are subjectively sorted into conceptually discrete classes (cf. Brunnacker & Streit, 1965; Laville, 1973), a procedure which is normally much less time-consuming than any available automatic classification using a continuous scale. Subjective analyses can be partially controlled by the use of statistical design (e.g. Latin squares), although an increase in the sample size and in manipulation time also results. All evaluation of complex variables, whether qualitative or automatic, suffers from the uncertainty as to what exactly is being measured. In practice it is notoriously difficult to separate such factors as sphericity, rounding, corrosion and friability. Until rapid, well defined methods of automatic classification can be developed, the results of subjective analyses must be weighted, as against more exact quantitative estimation of other variables, in order to show their lower order of dependability (cf. Riek, 1973, pp. 158-160, who interprets an entire sequence by rounding of limestone particles, despite the fact that he has obviously a profound understanding of the significance of other variables). As qualitative classification involves no calibrated scale, the practice of combining the results with figures from scaled quantitative analyses to produce "indices" must be abandoned (cf. Vertés, 1959).

Most disagreement, and error, occurs during the primary interpretation of geological processes, more exactly through the underestimation of complexity and multicausality. For example, one could cite the tendency of many N. European researchers to interpret the results for each variable separately, thus arriving at a series of vague climatic sequences which are made to correspond by further reduction in detail (cf. Vertés, 1959; Brunnacker, 1966). The possibility that the study of all the variables, layer by layer, could prove much more valuable is often ignored. One wonders how such expenditure of time and money can be justified, when competent sedimentologists (such as Vertés and Brunnacker themselves) could produce comparable results after an hour's visual examination of the sediments in situ. On the other hand, simple equation of a sediment variable with a geological process can produce unwarranted and possibly spurious detail. For instance, many researchers, especially the French (cf. Miskovsky, 1972; Laville, 1973), equate quantity and particle size of limestone rubble with cryoclasticism, when it has been known for some time that solution along structural planes, crystal wedg-

ing (cf. Wilhelmy, 1958) and rupture of rock masses in disequilibrium (cf. Renault, 1968) can also produce varying amounts of debris (cf. Farrand, 1975, who makes a valiant attempt to overcome these difficulties). Because the contribution of a process cannot as yet be accurately assessed, or can only be assessed with difficulty, its neglect is by no means justified.

Another complication, yet to be examined in detail, is the effect of one set of components in the sediment upon the elaboration of other components (eg. formation of a stalagmitic floor or of dispersed concretions depending upon the permeability of underlying deposits; intensity of secondary cryoclasticism depending upon reservoir capacity of the fine matrix; etc). Post-depositional changes in cave sediments are often largely denied (cf. Vertés, 1959), yet in most sequences compaction (with changes in permeability and structure, and with crushing of deposits), vertical migration of fine and soluble material, and erosion (superficial, or interior if impermeable layers or bedrock act to channel ground-water) have obviously occurred.

Half the problems are due to scientific narrowmindedness; if all the possible causes and combinations of causes for sediment variation are considered in the light of the growing research into contemporary sedimentation under various climates, the problems will not immediately disappear, but neither will they be side-stepped.

The last stage of enquiry is the synthesis of results from various sites into a regional schema. Care must be taken not to use back-to-front argument at this point. When plotted on graphs, individual "indices" and other variables from supposedly contemporaneous cave layers will show scatters that are almost totally meaningless, but which tempt the researcher to put more faith in certain variables than in others, depending upon tightness of clustering (cf. Vertés, 1959). All sorts of bias are introduced at this stage by allowing preconceived ideas concerning the "known" regional stratigraphy to influence judgement; if possible, only information from the sites in question should be used. To establish a correlation between cave sequences one must first concentrate upon those features which, at selected sites, are considered to provide firm isochrons (eg. palaeomagnetic data, "absolute dates", faunal and floral phases, palaeosols, sedimentary unconformities, and, with great caution, cultural phases). By incorporating information from as many different disciplines as possible, errors and circular arguments can be great reduced — sedimentary analysis should never be conducted in vacuo. If marked divergence between different types of information becomes apparent, there is still time to discover the reason; if this is not done, a loss of information is unavoidable.

I have concentrated on the short-comings of past research into cave sediments because the enormous potential of the techniques merits the effort. If continental researchers have born the brunt of the criticism, it is because they have undertaken the bulk of the work; to our knowledge, no really detailed examination of British cave sediments has ever been published, a situation which I hope to rectify in the near future.

References

Brunnacker, K. 1966. "Die Sedimente der Crvena Stijena". *Glasnik Sarajevo,* Vol. 21, pp. 31-65.

Brunnacker, K. & Streit, R. 1965. "Neuere Gesichtspunkte zur Untersuchung von Hohlensedimenten". *Jhe. Fur Karst-und Hohlenkunde,* H.5, pp. 29-44, Stuttgart.

Farrand, W.R. 1975. "Analysis of the Abri Pataud Sediments". in Movius H.L. "Excavation of the Abri Pataud, Les Eyzies (Dordogne)". *Peabody Museum, Harvard University, Bulletin 30,* pp. 27-68.

Laville, H. 1973. *"Climatologie et chronologie du Paleolithique en Perigord: etude sedimentologique de deposits en grottes et sous abris".* These de Doctorat d'Etat es Sciences naturelles, Bordeaux University I (400), 3 volumes.

Miskovsky, J.-Cl. 1972. *"Etude sedimentologique du remplissage".* in: Lumley, H. de, *"La grotte moustologique de l'Hortus (Valflaunces, Herault)."* C.N.R.S., Lab. de Paleont, Hum. et de Prehist., University of Provence, pp. 101-153.

Renault, P. 1968. "Contribution à l'étude des actions méchaniques et sédimentologiques dans la spéléogenèse: II — les effets méchaniques à l'échelle de la cavité" *Annales de Speleologie,* t.23, fasc. 1, pp. 259-307.

Riek, G. 1973. "Das Paläolithikum der Brillenhöhle bei Blaubeuren (Schwäbische Alb)." *Forschungen und Berichte zur vor — und Fruhgeschichte in Baden-Wurttemberg,* B.4/1, Stuttgart.

Schmid, E. 1958. "Höhlenforschung und Sedimentanalyse. Ein Beitrag zur Datierung des alpinen Paläolithikums." *Schriften des Instituts fur ur - und Fruhgeschichte der schweiz,* 13, Basel.

Vertés, L. 1959. "Untersuchungen an Höhlensedimenten: Methode und Ergebnisse." *Regeszeti Fuzetek,* Series II-7, Magyar nemz. muz. & torteneti muz., Budapest.

Wilhelmy, H. 1958. *"Klimamorphologie der Massengesteine."* Westermann Verlag, Braunschweig.

THE DATING OF CAVE DEVELOPMENT — AN EXAMPLE FROM BOTSWANA

H.J. Cooke
University of Botswana and Swaziland, Gaborone
Botswana.

B. Th Verhagen
Nuclear Physics Research Unit, University of the Witwatersrand, Johannesburg

The Problem

There are many examples in the literature of attempts to reconstruct and describe sequences of cave development and of others which seek to establish close chronologic relationships between external erosional and depositional landforms and sub-surface cave development. Where absolute dating by radiometric means is possible of either surface or cave deposits, this dating of either can then throw light on the other where a close relationship has been established between surface and cave landforms on purely geomorphic grounds.

In northwest Botswana a sequence of alternating erosional and depositional events both on the surface and underground has been established which moreover appears to be related to climatic oscillations between relatively wetter and drier periods (Cooke 1975). Drotsky's cave lies in Kwihabe hill, the largest of a group of six close-set outcrops of ancient dolomite which straddle the Kwihabe valley in lat. 20°03'S long. 21°26'E. The valley, which is narrow and gorge-like where it passes through the hills, is a fossil feature and is quite dry. The whole area is mantled by Kalahari sand, usually arranged in the form of degraded longitudinal dunes, now stabilized by a discontinuous cover of scrub and tussocky grass. Along the flanks of the valley four different calcretes have been recognized on lithological and stratigraphical grounds. Three of these calcretes and the dolomite bedrock have been affected at different times by faulting. The two older calcretes are mainly calcified aeolian sands, and show signs of silification. The later two are calcified fluvial gravels, and sands, and the younger contains freshwater mollusc shells. Within the cave three different sinters have been identified. These group into two older and a younger type, the distinction being made on degree of weathering, extent of re-solution, cracking and breaking, and on relative position in the cave and to each other.

The establishment of a close relationship between the Kwihabe valley and its calcretes on the one hand, and the cave and its sinter deposits on the other is not simply a problem of purely speleological interest. Caves containing extensive sinter deposits are the result of the movement of considerable bodies of water, and normally associated with a humid climate. Their occurrence therefore in an area which is now semi-arid and with the distinctive landforms of aridity, is of great interest to students of palaeoclimates.

To attempt to gain an absolute chronology for the cave's evolution and at the same time to gain information as to when probably the climate was wet (i.e. when sinter was being actively deposited on a large scale) and also to get some idea of the growth rate of stalagmites, samples of the different sinters and of the valley calcretes were collected and dated at the Environmental Isotope Laboratory of the Nuclear Physics Research Unit, University of the Witwatersrand.

The Samples

The samples made available for radiocarbon dating consisted of:

a) Slices cut across well-formed stalagmites
b) Fragments of stalactite, flowstone and other cave sinters
c) Various calcrete fragments.

Of these, the stalagmites are the best material to handle as they are solid, with clearly discernable and fairly regular growth rings. All other material presents uncertainties in that a regular growth pattern is not or only partly observable and in that material of widely different ages could be juxtaposed.

In the case of stalagmites, dating samples were obtained by aiming a coring drill along the axis of the slice. These cores show almost flat cross-sectional layers, which sometimes split as a result of sand deposits between them. From other materials, a suitably-sized piece was knocked off or sawn out from a supposedly representative site.

Measurement techniques

The stalagmite samples were finely ground, the others were coarsely crushed and cleaned with dilute hydrochloric acid. All samples were then consumed with 50% hydrochloric acid and the resulting CO_2 was converted to ethane gas via lithium carbide. The ethane is stored for 3-4 weeks to allow for radon decay. The radiocarbon activity was then determined in low-level gas proportional counters. Each measurement is repeated at least once after about 1 week (2 further half-lives of radon).

Results are given as a percentage of modern carbon, the latter being defined as 95% of the activity of the National Bureau of Standards oxalic acid standard. The errors stated are one standard deviation on the measurement. Ages are interpreted using a half-life of 5730 yr. Because of isotopic exchange with ancient limestone in the unsaturated zone, the radiocarbon concentration of the organic carbon dioxide dissolved in infiltrating ground water can be reduced from 100% to a probable value of about 85%, which implies an apparent 'ageing' of about 1300 (Münnich, 1957). This value is subtracted from the conventional radiocarbon age.

Results and Discussion

The results of the radiocarbon measurements, along with the age interpretations and brief description of the samples, are given in Table 1. The probably different stages of cave sinter and calcrete development, identified on geomorphological grounds, are indicated in decreasing ages as SI-SIV and CI-CIV, respectively (Cooke 1975).

The stalagmite dates form a highly consistent series (Samples C74/8,9,10). The SIII stage, representing an intensive period of sinter development, seems to fall in a fairly narrow bracket of 13 000 to 16 000 yr B.P. This coincides with the Würm Pleniglacial in higher latitudes, which might have displaced the tropical high rainfall belt further southward.

The growth rates (axial) of these stalagmites are fairly high, compared to European cave sinters (Geyh and Franke 1970) and range from 0,4mm/yr to 0,9mm/yr. A more recent sample (C73/St1 (a,b)), confirms the SIV classification and gives a similar growth rate of about 0,8mm/yr.

A sample of actively growing sinter (C74/23) shows the presence of bomb ^{14}C (>100% modern carbon). This implies a transit time of less than 20 years for rainwater to reach the cave — much smaller than the resolution of radiocarbon measurements.

Lab. No.	Sample No.	Sample Description	% Modern Carbon	Corrected Age (Years B.P.)
Wits 164	C74/8 (a) 1	Slice of Stalagmite SIII or SIV	13,47±0,44	15200±300
,, 165	C74/8 (a) 2	Same slice of Stalagmite	13,82±0,36	15100±200
,, 166	C74/8 (b)	Lower slice of Stalagmite	12,30±0,32	16000±200
,, 171	C74/9 (a) 1	Slice of Stalagmite SIII or SIV	17,23±0,52	13200±300
,, 167	C74/9 (a) 2	Same slice of Stalagmite	16,44±0,37	13600±200
,, 168	C74/9 (b) 2	Lower slice of Stalagmite	15,63±0,39	14000±200
,, 169	C74/10 (a) 1	Slice of Stalagmite SIII or SIV	17,98±0,23	13000±200
,, 170	C74/10 (b) 1	Lower slice of Stalagmite	17,42±0,37	13100±200
,, 195	C74/11 (b)	Slice of Stalagmite SIV	78,10±0,70	750±100
,, 163	C74/23 (2)	Nodule on growing Stalagmite	109,50±1,50	>20
,, 122	C73/Stl (a)	Slice of Stalagmite SIV	65,59±0,50	2200±100
,, 123	C73/Stl (b)	Lower slice of Stalagmite	62,79±0,45	2550±100
,, 306	C75/1	Stalactite section SII	1,40±0,27	34000±1700
,, 377	C75/1	,, ,, repeat	2,47±0,30	29300±1000
,, 309	C75/5	Remnant sinter flowstone SII	0,15±0,23	>45000
,, 313	C75/8	Hard old calcrete CII	0,13±0,25	>45000
,, 385	C75/9	Hard old calcrete CI	1,29±0,29	34700±2000
,, 315	C75/9	,, ,, repeat	5,48±0,33	22700±500
,, 307	C75/13	Soft calcrete CIII or CIV	25,39±0,50	10000±200
,, 375	C75/13	,, ,, repeat	25,99±0,33	9800±200
,, 308	C75/16	Sinter floor remnant SII	0,54±0,25	41900±5500
,, 386	C75/16	,, ,, repeat	0,97±0,18	37000±1700
,, 310	C75/17	Sinter floor remnant SII	0,15±0,25	>45000
,, 314	C77/22	Soft recent calcrete CIV	22,75±0,27	11000±100
,, 376	C75/22	,, ,, repeat	23,20±0,34	10800±100

The problem of assaying non-stalagmite material is demonstrated by the results on older sinters and calcretes. Apparently similar sections of a sample can give quite divergent ages (cf. repeats, C75/1,9), whilst younger calcretes (C75/13, 22), can give good reproducibility. Calcrete 75/9 has clearly been invaded by more recent deposits, the original matrix being in all probability beyond the datable limit (>45 000 yr), as in C75/8.

Generally, the radiocarbon dates support the age classifications based on geomorphological arguments, as well as general correlations between cave sinter and calcretes. In particular, the requirement of a fluctuating but generally falling water-table proposed by Netterberg (1969) for the formation of thick layers of calcrete could be supported by the dates of 10 000 – 11 000 yr on the soft calcretes (C75/13,22), following as they do on the SIII high rainfall period.

Acknowledgements

For financial support to conduct the radiocarbon analyses, the authors are indebted to the University of the Witwatersrand. They also would like to thank the staff of the Environmental Isotope Laboratory and particularly Mr. E. Ndhlovu, for their assistance.

References

Cooke, H.J. 1975. The palaeoclimatic significance of caves and adjacent landforms in western Ngamiland, Botswana. *Geogr. Jnl. 141*, pt. 3, 430-444.

Geyh, M.A. & Franke, H.W. 1970. Zur Wachshumsgeschwindigkeit von Stalagmiten. *Atompraxis,* 16, 1: 46-48.

Münnich, K.O. 1957. Messungen des ^{14}C-Gehaltes von hartem Grundwasser. *Naturwiss.* 44, 2:32-34.

Netterberg, F. 1969. The interpretation of some basic calcrete types. *S. Afr. Arch. Bull.* 24: 117-122.

SOME KARST CHARACTERISTICS OF THE RYE HOUSE RISINGS, NEAR HELMSLEY, YORKSHIRE

R.G. Cooper and A.F. Pitty
Geography Dept., University of Hull,
Hull, U.K.

The Vale of Pickering, in north-east Yorkshire, extends some 48km from west to east and is about 13 km broad. Structurally, it lies at the southern edge of the southern flank of the North Yorkshire Moors and, to the north and west, Jurassic uplands rise gradually to over 300 m O.D. The southward-dipping Jurassic strata are capped by the Coralline Oolite Formation (Wright, 1972), consisting largely of alternating calcareous sandstones and impure oolitic limestones. Therefore, despite a mean annual rainfall above 900 mm for much of the Moors, the River Rye loses part of its surface flow where it crosses this outcrop near Helmsley (Figure 1). The

Kimmeridge Clay floor of the Vale and its extensive drift cover of up to 30 m in thickness make it difficult to comprehend the pattern of underground drainage development.

From its sink in Dunscombe Park, the River Rye is generally thought to resurge some 3.2 km down-valley in a string of risings at Rye House in Coralline rocks throughout. Although the risings are only 15 m lower in altitude than the sinks, they emerge on the opposite side of the river from Dunscombe Park. In order to support more precise inferences about the groundwater pattern and solutional activity in this locality, water samples and temperatures were taken at the six most prominent risings in the Rye House group. Samples were collected at 2 – 4 week intervals on 18 occasions between October 1973 and September 1974, and calcium, total, and alkaline hardness were determined in the laboratory.

Hardness Variation

E.T. Shuster and W.B. White (1971) proposed the coefficient of variation of total hardness as an index for the characterisation of flow types as approaching either a diffuse or a conduit regime. The CVs of the Rye House risings are given in Table 1, and their relative positions are shown in fig. 2.

TABLE 1. Means (PPM or °C) and coefficients of Variation (%) for the Rye House Risings

Rising	*RH1*		*RH2*		*RH3*		*RH4*		*RH5*		*RH6*		*River*	
	Mean	*CV*	*Mean*	*CV*	*Mean*	*CV*	*Mean*	*CV*	*Mean*	*CV*	*Mean*	*CV*	*Mean*	*CV*
Calcium Hardness	154	15.37	148	18.42	145	19.95	146	19.91	166	16.04	165	15.72	130	10.98
Magnesium Hardness	18	33.49	17	24.34	17	25.93	19	29.85	17	33.04	18	31.56	17	37.91
Total Hardness	172	16.79	165	18.11	162	18.88	165	19.74	183	15.46	183	16.49	147	8.85
Alkaline Hardness	130	15.47	121	17.82	117	18.86	117	18.48	138	13.75	137	14.87	103	16.93
Temperature	8.7	22.77	8.5	30.24	8.4	33.29	8.5	33.18	8.7	17.34	8.7	17.43	9.7	54.26

Using Shuster and White's criteria (1971), these results indicate that all the risings are predominantly flows of the conduit type, i.e. they show karst development. At the point where the river was sampled, just upstream from RH6, its water had not been in direct contact with limestone for over a mile, and its solute levels may be assumed to have equilibrated with the atmospheric partial pressure of carbon dioxide.

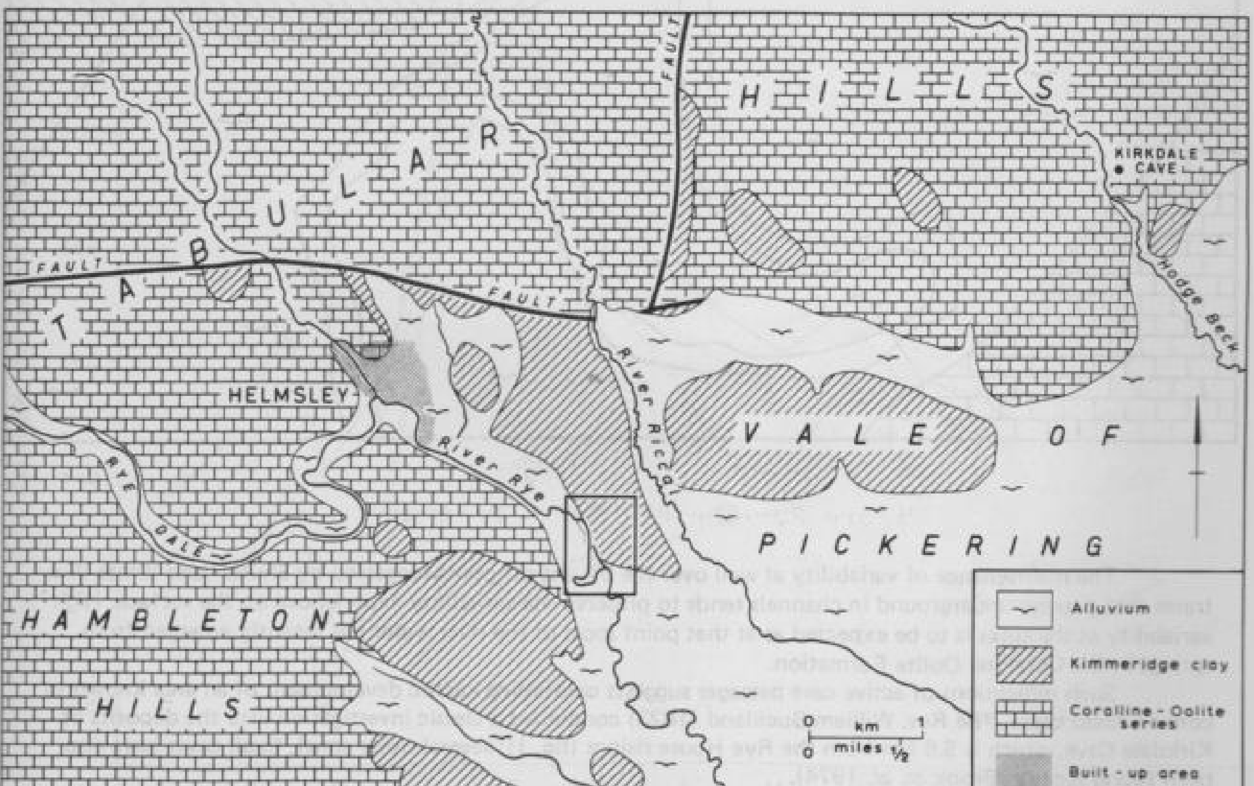


Figure 1. Generalised surface geology of the area around Helmsley, Yorkshire.

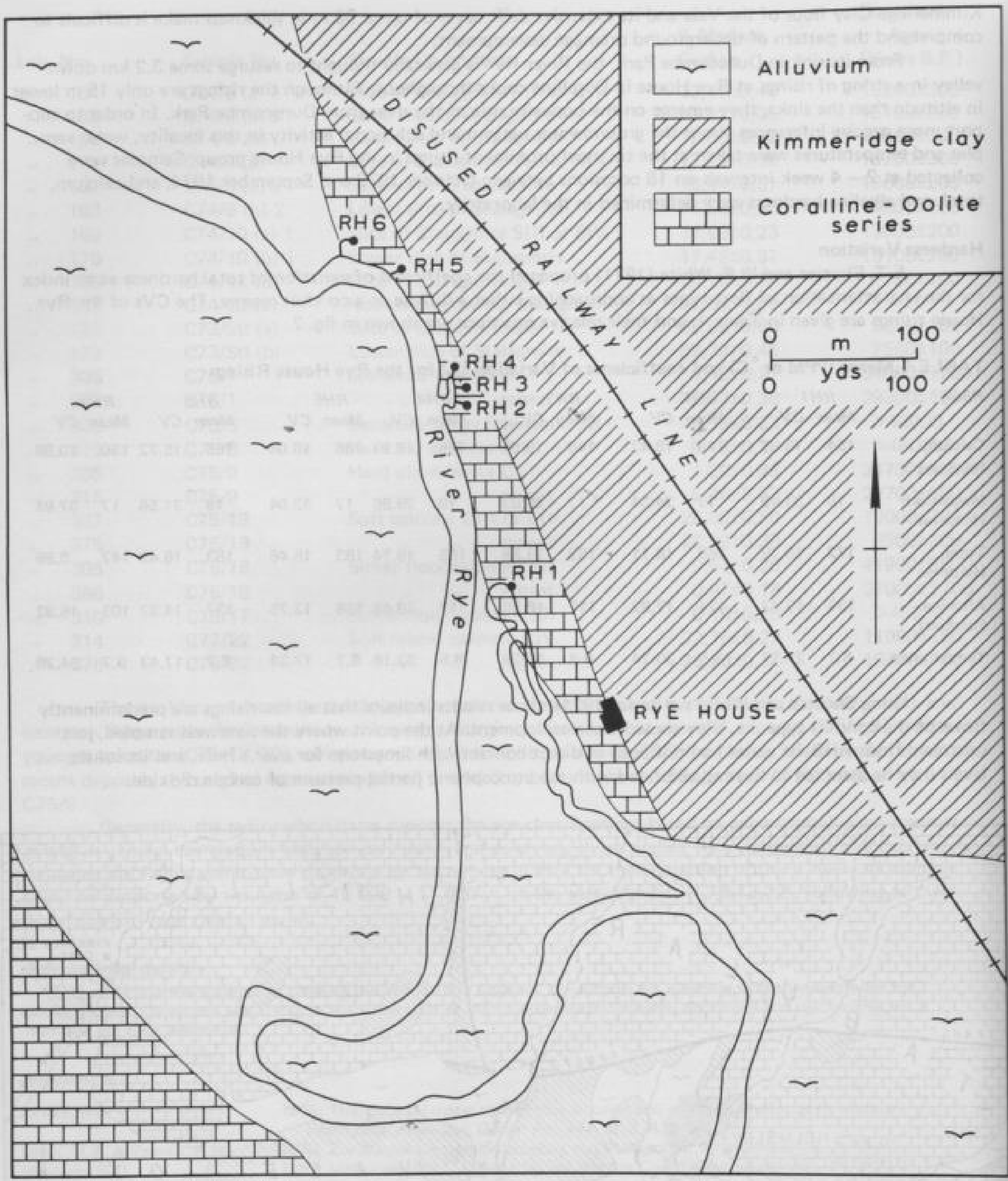


Figure 2. The Rye House risings.

The maintenance of variability at well over the 5% cut-off point suggested by Shuster and White illustrates that passage underground in channels tends to preserve the variability experienced on the surface. High variability at the sinks is to be expected as at that point most of the river water has recently emerged from springs in the Coralline Oolite Formation.

Such indications of active cave passages suggests continuing karstic development of an area known to contain fossil caves. The Rev. William Buckland (1823) conducted a classic investigation into the deposits of Kirkdale Cave, which is 5.6 km from the Rye House risings (fig. 1); several other small, fossil caves have also been found locally (Brook *et. al.* 1974).

It is clear from the CV values that the solute levels of the risings do not vary in precisely similar ways or to precisely similar extents. This is highlighted by comparing their mean solute levels (Table 1), which show that the risings fall into three groups which correspond to their spatial grouping along the river bank. The upstream risings, RH5 and RH6, have the highest hardnesses, while the downstream rising RH1 has intermediate hardness levels. The group of three risings, RH2, RH3, and RH4, have the lowest hardness levels.

The pattern of variation of calcium hardness throughout the year of sampling is shown in fig. 3. All

the risings have a similar pattern of fluctuations; the differences in their mean hardness levels are therefore a reflection of small differences which persist throughout the year.

Conclusions

The results quoted appear to show that the water issuing from each of the risings is not precisely the same. However the similarity of the patterns of fluctuation suggests that the risings do have their major water component in common, and this is probably the water from the sinks in the bed of the Rye. It is noteworthy that the river shares this pattern of fluctuation for most of the year, but departed from it markedly during January, February, March and April 1974, when the calcium hardness levels of the risings were at their highest (fig. 3). During the same period of four months, discharge was at its highest level at all the risings. At least three additional water outlets were operating at this time in the vicinity of RH3, and RH4. Similar high-flow multiple-exist systems are a common feature in the Carboniferous Limestone area of N.W. Yorkshire (R.A. Halliwell, personal communication, 1974).

The results of other workers suggest that the arbitrary 5% value of CV, which is suggested by Shuster and White (1971) for distinguishing diffuse from conduit flows, is not applicable in all karst areas. For example, Pitty (1966a, p. 23) found values varying from 3.19% to 9.24% in cave seepages of presumed diffuse flow from Poole's Cavern, in the Carboniferous Limestone of Derbyshire, with one value as high as 13.19% The same writer (1966b, p. 238) found values varying from 14.07% to 25.19% in surface streams in the same general area. Ternan (1972) has reported CVs of up to 10.6% on presumed diffuse flow systems in the Carboniferous Limestone of the Central Pennines, with a mean of 13.5% for presumed conduit systems. Compared with such results, the CVs of the Rye House risings are all above the highest reported value from a presumed diffuse flow, and well within the reported range of values from presumed conduit flows.

The mean levels of solute tend to differ between the individual Rye House risings, by more or less constant amounts. This could be due to varying degrees of admixture of a more dilute karst water from a hydrogeologically similar area, e.g. water from the river Riccal, (fig. 1). The complexity of the inter-relationships between the risings indicates that there need not be only one such other conduit water source.

It is possible that the multiple outlets at Rye House represent diversion of the main underground water flow by risings which are located successively further downstream. In this case the higher solute levels of RH5 and RH6 could indicate a higher proportion of percolation water emerging from them.

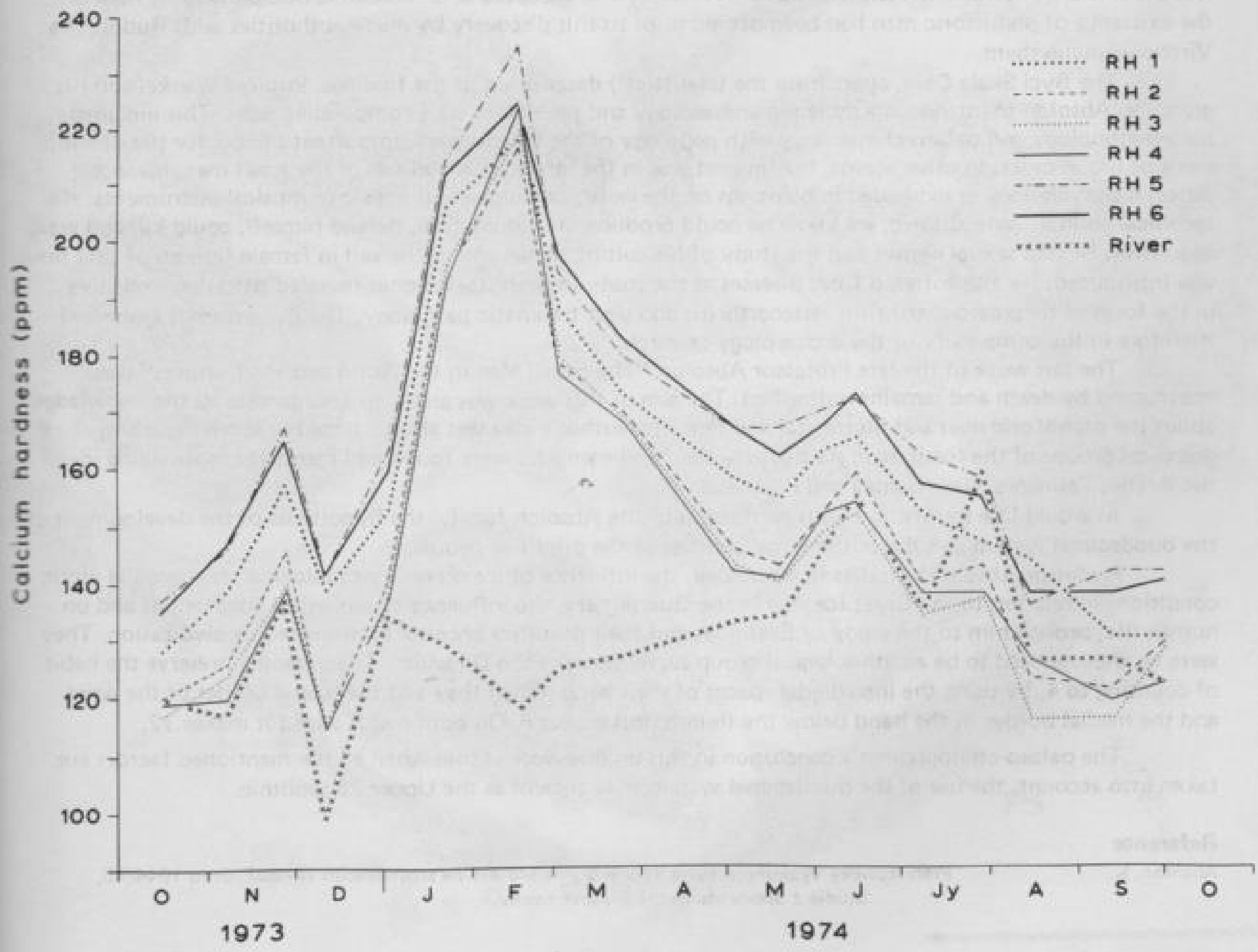


Figure 3. Seasonal variations in calcium carbonate content of the Rye House risings.

References

Brook, D., Davies, G.M. Long, M.H. & Ryder, P.F. 1974. *Northern Caves. Volume Five. The Northern Dales.* Dalesman Books, Clapham (via Lancaster), 144pp.

Buckland, W. 1823. *Reliquiae Diluvianae; or Observations on the Organic Remains Contained in Caves, Fissures and Diluvial Gravel, and on Other Geological Phenomena Attesting the Action of a Universal Deluge.* London.

Fox-Strangeways, C. 1892. *The Jurassic Rocks of Britain. Vol. I. Yorkshire. Mem. Geol. Surv.* 551 pp.

Shuster, E.T. & White, W.B. 1971. Seasonal fluctuations in the chemistry of limestone springs: a possible means for characterizing carbonate aquifers. *J. Hydrol.* 14, 93-128.

Wright, J.K. 1972. The stratigraphy of the Yorkshire Corallian. *Proc. Yorks. Geol. Soc.* 39, 225-266.

Pitty, A.F. 1966a. *An approach to the study of karst water, illustrated by results from Poole's Cavern, Buxton.* Univ. Hull Occ. Pap. Geogr. 5. 70 pp.

Pitty, A.F. 1966b. *Landform studies in the Peak District of Derbyshire.* unpubl. D. Phil. thesis, Univ. Oxford.

Ternan, J.L. 1972. Comments on the use of a calcium hardness variability index in the study of carbonate aquifers: with reference to the Central Pennines, England. *J. Hydrol.* 16. 317-321.

AN INTRODUCTION TO THE MONOGRAPH "THE FOSSIL MAN IN THE WORLD AND HIS CULTURES"

E. Coufalik
c/o Medical Research Council, Harrow, U.K.

The Prehistory and the cultural history of the Byci Skala Cave in the Moravian Karst is of international renown. For the spelaeologist it is important to know that this was the first cave in the world, so far known, where an expert cartography was performed in 1867. The two cartographers were E. Mladek and A. Medritzer, co-workers in Wankel's team. For the prehistorian is also interesting to know that this was the first cave in Central Europe where a skeleton of a fossil man was discovered in 1868. It had a well preserved cranium, mandible, humerus, radius and ulna, tibia and scapula, together with bones of the bear *Ursus spelaeus.* The material was presented by Wankel in Vienna in 1870. Prehistory was accepted as an academic discipline since then as the existence of prehistoric man had been denied prior to this discovery by many authorities with Rudolf von Virchow among them.

The Byci Skala Cave, apart from the (statistical) description of the findings, inspired Wankel and his grandson Absolon to introduce a dynamic archaeology and prehistory on a comparative basis. This included palaeo-ethnology and palaeo-climatology with pedology of the Quarternary, important factors for the development of life in caves. In other words, the interest was in the intellectual abilities of the fossil man, his intelligence, his psychology as expressed in paintings on the walls, in sculpture in music or musical instruments. His technical abilities were studied; we know he could produce fire, could hunt, defend himself, could kill and was aggressive. He had sexual desires and the study of his cult of Venus and of the veil in female fashion of that time was introduced. He also suffered from diseases as the study of prehistoric bones revealed pathologic changes in the form of rheumatoid arthritis, osteoarthritis and post traumatic pathology. The dynamism is expressed therefore in the complexity of the archaeology research.

The last work of the late Professor Absolon "The Fossil Man in the World and His Cultures" was interrupted by death and remains unfinished. The aim of this work was and is to amalgamate all the knowledge about the prehistoric man and his mental abilities. The author's idea was also to trace the surviving ethnographical groups of the fossil man, particularly the fossil men who were found and identified as surviving in the Arctic, Tasmania, New Guinea and Polynesia.

In would like to mention with permission of the Absolon family, the hypothesis of the development of the duodecimal system and the arithmetical abilities of the primitive people.

Professor Absolon's studies in glaciology, the influence of ice on geomorphological changes, the arctic conditions in relation to the Great Ice Age in the Quarternary, the influence of biological adaptations and on human life, brough him to the study of Eskimoes and their primitive ancestors untouched by civilization. They were or are supposed to be an ethnological group surviving since the Diluvium. These people preserve the habit of counting to 4, by using the interdigital spaces of their hand. When they add the lateral border of the wrist and the medial border of the hand below the thumb, this makes 6. On both hands added it makes 12.

The palaeo-ethnographer's conclusion in this unique work is that when all the mentioned factors are taken into account, the use of the duodecimal system is as ancient as the Upper Palaeolithic.

Reference

Absolon, K. Prehistorický výzkum jeskyne Býčí skály na Moravě na srovnávacím základě. Brno 1944/45, Studie z oboru všeibecné krasové nauky.

A 'LIVING FOSSIL' IN THE TWILIGHT ZONE: A CAVE-WALL BACTERIUM OF UNIQUE ULTRASTRUCTURE

Guy Cox.
Electron Microscope Unit, University of Sydney,
N.S.W. 2006, Australia.

A study of the photosynthetic microorganisms of the twilight zone of cave entrances (Cox & Marchant, this volume) revealed that they are only part of a complex community. Other members are occasional fungi and a wide range of bacteria. The bacteria included both gram negative and gram positive species; some resembled common soil bacteria while another species was identical to that forming large colonies ("wall fungus") in the dark zone (Cox, 1976). One other bacterium, however, was of strikingly unusual appearance, and this paper presents a description of this and a preliminary attempt at assessing its evolutionary position.

Materials and Methods

Material was collected and prepared for electron microscopy as described by Cox & Marchant (this volume).

Results

A colony of the bacterium is seen in Fig. 1. Colonies are typically of 6 or more cells, each cell being ovoid in shape and measuring approximately 1 µm x 0.6 µm. The cells are embedded in a fibrillar sheath (FS) of variable thicknesses; the thickness of the sheath and the shape of the cells seem to reflect the plane of last division. The colony as a whole is surrounded by a layer or tubular scales (SC) each scale being between 25

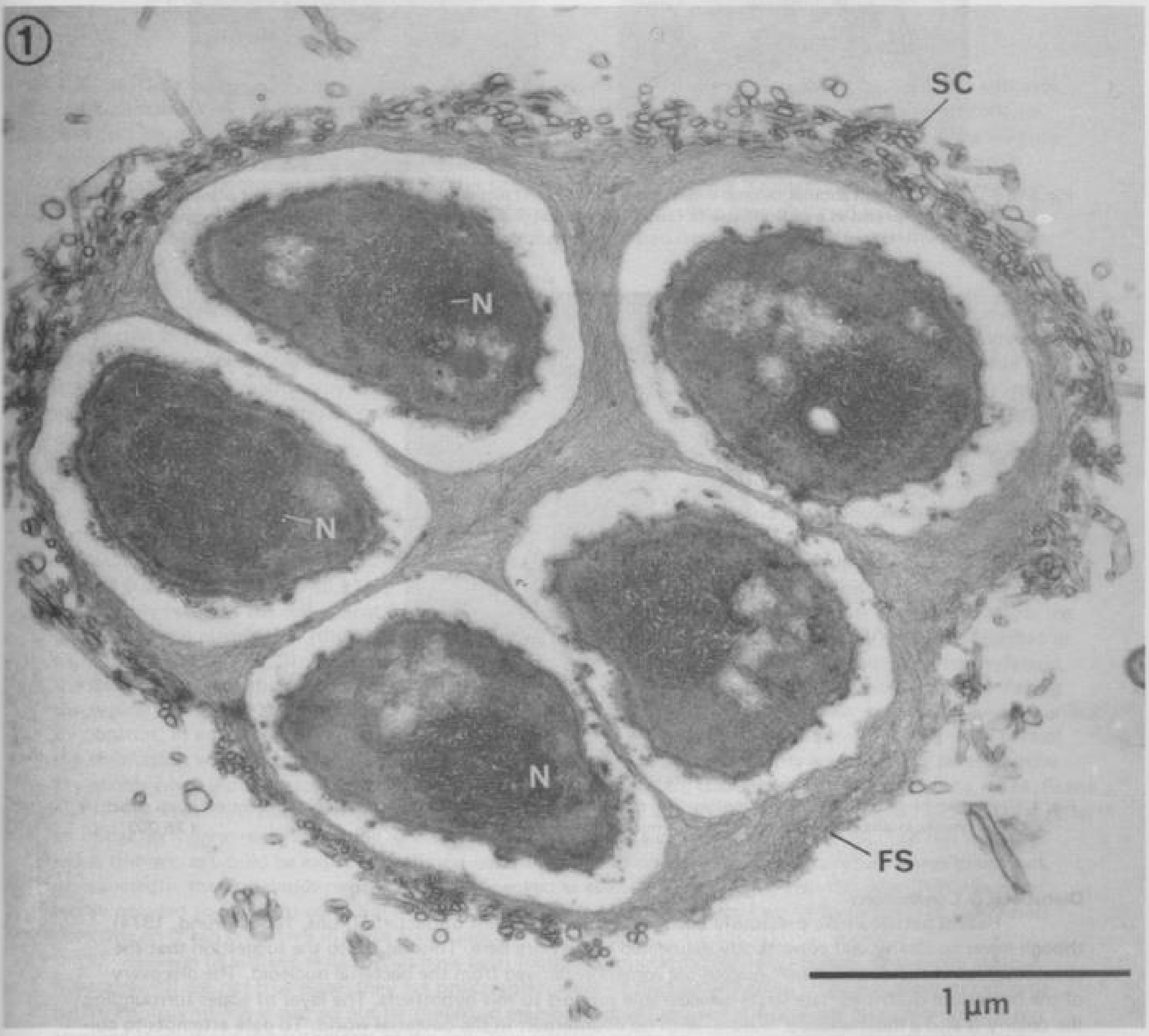


Fig. 1. Colony of bacteria held together by a common sheath (FS) of fibrillar material. The colony is surrounded by tubular scales (SC). The chromatin of the nucleoid (N) shows an organised structure. x 50 000

& 60 mm in diameter. A clear layer separates each cell from the sheath, though this may simply result from shrinkage during processing. The cell membrane (M, Fig. 3) consists of several layers of different staining properties, corresponding to those seen in a gram-negative bacterium (Murray, Steed & Elson, 1965). Although the gram stain has not been attempted since a pure culture has not been obtained, this seems sufficient evidence that the organism is gram-negative. The protoplast is dense, with irregular lighter areas, but no internal membranes or inclusions are seen. The only notable feature, and the most striking characteristic of the organism, is the nuclear material (N). The fibres of DNA are arranged in a complex pattern; the form seen depends on the plane of sectioning (Fig. 2 & 3), but it seems to correspond to a spiral of low pitch. An identical pattern is seen in chromosomes of dinoflagellate algae (Pyrrophyta), the most primitive organisms to possess a true nucleus (Dodge, 1971) (Fig. 4).

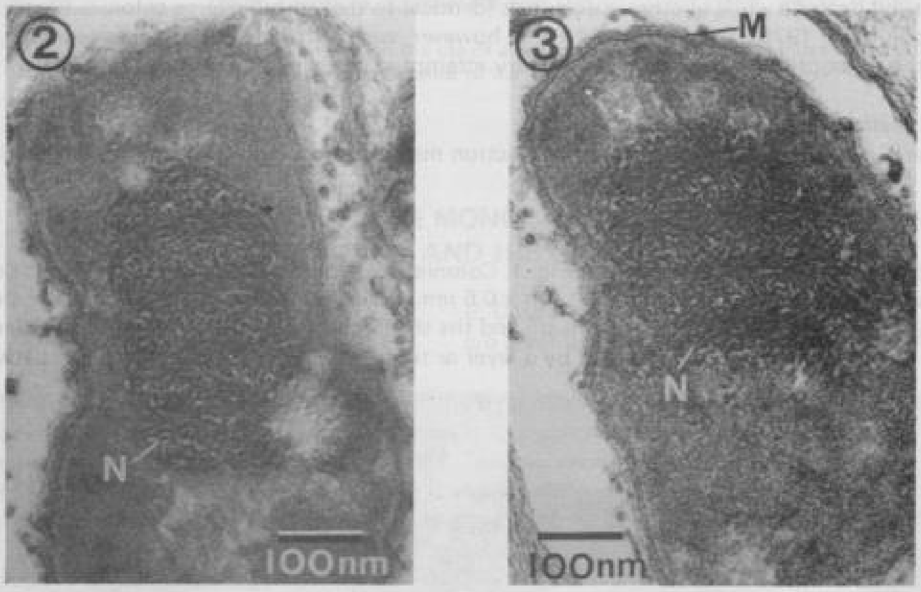


Fig. 2 & 3 Bacteria from another colony, showing the nucleoid (N) sectioned in two slightly different planes. Fig. 3 can be interpreted as a section close to the axis of a spiral, Fig. 2 as slightly off axis. The cell membrane (M) has a multi-layered structure. Both x 110 000

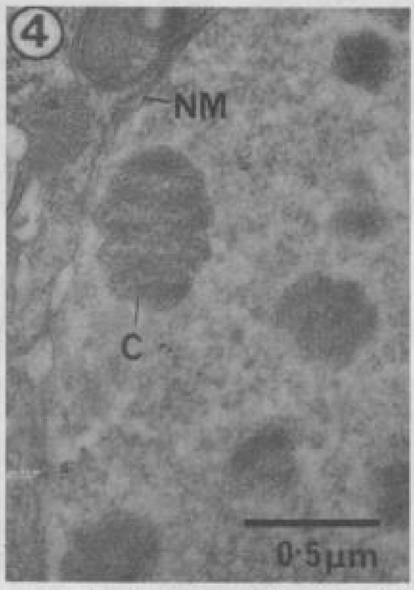


Fig. 4. Part of the nucleus of the dinoflagellate alga *Gymnodinium microadriaticum*. Note the identical spiral structure visible in one chromosome (C). NM – nuclear membrane. x 35 000

Discussion & Conclusions

Helical patterns have previously been seen in the nucleoids of bacteria (Fuhs, 1969; Grund, 1974), though never so clearly and consistently delineated as they are here. This has led to the suggestion that the chromosomes of the dinoflagellate nuceus are somehow derived from the bacterial nucleoid. The discovery of the bacterium described here lends considerable support to this hypothesis. The layer of scales surrounding the colony is also a most unusual feature, with no counterpart in the bacterial world. To date attempts to culture this bacterium have been unsuccessful, so it cannot be formally named. It is, however, quite distinct at least from all bacterial taxa so far examined in the electron microscope. Whether or not it stands in the direct

line of evolution of the eukaryote nucleus (and this is conceivable) it is important in helping our understanding of how the nucleus evolved. It seems that the cave environment has provided a specialised niche, with reduced competitive pressure, in which this unusual species has survived.

Acknowledgements

I am indebted to Helen Scott for her prowess in sectioning some very difficult material, to Maret Vesk for helpful and stimulating discussion and to Elizabeth Deane for the specimen of *Gymnodinium*.

References

Cox, G.C.	1976. Micro-organisms on cave walls in the deep twilight zone. *Proc. XI Bienn. Conv. Aust. Spel. Fed.*, in press.
Dodge, J.D.	1971. Fine structure of the Pyrrophyta. *Bot. Rev. 37*, 481-508.
Fuhs, G.W.	1969. *The Nuclear Structures of Protokaryotic Organisms.* (Protoplasmatologia, V [4]) Springer-Verlag, Wien & New York. 186 pp.
Grund, S.	1974. Hochgeordnete Feinstruktur des Chromosoms in *Escherichia coli. Zbl. Met. Vet.* B, *21*, 73 - 92.
Murray, R.G.E., Steed, P. & Elson, H.	1965. The location of the mucopeptide in sections of the cell wall of E. coli and other gram-negative bacteria. *Can. J. Microbiol. 11*, 547-560.

PHOTOSYNTHESIS IN THE DEEP TWILIGHT ZONE: MICRO-ORGANISMS WITH EXTREME STRUCTURAL ADAPTATIONS TO LOW LIGHT

Guy Cox,
Electron Microscope Unit, University of Sydney,
N.S.W. 2006 Australia.

Harvey Marchant,
Research School of Biological Sciences,
Australian National University,
Canberra A.C.T. Australia.

On a visit to Hennings Cave, Jenolan, N.S.W., a green tinge was noted on cave walls near the entrance, in illumination so low that vision required lengthy dark adaptation. The entrance itself is a boulder collapse, and the chamber within receives only indirect illumination. Samples were taken from a site where the illumination at midday in bright sunlight is around 0.2 1x (measured with a United Detector Technology Model 40a battery-powered photometer). The rock at this site was fairly soft, and the fragments collected showed a distinct green tinge at the outer surface only. Similar green tinges have since been observed in similar light conditions in other caves, but only Hennings Cave material is presented here.

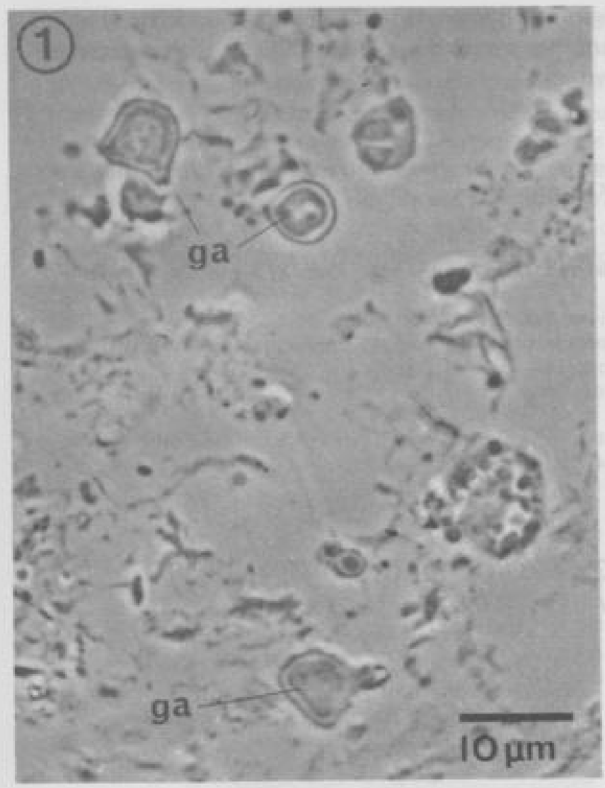
Techniques

Examination of fresh material in the light microscope yielded only limited information, and material was therefore prepared for sectioning. Samples were fixed in glutaraldehyde, with EDTA added to remove some of the limestone, postfixed in osmium tetroxide, dehydrated and embedded in epoxy resin. Sections were cut 1 μm thick for light microscopy and 0.07 μm thick for electron microscopy. Light microscope sections were examined unstained, using phase-contrast optics; electron microscope sections were stained with lead citrate and uranyl acetate.

Results & Discussion

A variety of organisms is present, both photosynthetic-green algae and cyanophytes (blue-green algae) and heterotrophic-fungi and bacteria. The only photosynthetic eukaryote (cell with a true nucleus) is a unicellular green alga (Chlorophyta) belonging to the genus *Chlorella*, and the cell as found in the cave is shown in Figs. 1 & 2. It is around 6 μm in diameter, with a very thick wall of rather distinctive irregular shape. This wall, up to 1 μm thick, presumably protects the cell against desiccation. The chloroplasts of this alga have a most unusual structure, the photosynthetic membranes (thylakoids) being packed so closely together that they can only be distinguished at high magnification (Fig. 3). Microdensitometer tracings showed 170 membrane profiles per μm; one thylakoid, the basic photosynthetic element, is a pair of membranes, so this corresponds to 85 thylakoids per μm. Taking the typical membrane thickness as ~6 nm, this implies that there is effectively no space between the membranes. By contrast, in a typical laboratory-grown *Chlorella* culture (Fig. 5) the thylakoids occupy only a small part of the chloroplast volume, averaging around 20 membrane pairs per μm. Many plants are known to develop more thylakoids when grown in low light (Boardman, Anderson, Björkman, Goodchild, Grimme & Thorne, 1974; Skene 1974). The cave *Chlorella* was therefore taken into liquid culture and grown in illumination of 500-1000 1x. After an initial lag it grew readily, and Fig. 6 shows the appearance of a culture-grown specimen. The cell walls are much thinner, as would be expected in liquid culture. The chloroplasts now show abundant starch grains but, unexpectedly, the thylakoids remain as densely packed as ever. It would appear that the cave *Chlorella* is so highly adapted to low-light conditions that it cannot revert to a more normal structure under high light levels even though it can grow well in these conditions.

Several blue-green algal species have been found, all unicellular (Chroococcales). Blue-green algae (Cyanophyta) are not true algae; they are prokaryotes, allies of the bacteria, with no true nucleus or cell organelles. Photosynthesis is carried out by thylakoid membrances which are not organised into chloroplasts, but arranged throughout the cytoplasm of the cell. Two patterns of thylakoid arrangement are typically found: 1) 2 or 3 concentric membrane-pairs running round the cell or 2) whorled membranes filling a larger part of



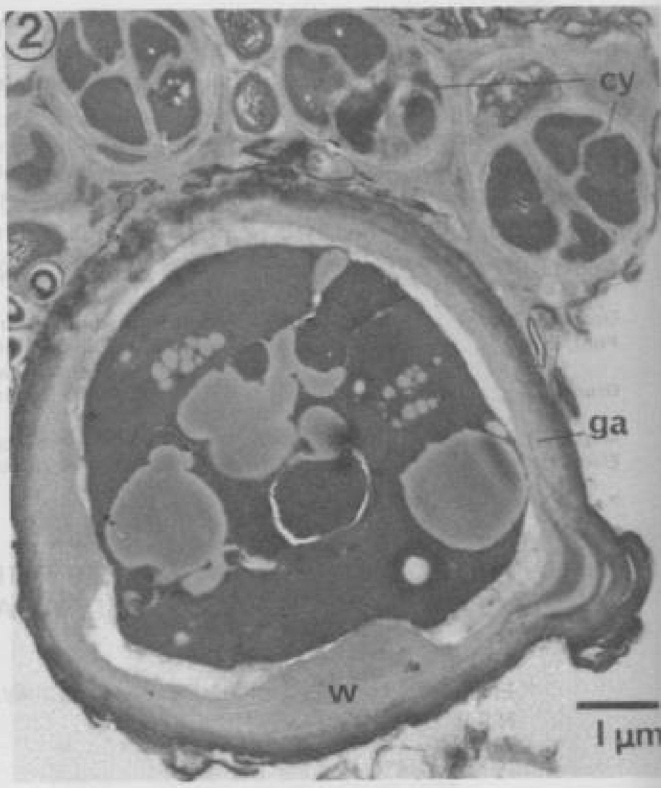
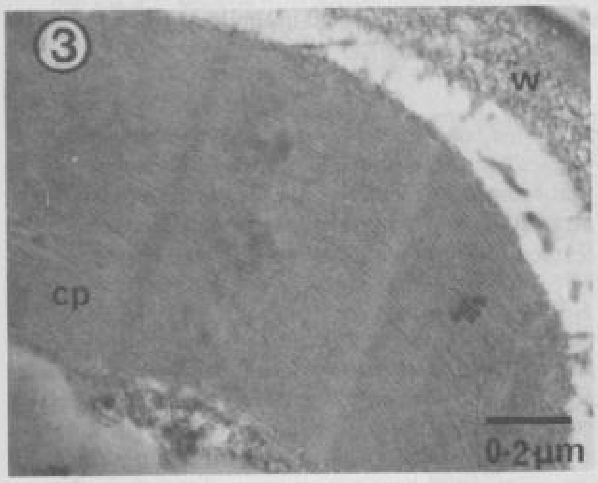


Fig. 1 Micro-organisms from Hennings Cave seen in section in the light microscope. The green alga [*Chlorella sp.*] (ga) is recognizable by its irregular shape and larger size. × 1 500

Fig. 2 Part of the same sample in thin section in the eletron microscope. Several colonies of a cyanophyte (cy) [*Chroococcus sp.*] are attached to the thick wall (w) of a *Chlorella* cell (ga). × 11 000



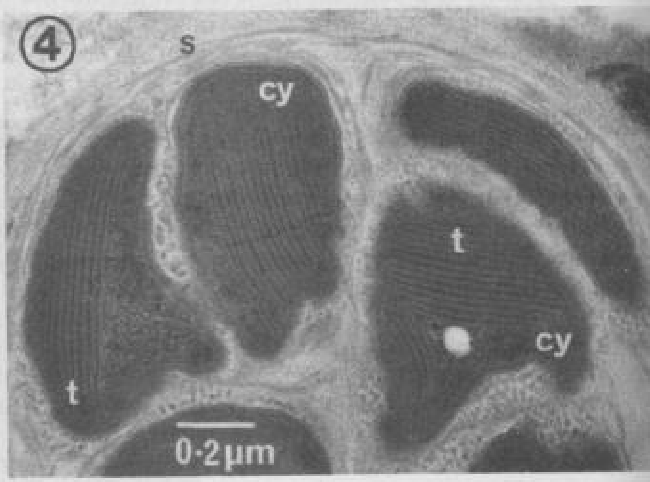
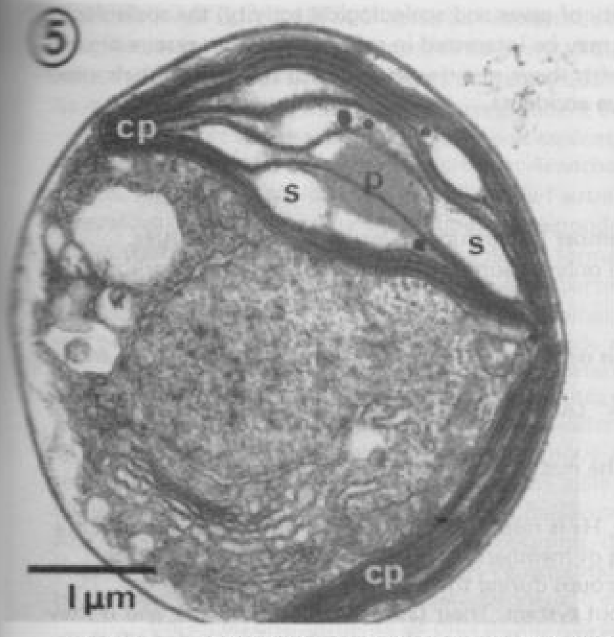


Fig. 3 Part of the chlorplast (cp) of a *Chlorella* cell from the cave, at high magnification. Note how densely the membranes are packed. w - part of the cell wall. × 55 000

Fig. 4 Part of one of the cyanophyte colonies seen in Fig. 2. The thylakoids (t) are densely packed, though less so than in the *Chlorella* chloroplast. s - shearth; cy - individual cell of the cyanophyte. × 50 000

the cell. In culture the cyanophyte *Chlorogloea fritschii* shows the first pattern under high light levels and the second in low light (Peat & Whitton, 1967) though many species show only one or the other arrangement. Both patterns (in different species) were found at the Hennings Cave site. However, since the 'low light' conditions of Peat & Whitton's experiment were around 200 1x (1000x the illumination in the cave!) neither form can be regarded as an adaptation to the deep twilight zone. These species could well be strays from better-lit regions of the cave entrance. A third species (tentatively *Chroococcus* sp., following Stanier, Kunisawa, Mandel & Cohen-Bazire, 1971), showed a completely new thylakoid arrangement (Figs. 2 & 4). This was also the smallest species found, with cells 0.5 – 1 µm in diameter arranged in spherical colonies, 2 µm across, enclosed in a common microfibrillar sheath. The thylakoids are arranged in close-packed parallel arrays; not quite so densely arranged as in the *Chlorella,* since the membranes are noticeably paired, but still reaching 53 thylakoids/µm (or 106 membrane cyanophytes, and must be an adaptation to a very low light existance. The *Chroococcus* has not yet been isolated in culture, so its response to higher light levels still awaits investigation.



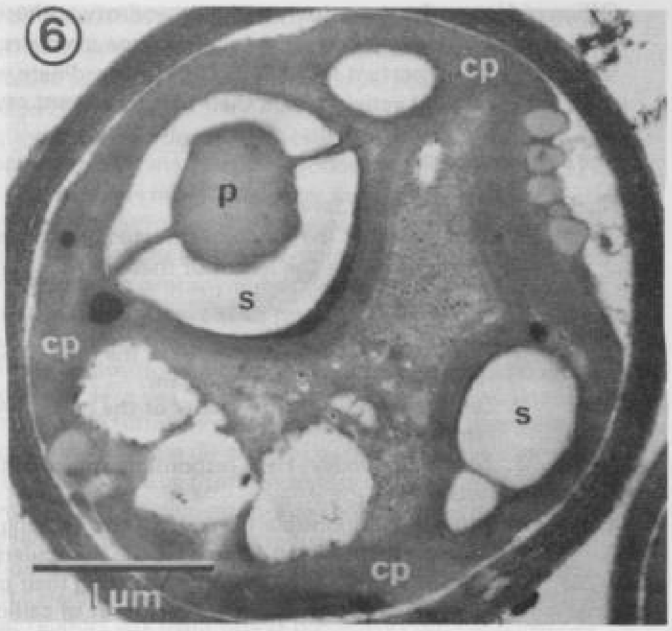


Fig. 5 *Chlorella pyrenoidosa* [strain 211/86 CCAP] from a laboratry culture. The thylakoids in the chloroplast (cp) are much less densely packed than in the cave *Chlorella*. The chloroplast contains a pyrenoid (p) and starch grains (s). × 17 000

Fig. 6 *Chlorella sp.* from Hennings cave grown in culture conditions similar to those of *C. pyrenoidosa* in Fig. 5. The chloroplast (cp) occupies a similar position in the cell; a pyrenoid (p) is visible and starch grains (s) are very much in evidence. The thylakoids, however, remain so densely packed that, at this magnification, they can barely be distinguished. × 24 000

Conclusions

Only simple, single-celled microorganisms are able to survive photosynthetically in the very low light conditions found well inside cave entrances. One Chlorococcalean alga, *Chlorella* sp., and one Chroococcalean cyanophyte, *Chroococcus* sp., shows a very marked increase in thylakoid density, presumably in adaptation to these conditions.

Acknowledgements

Our thanks are due to Helen Scott for her capable sectioning of some technically very demanding material.

References

Boardman, N.K., Anderson, J.M. Björkman, O., Goodchild, D.J. Grimme, L.H., & Thorne, S.W. 1974. Chloroplast differentiation in sun and shade plants: relationship between chlorophyll content, grana formation, photochemical activity and fractionation of the photosystems. *Port. Act. Biol.* Ser. A, *14*, 213-236.

Peat, A. & Whitton, B.A. 1967. Environmental effects on the structure of the blue-green alga *Chlorogloea fritschii*. *Arch. Mikrobiol*, *57*, 155-180.

Skene, D.S. 1974. Chloroplast structure in mature apple leaves grown under different levels of illumination and their response to changed illumination. *Proc. Roy. Soc. Lond. B 186*, 75-78.

Stanier, R.Y., Kunisawa, R. Mandel, M. & Cohen-Bazire, G. 1971. Purification and properties of unicellular blue-green algae (order Chroococcales). *Bact. Rev. 35*, 171-205.

THE STRUCTURE AND ACTIVITY OF THE HUNGARIAN CAVE RESCUE SERVICE

Laszlo Csernavolgyi
H-1092 Budapest
Kinizsi u. 22, Hungary

The CRS is a social organisation, founded to search, give first-aid and carry to a safe place those people who suffered an accident or lost their way and are in danger of their life in a cave or other inaccessible place.

The statistics of the past 15 years more and more confirm the need for the CRS and particularly the desirability of better qualifications. There were 4 call-outs in 1960-65; 12 in 1966 to 1970 and 38 in 1971 to 1975. The persons rescued in the same period were 4 in 1960-65, 24 in 1966-1970, and 47 in 1971-75.

The members of the CRS are those speleologist sportsmen, who, with several years caving experience, good technical and first-aid knowledge are up to the aims of the Service. They voluntarily and consciously assume the prescribed discipline, the difficulty and danger of this work.

The CRS is assisted by other organisations, first by the different sections of the Ministry of Interior, as they often need the help of the service, the Hungarian Speleological Society, the OTvH (Hungarian National

Office of Nature Conservation), as the supervisory authority of caves and speleological activity, the speleological departments of different sports clubs, whose members may be interested in rescue, and other rescue organisations. It is an important task of the CRS to coordinate with above mentioned and with the help of their experience, proposals and activity to do their best to prevent cave accidents.

The structure of the CRS

A., The leadership of the Service

1. The labour of the service is directed by a 3 member leadership – a leader and two deputies.
2. During a rescue the leader of that action is the only responsible director of the rescue work.

B., The structure of the Service

1. *The leader of the Service* – with the help of his deputies – directs the activity of the Service and represents it before other organs.
2. *Operative deputy* is the leader of the group "A" (Alarm). He is responsible for the arranging of rescues.
3. *Technical deputy*. He is responsible to assure the material, financial and technical conditions of rescue work.
4. *Official* – responsible for registry and training. He is responsible for arranging training and practise sessions, and to keep up to date the particulars of members and call-out plans.
5. *Leaders of groups* – They are directing their groups during the rescue.
6. *The "A" group* – This is the first unit of call-out system. Their task is to find the place, and if they are enough to solve the problem to arrange the rescue. If some other members are needed till their arrival the "A" group has to do the most important preparations.
7. *Additional team* – Second level of the call-out system. These are members of CRS but not of the "A" group.
8. If it is necessary, the additional supply may be given by all other people who are interested in cave-tourism and are skilled in cave communication and are reachable.

Experience of CRS

With growing cave tourism, the number of cave accidents are also increasing. This may be only simply losing the way or serious injury. The accidents happen mostly near Budapest, as in the Buda-hills more than 100 dangerous caves and clefts can be found. Figures 1 and 2 represent the growing number of accidents. Most of these cases happened in the above mentioned Buda territory.

The tasks of the CRS are also increasing. Today the well-organised call-out system and the ability of quick and effective help are basic requirements.

It is a very important aspect to try to prevent accidents by appropriate propaganda. This can be given by radio, papers and special cave publications. The CRS in the interest of the more effective work, is sending representatives to the meetings organised by UIS Cave Rescue Committee. The knowledge obtained at these meetings is very useful for practice work.

It is a serious problem of our activity, that we have no possibility to buy all the modern means of rescue work in home trade, so we have to manufacture or to let them be manufactured for the CRS by craftsmen, or industrially.

Most of the accidents are in connection with this problem, because our caves have still less possibility to obtain the necessary equipment.

CERTAINS CRITERES D'IDENTIFICATION DES RAPPORTS DE PARENTE ENTRE LES GENRES DE LA FAMILLE DES NEOBISIIDAE (PSEUDOSCORPIONES, ARACHNIDA)

Bozidar P.M. Ćurčić
Institute za zoologiju, Prirodno-matematicki fakultet,
Univerzitet u Beogradu, 11000 Beograd.
Yugoslavia

How to determine affinity is the crucial problem in classification; it is of extreme important in delimiting the genus as well as in determining the related genera. To provide a sound and stable classification, it is necessary to analyse the data on the species that constitute a genus in correlation with the geographic distribution of members of such a taxon.

If one follows the assumption that the genus is the lowest among the higher categories and the lowest category that is characterised by strictly comparative data, the aim of this work has been how to determine affinity between genera on the basis of the comparative morphology of their species as well as on the geographic origin of genera. In that sense, six genera of the pseudoscorpion family Neobisiidae have been studied; they are *Neobisium* Chamberlain 1930, *Novobisium* Muchmore 1967, *Roncus* L. Koch 1873, *Acanthocreagris* Mahnert 1974, *Roncocreagris* Mahnert 1974 and *Balkanoroncus* Curcic 1975.

Prenant en considération les bases sur lesquelles un genre est fondé, nous avons essayé, dans ce travail, de déterminer, à partir des données morphologiques comparées des espèces, le degré, de parente entre six genres de la famille des Neobisiidae (Pseudoscorpiones, Arachnida); ce sont *Neobisium* Chamberlin 1930, *Novobisium* Muchmore, 1967, *Roncus* L. Koch 1873, *Acanthocreagris* Mahnert 1974, *Roncocreagris* Mahnert 1974 et

Balkanoroncus Curcic 1975. D'après les résultats de nos recherches (Curcic 1977) et d'après ceux des autres chercheurs, on distingue deux groupes de genres. Pour les deux groupes des genres indiqués on peut souligner un complexe de caractères identiques de nature qualitative surtout, qui indiquent une parenté mutuelle entre les genres dans le cadre d'un groupe correspondant de genres.

D'après les caractères communs aux espèces, il est possible de repartir les genres étudiés en deux groupes de genres apparentés, notamment le groupe: *Acanthocreagris, Balkanoroncus* et *Roncocreagris* d'une part et le groupe: *Neobisium, Novobisium* et *Roncus* de l'autre. Les données morphologiques comparées, constatées chez les espèces de ces genres dans les groupes correspondants sont: l'existence, ou l'absence, des chètes accessoires sur les sternites abdominaux, forme de galéa et forme du flagelle. Les propriétés mentionnées caractérisent les espèces de chacun des groupes de genres cités à partir du stade de protonymphe déjà. Non moins importants sont la forme et la position mutuelle des sacs génitaux et le nombre des chètes maxillaires, qui caractérisent les espèces des groupes de genres étudiés, mais au stade adulte seulement.

D'après les traits mentionnés, on peut déterminer la position de chaque genre dans le cadre du groupe correspondant. Ainsi, par exemple, les particularités du complexe des caractères metionnés ci-dessus, telles la présence des chètes accessoires sur les sternites abdominaux, la forme de galéa et la structure du flagelle chez les espèces de l'*Acanthocreagris* placent, selon nous, ce genre à la base du groupe des genres qui lui sont apparentés. Les caractéristiques de l'appareil génital mâle des espèces de ce genre en sont la preuve. Par rapport à l'*Acanthocreagris*, chez les représentants du *Balkanoroncus* les changements qui se sont produits ont été orientés vers la réduction du nombre des chètes accessoires, la réduction de galéa et la réduction du nombre de soies flagellaires penniformes et dentelés (vers l'augmentation du nombre de soies flagellaires lisses). Ce qui caractérise encore les représentants du *Balkanoroncus*, c'est l'élargissement de tous les trois sacs génitaux.

Enfin, les changements les plus prononcés par rapport aux deux genres précédents ont été constatés chez les espèces du genre *Roncocreagris*, surtout en ce qui concerne la structure du flagelle (tous les soies flagellaires sont dentelés d'un côté) et l'aspect des sacs génitaux (les sacs latéraux s'allongent et le sac médian racourcit). D'après tout ce qui vient d'être exposé, et d'après les caractéristiques comparées des espèces, le genre *Acanthocreagris* est plus primitif que les deux autres genres apparentés, le *Balkanoroncus* et le *Roncocreagris*. Il est également probable que le *Roncocreagris* soit plus éloigné du genre *Acanthocreagris* que ce n'est le cas du genre *Balkanoroncus*.

La preuve de la parenté et de l'origine commune éventuelle du groupe de genres cités *(Acanthocreagris, Balkanoroncus* et *Roncocreagris)* est fournie également par la distribution géographique de leurs espèces. Ainsi, les espèces du genre *Acanthocreagris* (on en connait 24 en tout) peuplent les régions septentrionales de la Méditerranée, avec deux centres de radiation. Dix espèces (ou 41.67% du nombre total) sont représentées dans les régions occidentales de la Méditerranée (Espagne, France, Italie) tandis qu'on trouve également dix espèces (41.67% du nombre total) sur la Péninsule Balkanique. Un certain nombre d'espèces (quatre ou 17.66%) ont été constatées en Asie Mineure et en Iran. Le genre *Balkanoroncus*, dont on ne connaît que deux espèces jusqu'à présent, provient de la partie orientale de l'aire de distribution du genre précédent (Bulgarie), tandis que le *Roncocreagris*, avec toutes ses espèces connues (lo en tout) peuple uniquement la partie occidentale de l'aire du genre *Acanthocreagris* (Portugal, Espagne, Suisse, Grande Bretagne).

Le *Neobisium*, le *Novobisium* et le *Roncus* constituent le second groupe de genres apparentés. D'après les caractères idéntiques qui ont été analysés chez les espèces du groupe précédent, dans ce groupe de genres on distingue également des différences au niveau de l'organisation. C'est ainsi que le *Neobisium* constitute la base à partir de laquelle il est permis de suivre les changements de l'organisation mentionnée orientés vers les représentants du genre *Novobisium* et du genre *Roncus*. Tandis que chez les représentants du *Neobisium*, par exemple, les sacs génitaux sont recourbés, longs et cylindriques, chez le genre *Novobisium* ceux-ci changent en ce sens qu'ils deviennent plus courts et tendent à se redresser et que chez les espèces du *Roncus* les sacs génitaux sont presque droits, ou très peu recourbés, et courts. Certains autres caractères (la forme et la position des soies flagellaires, par exemple) présentent des changements déterminés dans le sens qui va des espèces du *Neobisium* jusqu'à celles du genre *Roncus*. Il est évident que le groupe des caractéristiques mentionnés chez les espèces de ces genres est signe indicatif pour déterminer la parenté entre les genres.

La distribution des espèces de ce groupe de genres est, elle aussi, au profit de l'estimation de la parenté assez proche des genres *Neobisium, Novobisium* et *Roncus*.

Résumé et conclusions

D'après les caractéristiques communes des espèces, on a constaté deux groupes de genres: (1) *Acanthocreagris, Balkanoroncus* et *Roncocreagris*, et (2) *Neobisium, Novobisium* et *Roncus*. Des traits communs caractérisent les genres apparentés de chacun des groupes constatés: l'existence, ou l'absence, de chètes accessoires sur les sternites abdominaux, la forme de galéa, la forme du flagelle, la forme et la position mutuelle des sacs génitaux et le nombre des chètes maxillaires.

D'après l'organisation étudiée des espèces, on a évalué la position des genres dans chaque groupe de genres. A la base du premier groupe se situe le genre *Acanthocreagris*; ses parents, le *Balkanoroncus* et le *Roncocreagris* ont subi divers changements par rapport au genre *Acanthocreagris*. D'après les mêmes données morphologiques comparées des espèces, on a également constaté des régularités dans le rapport mutuel des genres du second groupe; le *Neobisium* se situe à la base du second groupe et ses parents: le *Novobisium* et le *Roncus* ont subi des changements spécifiques par rapport au *Neobisium*.

Etant donné que les caractéristiques géographiques sont en correlation avec la certitude de la classification des taxa supérieurs, on a analysé le problème de l'origine géographique des genres de chaque groupe de genres en particulier. Par conséquent, la distribution géographique des espéces de chacunà donné comparison

sur leur répartition, les espèces du genre *Neobisium* ont été constatées surtout en Europe et en Asie Mineure. Cependant, on peut souligner que sur les 155 espèces connues de ce genre, la majorité (soit 132 espèces ou 85.16% du nombre total) peuplent la Méditerranée septentrionale. Du nombre total des espèces connues habitant ces régions, 75 espèces ou 56.82% sont endémiques dans les régions de la Pêninsule Balkanique, de sorte que l'on pourrait considérer cette région comme centre de radiation du genre.

Par les spécificités communes à toutes ses espèces, le *Novobisium* est très proche du genre *Neobisium* et, selon toute apparence, il provient d'ancètres apparentés au *Neobisium*, constituant ainsi une branche latérale isolée, selon les données actuelles, dans les régions de la partie est et sud-est de l'Amérique du Nord.

Cinquante espèces du genre *Roncus* sont connues jusqu'à présent, dont 45 sont répandues dans la partie septentrionale de la Méditerranée; parmi ces espèces, 27 (ou 60.00% du nombre total) proviennent de la Péninsule Ibérique et de la Péninsule des Apennins, tandis que 18 espèces (ou 40.00% du nombre total peuplent la Péninsule Balkanique).

Il est nécessaire de souligner que l'abondance des espèces endémiques des deux groupes de genres mentionnés, surtout sur les Peninsules Ibérique et Balkanique, est étroitement liée à leur provenance des milieux souterrains. Certaines espèces du genre *Novobisium* en Amérique du Nord proviennent aussi de stations souterraines. Un grand nombre de nouvelles espèces des genres étudiés (les espèces des genres *Acanthocreagris, Neobisium, Roncocreagris* et *Novobisium)* et même des genres nouveaux des groupes de genres mentionnés témoigne aussi de leur parenté et de leur origine éventuelle (aspect phylogénétique).

Dans l'aire de distribution du genre *Acanthocreagris* on trouve surtout les aires des espèces des genres *Balkanoroncus* et *Roncocreagris*. La distribution des espèces endémiques du genre *Roncus* s'insère dans l'aire du genre *Neobisium*, à cette différence près que les centres de radiation des deux groupes se trouvent dans des régions géographiques différentes: du genre *Neobisium* sur la Péninsule Balkanique surtout, et du genre *Roncus* surtout dans la partie septentrionale de la Méditerranée du Nord. Le genre *Novobisium*, avec ses espèces endémiques de l'Amérique du Nord, représente, selon toute apparence, la branche latérale du groupe de genres étudié.

Les caractères morphologiques comparés des espèces, ainsi que la distribution des espèces qui entrent dans la composition du taxon supérieur correspondant, sont d'une importance toute particulière pour l'interprétation de l'aspect phylogénétique des taxa supérieurs, c'est-à-dire des genres et des groupes de genres de la famille des Neobisiidae.

References

Cain, A.J. 1956. The genus in evolutionary taxonomy, *Syst. Zool.*, 5, 91-109.

Ćurčić, B.P.M. 1975. *Balkanoroncus* (Arachnida, Pseudoscorpiones, Neobisiidae), a new genus of pseudoscorpions based on *Roncus bureschi* Hadzi 1939. *Bull. Mus. Hist. Nat. Belgrade*, 30B, 143-145.

Curcic, B.P.M. 1977. Uporedno-morfoloska obelezja — njihov znacaj i primena u klasifikaciji taksona porodice Neobisiidae (Pseudoscorpiones, Arachnida). Belgrade Univ., Ph. D. Thesis.

Mayr, E. 1969. *The principles of systematic zoology*, McGraw-Hill, New York.

1976. Species concepts and definitions. In: *Topics Phil. Biol. Dordrecht-Boston*, 353-371.

Mahnert, V. 1974. *Acanthocreagris* nov. gen. mit Bermerkungen zur Gattung *Microcreagris*, *Rev. suisse Zool.*, 81, 845-885.

1976. Zur Kenntnis der Gattungen *Roncocreagris* und *Acanthocreagris*. *Rev. suise Zool.*, 83, 193-214.

Muchmore, W.B. 1967. *Novobisium* (Arachnida, Chelonethida, Neobisiidae, Neobisiinae), a new genus of pseudoscorpions based on *Obisium carolinensis* Banks. *Ent. News*, 78, 211-215.

Simpson, G.G. 1961. *Principles of animal taxonomy*. Columbia University Press, New York.

BREAKOUT DOMES IN SOUTH WALES CAVES

C.W. Davies

University College, Swansea, Wales.

Cavern breakdown is the term originally adopted by American speleologists to describe the large products of bedrock collapse found in caves. W.E. Davies (1949), working in West Virginian caves, classified the products of breakdown according to shape: block, slab, chip and plate. A classification by White and White (1969) combined chip and plate breakdown to cover material derived from the fragmentation of a single bed. An attempt to explain form and development of cavern breakdown was made by Davies (1951) by the application of basic engineering principles employed by mining engineers. Ceiling strata were regarded as fixed beams with span equal to the passage width and thickness equal to the bedding thickness. If the rock is broken or well jointed cantilever beams may develop. However, it is assumed that the mechanical strength of the beam is stronger than the bedding plane junction. In horizontally bedded rocks, small elastic sags separate individual roof strata (Davies, 1951); rock fracture in such a sagging ceiling beam, according to Davies, is likely to occur at the areas of most tension, namely in the centre of the chamber and close to its walls. He considered that subsequent collapse of ceiling beds through successive strata produced a dome-shaped chamber which is often capped by a thicker competent bed. Detailed observations by White and White (1969) in large cavern breakdown areas of the Central Kentucky and Appalachian Mountain Karsts reveal a range of domes sizes. They are said to vary from 3 metres in diameter, which involve only one or two beds, to large chambers such as 'Chief City' in Mammoth Cave, with floor dimensions of over 30 metres and ceiling

heights of nearly 30 metres. The term 'breakout dome' is used by White and White (1969) to apply to features of all sizes.

A debris cone is a characteristic feature associated with the breakout dome, and appears to vary in size from dome to dome. White and White (1969), suggest circulating waters at the base of the dome may reduce the size of the debris pile in some cases, this may allow further enlargement by progressive spalling of the walls.

Although no large breakout domes of the tension dome type have been recognised in British caves, distinctive breakout domes formed in shaly limestones can be found in some caves of South Wales.

Breakout domes in South Wales

The writer has identified breakout domes in some caves in South Wales in the caves of the Llangattwg Escarpment near the village of Crickhowell, Powys. The area is situated on the edge of the South Wales coalfield syncline, underlain by Old Red Sandstone; the limestone comprises in the main, a truncated sequence of Avonian (Carboniferous) limestones capped by Namurian grits and shales (North, 1955). The Avonian Limestone is 140 metres thick, comprising limestone shale (35 metres), an oolite group (40 metres), a calcite-mudstone group (18 metres) and the varied limestones of the Seminula zone (50 metres) (after Leitch 1960). Structurally, the area contains few faults and the bedding dips gently to the south (5 – 10°) in accordance with the major syncline development of the coalfield basin (George, 1954).

Many caves are known in the area, the largest and most impressive system with over 21 Km of passage is Ogof Agen Allwedd. Of the smaller caves, Ogof Daren Cilau approximately 2000 metres, is of note here.

Most of the caves at Llangattwg are situated within the Oolite group; few openings are known in the other potentially speleogenetic group in the Seminula zone. Although cave passages are found at all levels within the oolite group, many are aligned along the underside of impure bands (about 1 metre thick), of dolomite. This appears anomalous as one might expect passages to develop in the limestone lying on top of an impervious layer rather than in the limestone immediately beneath the shale layers. Higher passages occasionally develop exposing the grey-green shales of the upper oolite and the calcite-mudstone group. These beds are composed of alternating shales and sandy limestones 13-18 metres in thickness. Individual layers of shale and limestone range from a few millimetres to 0.25 metres, but the distinctive grey-green and purple shales are more abundant than the dark brown sandy limestones. It is at these contact points in the higher passages that breakout domes are to be found.

Breakout domes are evident in Ogof Agen Allwedd and Ogof Daren Cilau. Agen exhibits several examples, notably in Erse Passage and the Inner Circle Passage, the largest of which, found in the latter passage, is 25 metres across and known as St. Pauls. One breakout dome had been found in Daren Cilau, above the approach passage to the final chamber. In figure 1, the plan, profile and cross-section of the above mentioned breakout domes is illustrated.

All the breakout domes are roofed by a broad flat limestone bed, containing a well defined pattern, of irregularly surfaced, closed joints. The faces of protruding beds correspond in alignment with the joint pattern. There is no evidence to show that percolation of water occurs through the joints.

Three breakout domes are circular in form: the breakout dome in Ogof Daren Cilau, the second breakout dome in Erse Passage and the smaller breakout dome in the Inner Circle Passage. The other breakout domes are ellipsoid in form, the longer axis being in line with the passage below for the first and third breakout domes in Erse Passage, but at right angles to the passage in St. Pauls.

In all instances the dome base which lies along the limestone-shale junction is broader in section than the underlying cave passage contrary to any domes described in the United States.

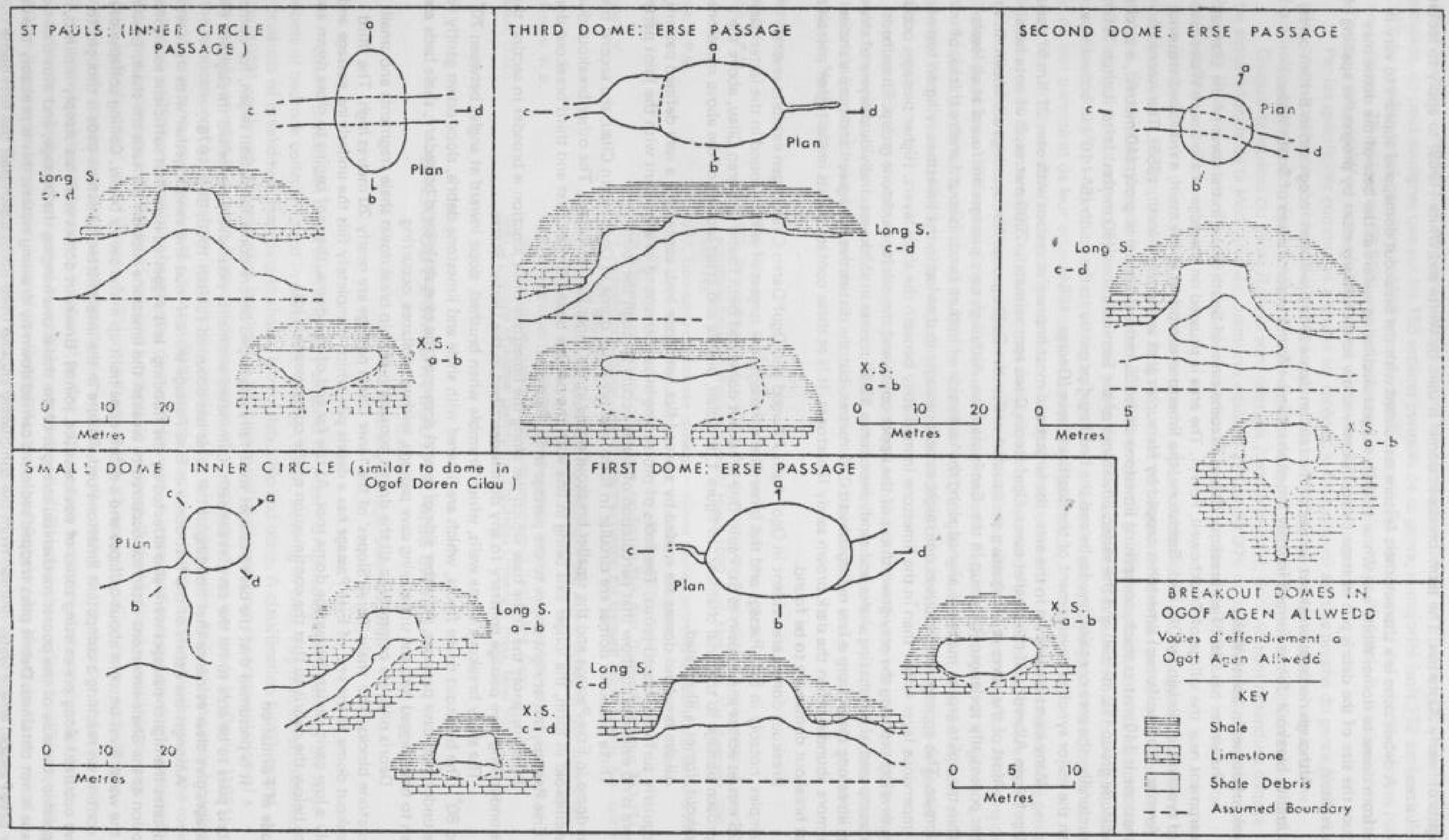
The shaly breakout dome walls, which crumble when brushed, slope inward at angles between 70° and 80°. The breakout dome floors, which are littered with shale and limestone debris, slope down gently to the underlying cave passages. At either side of several domes of the cave shale-band boundary, shale beds are seen to have sagged into the underlying cave passage, without collapse occurring.

Debris piles are common to all the domes consisting of chip breakdown shale fragments and small limestone blocks. The shaly 'Scree Slopes' of the Inner Circle passage are nearly 20 metres high. The third breakout dome at the end of Erse Passage has a debris pile which completely fills the underlying passage and only a low cavity exists below the dome root. At the far end of this dome, the roof begins to close down and dips below the debris so that the continuation of the core passage is lost.

Mode of Formation

It is presumed that the cave passages were fully developed before dome formation began, for dome debris piles to be able to fill the cavities beneath. Laminated sediments extensively deposited throughout the passages give clear evidence that flooding of the caves has occurred (Leitch 1960; Bull, 1976).

Amongst the debris of the first dome in Erse Passage there is mud and sand together with shale which indicates the higher passages were also affected by the flooding. It is suggested here that sufficient solutional erosion at the Shale-limestone interface occurred to weaken the limestone support beneath the shale. Lowering at the water level brought about collapse and a debris cone built up in the cavity below. Ceiling collapse ceased to contine on reaching a competent limestone bed. Failure in the intermittent limestone beds is thought to have occurred along pre-existing zones of weakness (i.e. joints). Breakout domes walls are steeply inclined, it is suggested, because of the poorer mechanical strength of the shales overhanging the passage, and thus true dome shape is not obtained. Debris piles trapped sediment carried down by draining waters; this is probably the case for Erse Passage, where water drained from the completely choked third dome down past the first dome to Main Passage (the main drain). (per comm. Bull 1976).


ST PAULS: (INNER CIRCLE PASSAGE)
Plan
Long S. c-d
X.S. a-b
Metres
THIRD DOME: ERSE PASSAGE
Plan
Long S. c-d
X.S. a-b
Metres
SECOND DOME. ERSE PASSAGE
Plan
Long S. c-d
X.S. a-b
Metres
SMALL DOME INNER CIRCLE (similar to dome in Ogof Doren Cilau)
Plan
Long S. a-b
X.S. c-d
Metres
FIRST DOME: ERSE PASSAGE
Plan
Long S. c-d
X.S. a-b
Metres
BREAKOUT DOMES IN OGOF AGEN ALLWEDD
Voûtes d'effondrement à Ogof Agen Allwedd
KEY
Shale
Limestone
Shale Debris
Assumed Boundary

Conclusions

The factors leading to the development of the Llangattwg breakout domes are summarised as follows:

1. Cave passages develop in an oolite limestone which lies immediately beneath a mechanically incompetent rock series.
2. During one or more periods of flooding water stands within sections of the cave passages leading to weathering at the contact zone.
3. Drainage of the passages is followed by collapse of the weathered incompetent beds until a stable ceiling bed is reached.

A detailed understanding of the mechanisms of dome collapse has yet to be reached. The writer is presently undertaking an analysis of the mechanics of dome formation in order to find critical stress field relationships to ceiling bed thickness. Where domes are elliptical in shape, more complex mathematics are needed to account for a three dimensional stress relationship. The situation is to be modelled using a two dimensional plane strain finite element idealisation. Briefly, the method introduces a network of imaginary lines to the rock mass surrounding the cave to form a number of 'finite elements'. Details of the type of rock, its structure and strength properties are ascribed to each element and a two dimensional stress pattern around the cave is resolved.

Acknowledgements

The author gratefully acknowledges the helpful comments from Miss. G. Groom and Dr. P. Bull, and would like to thank the Nature Conservancy and Agen Allwedd Cave Management Committee for permission to work in the caves.

References

Bull P.A. 1976. *'A Cave Sediment Study in South Wales'*, Unpub. Ph.D. Thesis, University of Wales.
Davies, W.E. 1949. 'Features of Cavern Breakdown', *Bull. Natl. Speleol. Soc. Amer.* Vol. 11, pp.34-35,72.
Davies, W.E. 1951. 'Mechanics of Cavern Breakdown', *Bull. Natl. Speleol. Soc. Amer.*, Vol. 13, pp.36-43.
George, T.M. 1954. 'Pre-seminula Main Limestone of the Avonian Series in Breconshire', *Quart. Journal Geol. Soc. London*, 110, p. 283.
Leitch, D.E. 1960. 'Ogof Agen Allwedd in Relation to the Mynydd Llangattwg', *Cave Research Group of G.B. Special pub.* No. 10, p. 56.
North, F.J. 1955. 'The Geological History of Brecknock'. *Brycheinog*, Vol. 1, The Brecknock Society.
White, F.L. & White, W.B. 1969. 'Processes of Cavern Breakdown', *Bull. Nat. Speleol. Soc. Amer.*, Vol. 31, No. 34.

SURFACE ROUGHNESS IN TROPICAL KARST TERRAIN

Michael J. Day
Department of Geography,
University College Dublin, Belfield,
Dublin 4, Ireland.

One approach to the description of terrain in unambiguous, numerical terms, within the context of what Evans (1972) has termed general geomorphometry, is the estimation of surface roughness (Dellwig and Moore, 1966; Hobson, 1967, 1972). The definition of surface roughness is somewhat problematic (Hobson, 1972) the objective being to describe a landscape on the basis of its surface irregularities or non-systematic elevation changes.

Tropical karst, characterised by surface irregularities, is amenable to roughness quantification yet there exists no published attempt to apply this or other general geomorphometric techniques to the analysis of such terrain, previous morphometric analysis (Williams, 1971, 1972a, b; Day, 1976) being of the specific type (Evans, 1972). The following paragraphs indicate the possible application of surface roughness determination to the description and classification of tropical karst styles.

Procedure

Hobson (1972) examines three parameters which describe terrain roughness. These are (1) the comparison of estimated actual surface area with the corresponding planar area, (2) the estimation of 'bump' or elevation frequency distribution and (3) the comparison of the distribution and orientation of approximated planar surfaces within sampling domains. Of these three parameters the third was selected for trial in the present context.

The structure of the sampling design is crucial to the use of this technique, particularly with respect to the spacing of the sampling grid. Grid spacing will have a marked effect upon roughness values in that height variation will increase with increasing number of sampling points (Figure 1).

The data required for this determination, an array of regularly spaced elevation within a sample area, was derived from topographic maps of various scales. Ten small ($1km^2$) sample areas were selected, covering a range of terrain types from subdued 'doline' karst to impressive 'tower' karst which occur in Central America and the Caribbean islands (Table 1). These ten sample areas were gridded at 200m. intervals, twenty-five points thus being sampled for elevation within each $1km^2$ area. This grid spacing was subjectively selected as being sufficiently fine to sample within the majority of topographic locations within each sample area.

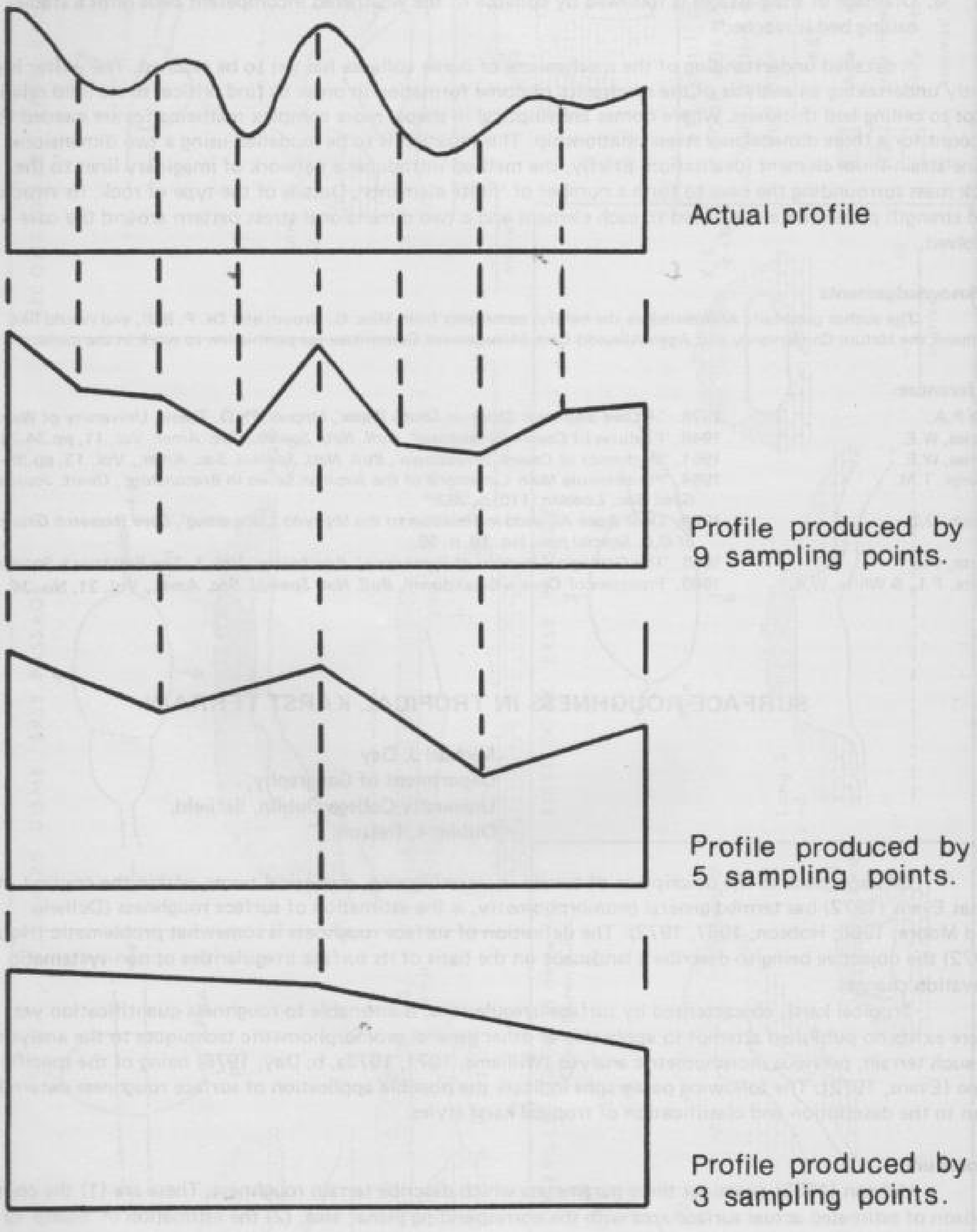


FIG. 1. The effect of sample spacing on roughness determination.

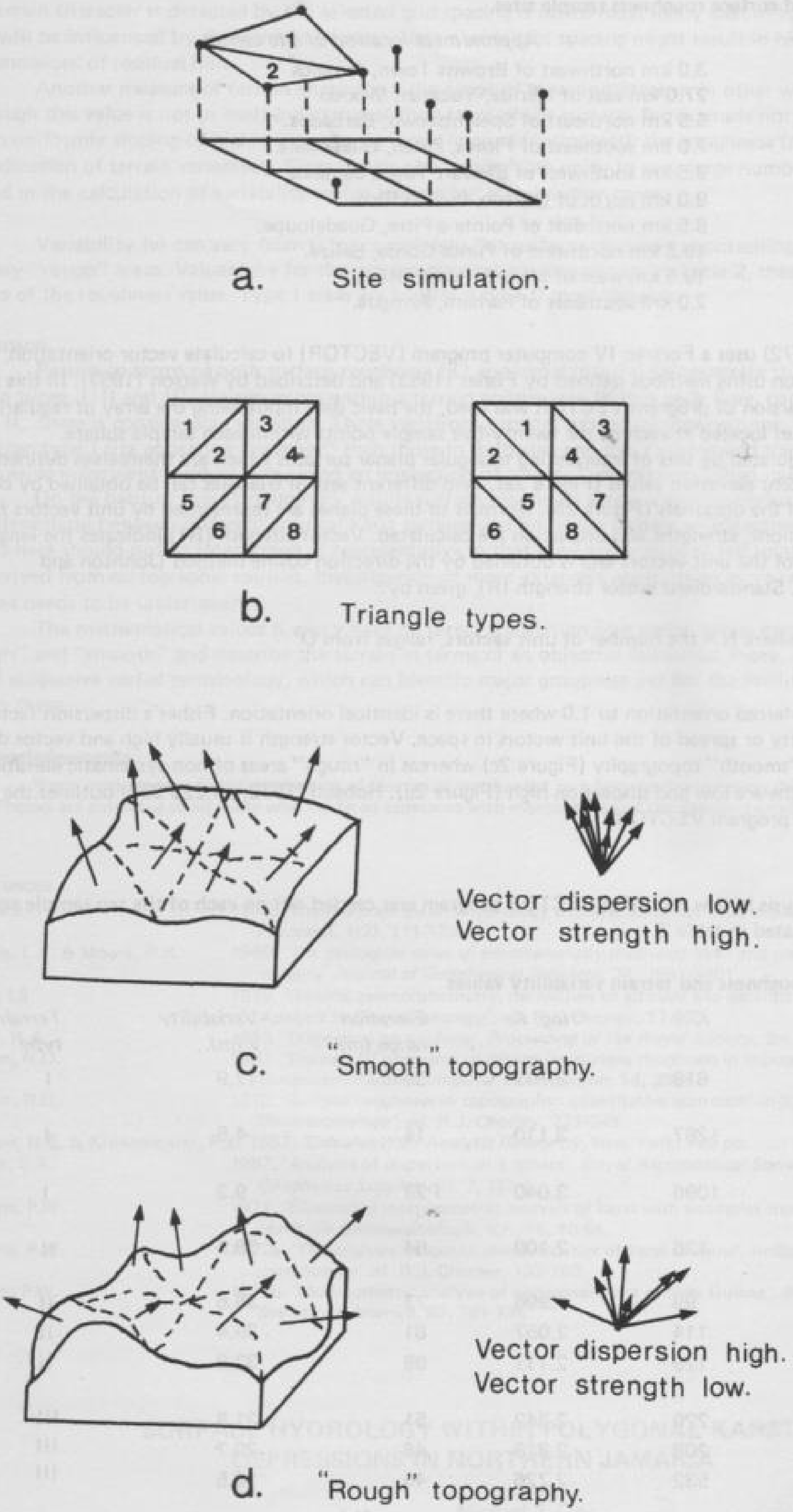


FIG. 2. Precedures involved in program VECTOR. (modifed after Hobson, 1972).

TABLE 1 Location of surface roughness sample sites.

Site number	*Approximate location of site centre.*
Ja. 1.	3.0 km northwest of Browns Town, Jamaica
Yuc. 1.	27.0 km east of Merida, Yucatan, Mexico
Bar. 1.	5.5 km northeast of Speightstown, Barbados.
Guat. 1.	7.0 km southeast of Flores, Peten, Guatemala.
Ja. 2.	3.5 km southwest of Stewart Town, Jamaica.
P.R.1.	9.0 km north of Utuado, Puerto Rico.
Guad. 1.	8.5 km northeast of Pointe-a-Pitre, Guadeloupe.
Bel. 1.	19.5 km northwest of Punta Gorda, Belize.
P.R.2.	19.5 km west of Manati, Puerto Rico.
Ant. 1.	2.0 km southeast of Parham, Antigua.

Hobson (1972) uses a Fortran IV computer program (VECTOR) to calculate vector orientation, strength and dispersion using methods defined by Fisher (1953) and described by Watson (1957). In this study a slightly modified version of program VECTOR was used, the basic data input being the array of regularly spaced elevation values located at each of the twenty-five sample points within each sample square.

Sites are simulated by sets of intersecting triangular planar surfaces which are themselves defined by groups of three adjacent elevation values (Figure 2a). Two different sets of triangles can be obtained by changing the orientation of the diagonals (Figure 2b). Normals to these planes are represented by unit vectors from which vector orientations, strengths and dispersion are calculated. Vector strength (R1) indicates the length of the resultant sum of the unit vectors and is obtained by the direction cosine method (Johnson and Kiokemeister, 1957). Standardised vector strength (R), given by:

$$R = \frac{\sqrt{R1^2}}{N}$$

, where N = the number of unit vectors, ranges from O

where there is no preferred orientation to 1.0 where there is identical orientation. Fisher's dispersion factor (K) indicates the variability or spread of the unit vectors in space. Vector strength is usually high and vector dispersion low in areas of "smooth" topography (Figure 2c) whereas in "rough" areas of non-systematic elevation change vector strengths are low and dispersion high (Figure 2d). Hobson (1972, pp.229-230) outlines the calculations involved in program VECTOR.

Results

Terrain analysis by the modified VECTOR program was carried out on each of the ten sample squares with the results indicated in table 2.

TABLE 2. Surface roughness and terrain variability values

Site location and number	*K*	*log. K.*	*Elevation range (m)*	*Variability v (m).*	*Terrain type*
North Central Jamaica (Ja.1.)	619	2.792	36	12.9	I
Northern Yucatan. (Yuc.1.)	1287	3.110	14	4.5	I
Northern Barbados (Bar.1.)	1096	3.040	28	9.2	I
Guatemala (Peten) (Guat.1.)	126	2.100	64	30.5	II
Jamaica (Ja.2.)	99	1.996	73	36.6	II
Puerto Rico (Pr.1.)	114	2.057	81	39.4	II
Guadaloupe (Guad.1.)	129	2.111	68	32.2	II
Belize (Bel.1.)	220	2.342	51	21.8	III
Puerto Rico (Pr.2.)	208	2.318	48	20.7	III
Antigua (Ant.1.)	532	2.726	45	16.5	III

Fisher's dispersion factor (K) is defined by: $K \frac{N-1}{N-R1}$

Where N is the number of observations (triangles) and R1 the vector strength. In "smooth" terrain K approaches infinity because unit vectors tend to the same orientation, thus R1 approaches N and N-R1 tends to zero. Conversely in "rough" terrain R1 tends to zero and thus K approaches 1.0.

K values presented in Table 2 demonstrate an apparent grouping of the terrain types into three classes, here termed I, II and III. These grouping subjectively correspond to 'doline', 'cockpit' and 'tower' karst. Of these type I is the "smoothest" and type II the "roughest", type III being intermediate. Although in all types the essen-

tial terrain character is detected by the selected grid spacing it seems most likely that in type III terrain the results will be influenced by this sampling factor. Here a wide grid spacing might result in high K values through the 'omission' of residual hills.

Another measure of terrain character is the range of elevation present, in other words the relative relief. Although this value is not in itself indicative of the nature of the surface, for example not differentiating between uniformly sloping or highly irregular surfaces, in combination with the roughness factor it provides a useful indication of terrain variability. Since values of K range from unity to very large numbers the value of log K is used in the calculation of variability which is given by:

$$v = \frac{\text{elevation range.}}{\log K}$$

Variability (v) can vary from 0 for completely flat surfaces to values approaching the elevation range for very "rough" areas. Values of v for the ten sample sites are also shown in Table 2, these again reflecting the results of the roughness value. Type I areas are least and type II most variable.

Discussion

Results in terms of both surface roughness (K) and variability (v) demonstrate that the three apparent terrain types, I, II and III, are groupings within a terrain continuum. Within each type, particularly within types I and II, there is considerable variation. These variations support subjective observations, for example the Jamaican type I site appearing "rougher" than those in Barbados and the Yucatan and the Antiguan type III area having infrequent residual hills giving an impression of greater "smoothness" than in Puerto Rico or Belize.

On the basis of these preliminary results surface roughness seems a potentially useful basis on which to differentiate between different tropical karst terrains and on which to base an objective classification. The results here should not be interpreted as representative in that they apply only to ten small sample sites and are derived from cartographic sources. Investigation of more extensive areas, using more reliable air-photographic sources needs to be undertaken.

The mathematical values K and v have no direct translation into verbal terms except in the context of "rough" and "smooth" and describe the terrain in terms of an objective numerical index, preferable to conventional subjective verbal terminology, which can identify major groupings yet has the facility to detect variations within these.

Acknowledgements

Work contributory to the production of this paper was funded by a Natural Environment Research Council studentship. Thanks are extended to all those who rendered assistance with manipulation of the data and production of the manuscript.

References

Day, M.J. 1976. 'The morphology and hydrology of some Jamaican karst depressions', *Earth Surface Processes*, 1(2), 111-129.

Dellwig, L.F. & Moore, R.K. 1966. 'The geological value of simultaneously produced like - and cross-polarized radar imagery' *Journal of Geophysical Research*, 71, 3597-3601.

Evans, I.S. 1972. 'General geomorphometry, derivatives of altitude and descriptive statistics', in *'Spatial Analysis in Geomorphology'*, ed. R.J. Chorley, 17-90.

Fisher, R.A. 1953. 'Dispersion on a sphere', *Proceeding of the Royal Society*, Ser. A, 217, 295-305.

Hobson, R.D. 1967. 'Fortran IV programs to determine surface roughness in topography for the CED 3400 computer', *Kansas Computer Contribution*, 14, 28pp.

Hobson, R.D. 1972. 'Surface roughness in topography: quantitative approach' in *Spatial Analysis in Geomorphology'*, ed. R.J. Chorley, 221-245.

Johnson, R.E. & Kiokemeister, F.L. 1957. *'Calculus With Analytic Geometry*,' New York, 709 pp.

Watson, G.S. 1957. 'Analysis of dispersion on a sphere', *Royal Astronomical Society Monthly Notices, Geophysics Supplement*. 7, 153-9.

Williams, P.W. 1971. 'Illustrating morphometric analysis of karst with examples from New Guinea', *Zeitschrift für Geomorphologie*, n.f., 15, 40-61.

Williams, P.W. 1972a. 'The analysis of spatial characteristics of karst terrains', In *Spatial Analysis in Geomorphology*, ed. R.J. Chorley, 135-163.

Williams P.W. 1972b. 'Morphometric analysis of polygonal karst in New Guinea', *Bulletin of the Geological Society of America*, 83, 761-796.

SURFACE HYDROLOGY WITHIN POLYGONAL KARST DEPRESSIONS IN NORTHERN JAMAICA

Michael J. Day.
Department of Geography,
University College Dublin, Belfield,
Dublin 4, Ireland.

Williams (1971, 1972a, b) has indicated that, in the polygonal karst terrain of New Guinea, enclosed depressions can be considered as ". . . small river basins of a special kind, characterised by intermittant and centripetally directed flow down poorly developed, gully-like channels." (1972a, p. 155). The solutional action of these stream systems he considers to be a most important factor in the subsequent development of the de-

pressions. In similar topography in Jamaica other authors (Sweeting, 1975; Smith and Atkinson, 1976) have indicated that these surface channels are either inactive under contemporary hydrologic conditions or are absent. Smith, Drew and Atkinson (1972) and Smith and Atkinson (1976) attribute the lack of ephemeral stream channels to the attainment by the limestone of a high degree of secondary permeability.

Depressions within 'doline karst' in northern Jamaica have also been shown to possess many of the characteristics of small drainage basins (Day, 1976). At times of intense and/or prolonged rainfall surface run-off occurs, water moving along small but distinct channels, accumulating in depression bases and being removed by subterranean drainage to reappear in valley systems up to 5.0km to the North.

The objectives of the present investigations were, in the case of a small number of polygonal karst depressions in northern Jamaica, to investigate the movement of water within the depression at times of rainfall, to attempt to trace this water to any external points and to investigate, by basic water chemistry analysis, the distribution of solutional activity within the depressions.

Procedure

The work was undertaken during March-April 1974 in two small areas in northern Jamaica, one an area of 'cockpit karst' 6 km south of Clarks Town, Trelawny and the other an area of 'degraded cockpit karst' 4km southwest of Brown Town, St. Ann in the vicinity of Tobolski in the Dry Harbour Mountains. In the first area the hydrology within two 'cockpits' was examined, in the latter three 'degraded cockpits' were investigated.

The nature of such solutional depressions in the Jamaican karst has been indicated by numerous authors and the differences between the 'cockpit' and the 'degraded cockpit' form have similarly been demonstrated (Sweeting, 1956, 1958; Aub, 1964; Smith, Drew and Atkinson, 1972). The essential variation between the two styles is that in the bases of the former there is very little superficial material, and near-vertical shafts are evident. In the 'degraded' form the bases are occupied by deposits of bauxitic material, commonly up to 10m in depth, the origin of which is presently undetermined (see discussion in Day 1976, p. 114).

Water tracing within and from the depressions was attempted using Rhodamine B dye, following the methods described by Drew and Smith (1969) and used successfully in adjacent areas (Day, 1976). Prior to and during periods of rainfall small quantities of dye were sited at various locations within the depressions. During rainfall the movement of water was monitored visually and, after the cessation of rain, detectors were checked to determine whether dyed water had followed particular courses. Detectors were also located in several valley systems, commencing about 5 km distant and leading down to the north coast, in order to determine whether water draining underground from the depressions reappeared therein.

During and after rainfall water within the depressions was collected and subsequently analysed for calcium and magnesium contents by means of E.D.T.A. titration.

Results

In the 'degraded cockpits' small channels, similar to those occurring in depressions north of Browns Town (Day, 1976) occur. These are however only present in the basal areas and are cut only in the superficial material, not in the limestone bedrock. Only once, during six monitored rainfall periods, was water observed to flow in these channels, this occurring during a two hour period during which approximately 6 cm of rainfall accumulated in a measuring cylinder. This flow collected in a small, 10cm deep pond in the depression base where it remained for several weeks. On this one occasion dye located in the channels was transported rapidly to a distinct basal pond, at all other times this dye, in common with that located on the superficial deposits but not in channels, was very slowly dispersed by rainfall, reaching the pond after several days, if at all.

By contrast, dye located on the upper slopes of the 'degraded' examples was lost to monitoring during rainfall, disappearing rapidly into surface rubble or fissures. This dye and the water carrying it was not detected at other points within the depression and did not reappear in the basal pond.

In the 'cockpits' the situation was very similar to that pertaining to the upper slopes of the 'degraded' examples, dye located on the surface being lost to monitoring by vertical infiltration. Furthermore, this dye made no reappearance within the central vertical shafts up to their maximum depths of 9.5m and 16.5m. No surface flow, either dispersed or within channels, was observed in any of the monitoring periods to traverse distances greater than 20cm.

In no case was it possible to trace water from the depressions to an external point. In the cockpits there was no concentration of water at any outlet point and in the 'degraded' examples attempted traces from basal ponds were unsuccessful. In no case was marked water detected in the north coast valleys.

Table 1 summarises the results of the chemical analyses with respect to carbonate contents of the water sampled from within the two groups of depressions.

TABLE 1 Summary of water hardness, results within polygonal karst depressions, March-April, 1974.

Location	*'Degraded cockpits'*			*'Cockpits'*			*Number of samples*
	Total	*$CaCO_3$*	*$MgCO_3$*	*Total*	*$CaCO_3$*	*$MgCO_3$*	
Water on bare limestone surface	58	48	10	53	45	8	5(3,2)
Water amongst limestone rubble	84	72	12	86	75	11	4(2,2)
Water flowing in channels on superficial deposits	32	25	7	–	–	–	3(3,0)
Water in basal ponds	124	109	15	–	–	–	4(4,0)
Water seeping from central shafts	–	–	–	147	128	19	2(0,2)
Rainfall	6	5	1	5	5	0	2(1,1)

Values in mg/l $CaCO_3$. Calcium hardness as $CaCO_3$, magnesium hardness as $MgCO_3$ total hardness as $CaCO_3$ + $MgCO_3$.

Discussion

The results indicate that, within the context of the small number of depressions monitored and the short time period involved, surface drainage channels such as those studied by Williams (1971, 1972a, b) are of little significance in the Jamaican polygonal karst. They are virtually absent from 'cockpits' and in 'degraded' examples are formed only on the superficial cover, even here carrying water only at times of intense and/or prolonged rainfall. Observation in adjacent areas suggests that these conditions are prevalent elsewhere too.

The results also support the hypothesis of Smith and Atkinson (1976) that the limestone possesse sufficient secondary permeability to preclude the maintenance of surface flow. It is possible that channels formerly existed and indeed the presence of large, often central, vertical shafts supports this hypothesis. These shafts, formerly acted as 'drains' at the foci of such channels under conditions of either lower secondary permeability and/or higher rainfall. At present, except perhaps at times of exceptionally high rainfall, they are inactive and essentially relict.

Results of the chemical analyses (Table 1) are in many ways similar to those obtained previously (Smith, Drew and Atkinson, 1972; Day, 1976). Using data from Smith and Mead (1962, p. 193), applied previously by Trudgill (1976), it is possible to predict the amount of calcium carbonate which will be dissolved at constant carbon dioxide concentrations using the formula $s = 249.998g^{.3209}$ where s is the amount of calcium carbonate in solution (mg/l) and g is the volume percent carbon dioxide concentration. Atmospheric carbon dioxide at 0.03% would be expected to produce a dissolved calcium carbonate content of approximately 82mg/l.

That the values recorded on bare limestone surfaces, amongst surface rubble and on superficial deposits are all below this level suggests that in the first two locations the water is moving too fast to achieve chemical equilibrium with respect to the air-water interchange and that, in the third, there is little contribution to carbonate content from the bedrock.

That water in basal ponds has a higher carbonate content suggests that the ponds are receiving water which has acquired more carbonate either within the superficial cover or at the interface between this and the bedrock. The similar values exhibited by seepage water within central shafts suggests that this has attained higher carbonate concentrations within the upper few metres of bedrock or within surface pockets.

Conclusions

Surface channels are less important in the Jamaican polygonal karst than in similar terrain in New Guinea. In 'cockpits' they are virtually absent and in 'degraded' forms they occur only on superficial deposits. Only on those deposits does any surface flow occur under present 'normal' meteorological conditions, elsewhere water infiltrates directly into the limestone via surface fissures. Vertical shafts in many 'cockpits' are essentially relict features relating to previous conditions of lower secondary permeability and/or increased rainfall.

Contemporary solutional activity is concentrated in the upper portion of the limestone, particularly at the limestone/superficial deposit interface.

Acknowledgements

This research was financed by a Natural Environment Research Council studentship, under the supervision of Dr. M.M. Sweeting. Staff of the departments of geology, geography and chemistry, U.W.I., Jamaica assisted with fieldwork preparation.

References

Aub, C.F.T. 1964. 'The nature of cockpits and other depressions in the karst of Jamaica'', Paper presented to the Symposium on Karst Phenomena at the *20th Internat. Geogr. Cong.*

Day, M.J. 1976. 'The morphology and hydrology of some Jamaican karst depressions', *Earth Surface Processes*, 1, (2), 111-129.

Drew, D.P. & Smith, D.I. 1969. 'Techniques for the tracing of subterranean drainage', *Brit. Geomorph. Res. Group, Technical Bulletin*, No. 2, 36p.

Smith, D.I. & Atkinson, T.C. 1976. 'Process, landforms and climate in limestone regions', In *'Geomorphology and Climate'*, ed. E. Derbyshire, 367-409.

Smith, D.I. Drew, D.P. & Atkinson, T.C. 1972 'Hypotheses of karst landform development in Jamaica', *Trans. Cave Res. Group, G.B.*, 14 (2), 159-173.
Smith, D.I. & Mead, D.G. 1962. 'The solution of limestones', *Proc. Univ. Bristol Speleol. Soc.*, 9, 188-211.
Sweeting, M.M. 1956. 'Hydrogeological observations in parts of the White Limestone areas in Jamaica, B.W.I.', *Geological Survey Dept. Jamaica*, Bull. 2, 27p.
1958. 'The karstlands of Jamaica', *Geogr. Jour.* 124, 185-199.
1975. 'Present problems in the karst denudation research in the World', *Proc. Internat. Sym. standardisation of field research methods of karst denudation (corrosion)*, Ljubljana, 7-15.
Trudgill, S.T. 1976. 'Field measurements of limestone erosion processes, Cockpit Country, Jamaica', Paper presented at the Tropical Workshop Session of the *Brit. Geomorph. Res. Group London Conference*, 5p.
Williams, P.W. 1971. 'Illustrating morphometric analysis of karst with examples from New Guinea', *Zeit. Geomorph.*, n.f., 15, 40-61.
1972a. 'The analysis of spatial characteristics of karst terrains', In *'Spatial Analysis in Geomorphology'*, ed. R.J. Chorley, 135-163.
1972b. 'Morphometric analysis of polygonal karst in New Guinea', *Bull. Geol. Soc. Amer.* 83, 761-796.

ON THE AFFINITIES OF SOME YUGOSLAVIAN TROGLOBITIC SPIDERS

Christa L. Deeleman-Reinhold.
Sparrenlaan 8
Ossendrecht, Holland.

It was from Carniola, the north-western part of present-day Yugoslavia, that in the early 19th century one of the earlist reports was made about the existence of underground-living, strongly modified arthropods.

The numerous itineraries in the early 20th century of the versatile scientist Absolon (Brno, Czechoslovakia) to the Dinaric Karst made it clear that the whole area parallel to the Adriatic coast is rich in interesting cave life. Kratochvil laid the basis of our knowledge of the cave spiders of this area in a series of studies and monographs.

Over the past 16 years we have prospected caves in the entire Dinaric Karst, resulting in a considerable extension of the known species. In the spider families Dysderidae, Leptonetidae, Agelenidae, Nesticidae and Linyphiidae blind forms occur side by side with taxa with normally developed eyes and with various intermediate states.

My study of the phyogenetic relationships of cave-dwelling and epigean *Troglohyphantes* species enabled me to establish coherent phylogenetic lines, composed of taxa with increasing complexity in homologous organs. I have been led to believe that, as soon as an underground population is severed from its epigean mother population, usually by local extinction of the latter, evolution of phylogenetic characters towards higher levels of organisation comes to a standstill, whereas adaptive hypogean evolution sets in leading to reduction of pigment and eye size, accompanied by physiological changes. Information gained from relative placing of a species into evolutionary sequences according to phylogenetic criteria combined with degree of regression is applicable in the assessment of the time elapsed since it became isolated underground. Disjunct distribution may be an indication of old age. For such an evaluation, a thorough knowledge of the group concerned is required. Indeed, we find a higher percentage of primitive archaic *Troglohyphantes* species among the troglobitic than among the others, supporting the proposed view. In the spider genus *Troglohyphantes* I have considered that group *marqueti* is one of the groups with most primitive characters. This group includes the small, troglobitic *coecus* Fage from the Pyrenees, as well as the large troglobitic *liburnicus* Di Caporiacco from the northern Dinarids, both species limited to a very small area, and possibly also *T.pisidious* Brignoli from Anatolia, of which species the male is unknown. A modern off-shoot émanated from this old stock: the wide-spread epigean and hypogean species *marqueti* and close relatives from the Pyrenees. In this species group, the lamella shows an evolutionary sequence, in which the external branch is gradually more coiled (fig. 1). The distribution is disjunct (fig. 2).

Within the predominantly circum-mediterranean family Dysderidae both the Dysderae and the Rhodeae include a number of forms adapted to the subterranean environment in Yugoslavia. The rare Rhodeae with a trans-mediterranean distribution (fig. 3) are according to present knowledge represented with at least three blind species there. Yugoslavia is also particularly rich in blind species of Dysderae. The northern Yugoslav genera *Stalita* Schiodte, *Parastalita* Absolon & Kratochvil, *Mesostalita* Deeleman and *Stalitella* Absolon & Kratochvil from the central Dinarids are composed of mere blind species, all having similar genital organs; the genera differ among them mainly in the shape and dentition of the chelicerae and leg armature. These genera apparently have no epigean relatives.

On the other hand, the blind cave Dysderids in the southern parts of the Dinaric Chain which formerly were ranged in the genus *Stalita*, are not related to the northern forms. Two new genera were created to accomodate these species: *Stalagtia* and *Folkia* (Kratochvil 1970, Brignoli 1974). However, for a long time blind animals seem to have blinded their describers with their pale, weird appearance. Some taxonomists still persist in their belief that blind cave forms cannot be close relatives of normal-eyed species and they range blind species into separate genera. In a classification system based on phylogeny, in many cases this cannot be maintained. Ample evidence from spiders, other invertebrates and fishes has accumulated, showing that absence or presence of eyes alone is no basis for generic splitting and may at best only support such a separa-

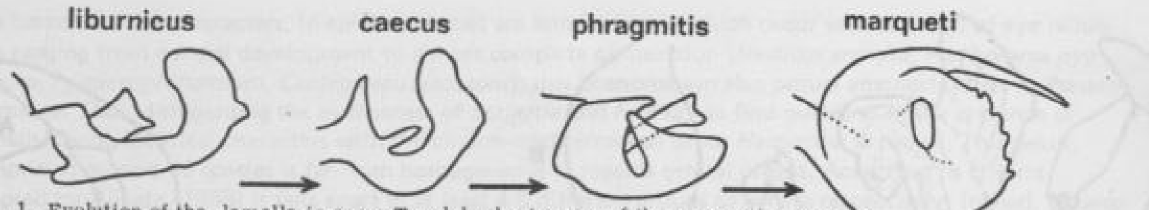


Fig. 1. Evolution of the lamella in some Troglohyphantes spp of the marqueti group.

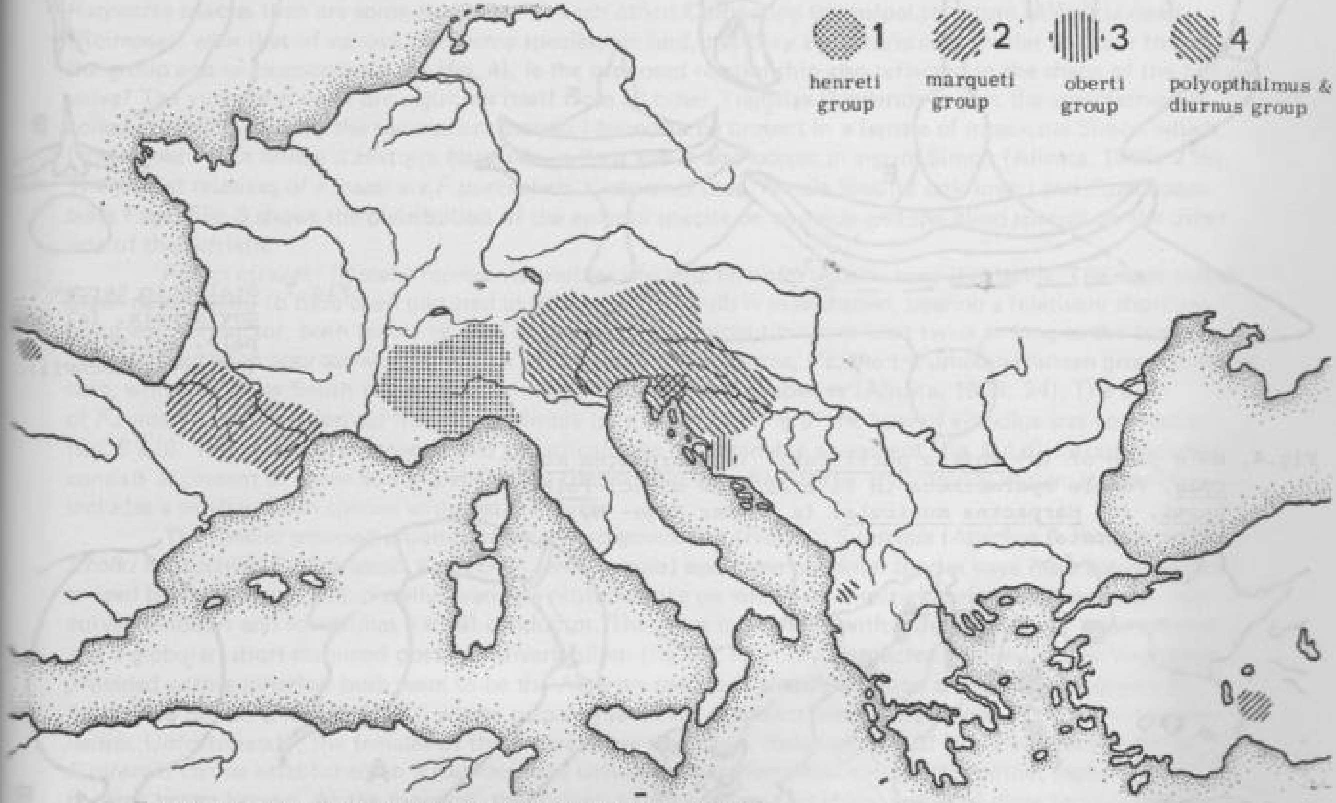


Fig. 2. Distribution of Troglohyphantes species of series B.

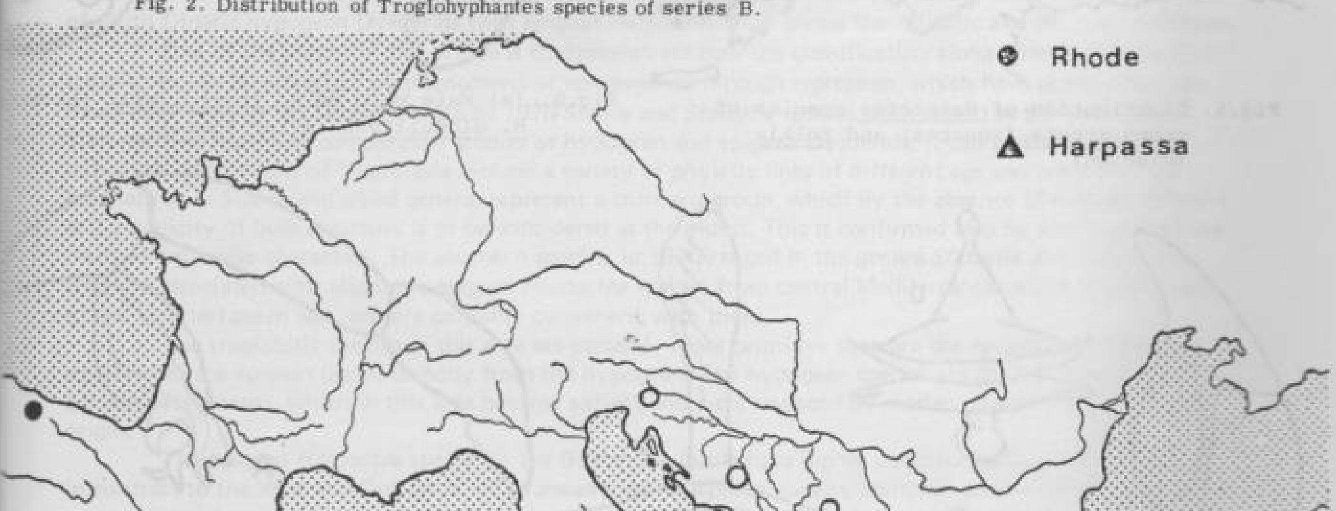


Fig. 3. Distribution of normal-eyed (black circles) and blind (white circles) species of Rhodeae.

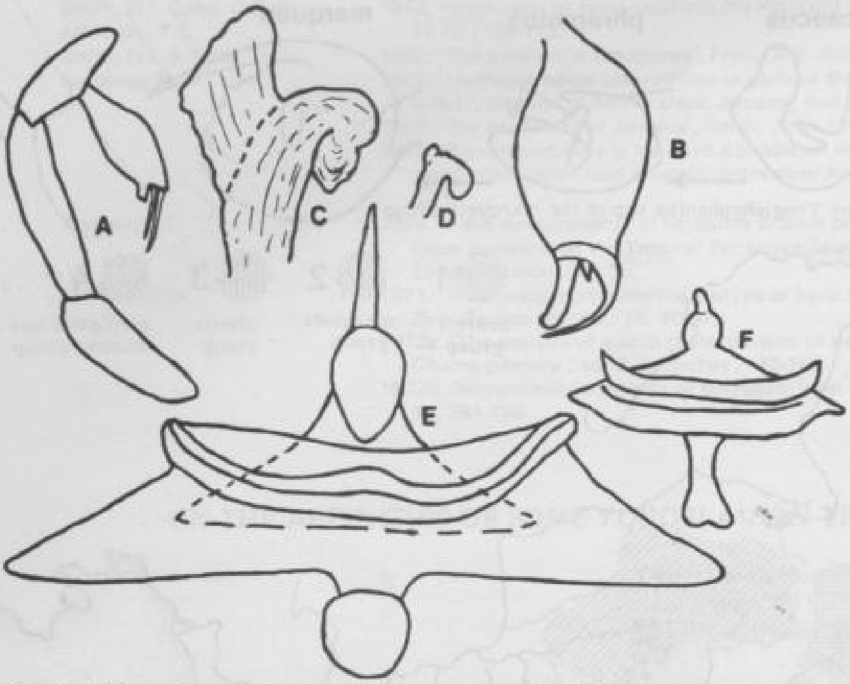


Fig.4. Male palp of (a) Folkia purkrabeki, (b) Harpactea musicola. Female spermatheca in lateral view of (c) Folkia haasi, (f) Harpactea musicola. (a, after Fage- b, f after Alicata).

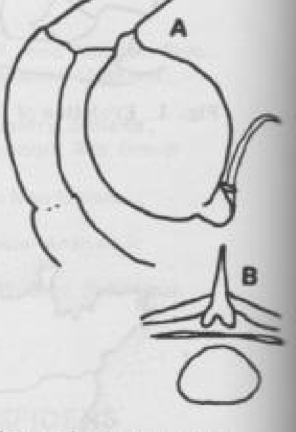


Fig.7. Stalagtia hercegovinensis, (a) male palp, (b) vulva (after Kratochvil).

Fig.5. Distribution of Harpactea species of group arguta (squares) and Folkia (circles).

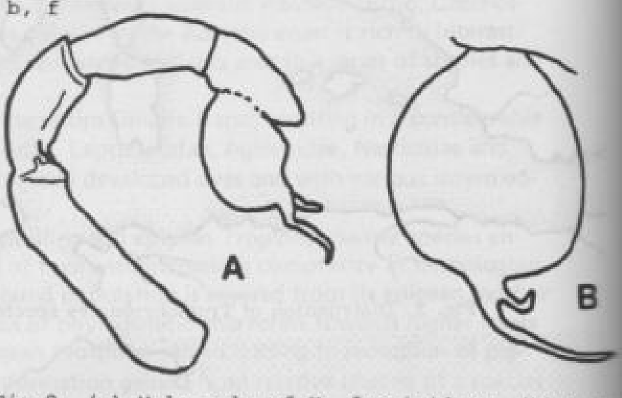


Fig.8. (a) Male palp of H. forcipifera, (b) bulb H. globulifera (after Simon).

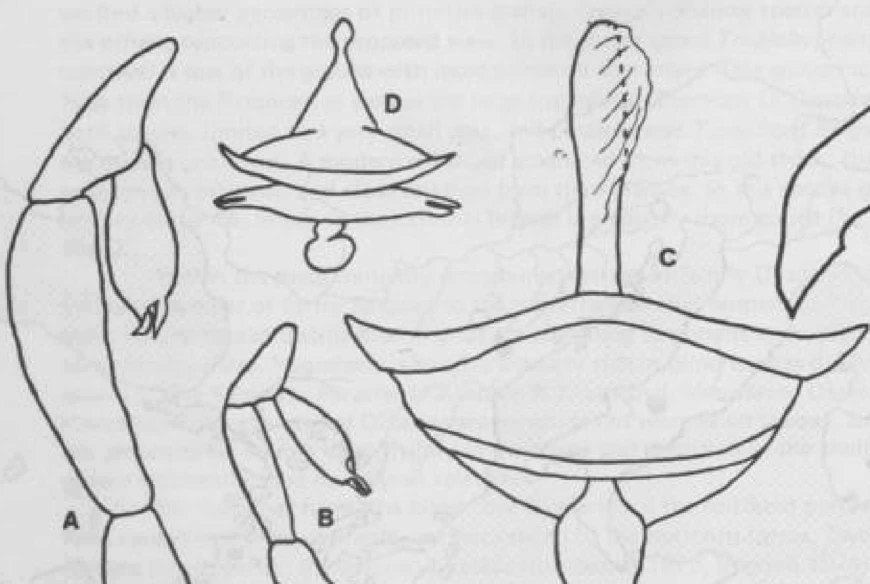


Fig.6. Male palp of (a) Folkia mrazeki, (b) Harpactea corticalis. Vulva in ventral view of (c) F. mrazeki, (d) H. corticalis (b, d after Alicata).

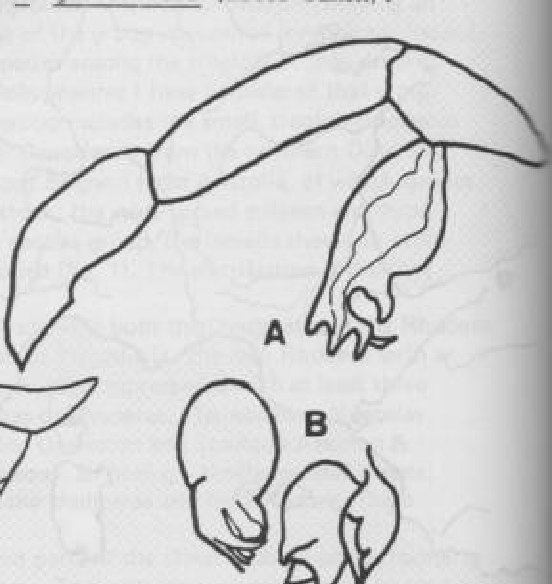


Fig.9. (a) male palp of H. prope lepidus, (b) bulb of H. saevus (after Kulczyński).

tion based on other characters. In spiders, species are known within which occur various states of eye reduction ranging from normal development to almost complete obliteration (*Nesticus eremita, Porrhomma pygmaeum, P. microphthalmum, Centromerus jacksoni*); this phenomenon also occurs amongst others in Pseudoscorpions. Thus, disregarding the eyelessness of *Stalagtia* and *Folkia,* we find ourselves in the presence of animals having identical characters with the circum-mediterranean genus *Harpactea* Bristowe. This genus, comprising around 40 species is far from homogeneous as regards genital organs. According to criteria adopted by Alicata (1966) it falls apart in at least 4-5 different groups or genera respectively. Indeed, *"Stalagtia"* and *"Folkia"* from Yugoslav caves and *"Minotauria"* Kylczynski from Greek caves are closer to certain *Harpactea* species than are some *Harpactea* to each other. Comparing the palpal structure of *Folkia haasi* (Reimoser) with that of various *Harpactea* species, we find that they are surprisingly similar to those found in the group *arguta-muscicola-sardoa* (fig. 4). Is the supposed relationship also reflected in the shape of the female vulva? The vulva of *F.haasi* distinguishes itself from all other Yugoslav Dysderids in that the spermatheca is coiled ventrally. Exactly the same phenomenon I found to be present in a female of *muscicola* Simon which I examined in the Musée d'Histoire Naturelle in Paris and it also occurs in *arguta* Simon (Alicata, 1966: 215). The closest relatives of *F.haasi* are *F.purkrabeki* Kratochvil (nec. female locality unknown) and *F.paucoaculeata* Fage. Fig. 5 shows the distribution of the epigean species on one side and the blind species on the other side of the Adriatic.

Folkia mrazeki (Nosek) represents another phyletic line of Yugoslav cave Dysderids. The male palpal organ never seems to have been pictured in literature. The bulb is pear-shaped, bearing a relatively short embolus and conductor, both feebly twisted at the base. The palpal tibia is at least twice as long as the tarsus. This configuration approaches that of one of the simplest *Harpactea,* viz. the transmediterranean group *corticalis,* which includes South Italian, Sicilian, Algerian and Tunisian species (Alicata, 1974: 24). The bulb of *F.mrazeki* could be derived from these simply by a slight twisting of the base of embolus and conductor (fig. 6 a,b). The vulvae of *F.mrazeki* and *H.corticalis* are in reasonable agreement (fig. 6 c,d). Group *mrazeki* consists at present of three South and Central Dinaric species, which differ enormously in size; it possibly includes a small epigean species with vestigial eyes.

The species grouped around *Stalagtia hercegovinensis* (Nosek): *S.inermis* (Absolon & Kratochvil), *S.folki* Kratochvil, *F.purkrabeki* Kratochvil (only female) and some unedited species have male palps characterized by a spherical bulb, distally bearing a protuberance on which are inserted at right angles a long, thin curved embolus and sometimes a small conductor. The vulva is provided with a short triangular spermatheca and a globular, short-stemmed posterior diverticulum (fig. 7). The only *Harpactea* species outside Yugoslavia provided with a spherical bulb seem to be the Algerian species *H.globifera* Simon and to a lesser degree *H. forcipifera* Simon (Alicata, 1974), whose palpal organs may represent precursory stages of that of *hercegovinensis.* Unfortunately, the females of these species are unknown. Relationships of this group and those of *F.mrazeki* can be established on a sounder base only when the *Harpactea* species from other regions have become better known. At the moment, the picture emerging from this study is that of close relationship of south Dinaric hypogean Dysderids with epigean *Harpactea* from across the Adriatic and the Mediterranean.

One of the scopes of this article is to demonstrate how the classification along criteria of natural relationships can be disturbed by phenomena of convergence through regression, which have profoundly confused taxonomy in the Dysderids. Up to 1970 *Stalita* and *Stalagtia* species were united in the same genus! Summarizing results of comparative studies of hypogean and epigean Dysderids, it can be stated that the hypogean populations of Yugoslavia include a variety of phyletic lines of different age and ancestry. The northern lines *Stalita* and allied genera, represent a coherent group, which by the absence of epigean relatives and simplicity of bulb structure is to be considered as the oldest. This is confirmed also by the firm establishment of regressive characters. The southern species, in 1970 ranged in the genera *Stalagtia* and *Folkia* are strongly associated with allopatric epigean *Harpactea* species from central Mediterranean areas on either side of the Mediterranean Sea, and are certainly congeneric with them.

The troglobitic species in this area are certainly more primitive than are the epigean; this does not signify that the epigean derive directly from the hypogean. The hypogean species are the heritage of early epigean settlements, which in this area became extinct and were replaced by modern stocks from eastern origin.

The epigean *Harpactea* species in the Balkan Peninsula have highly complex bulb structures (fig. 9) in contrast to the West and Central Mediterranean species (*lepidus, saevus, henschii,* various Greek species, some unedited species), indicating that a recent wave of diversification in bulb structure in the various lines has swept over the area. A few of these forms occur occasionally in caves, but show no area. A few of these forms occur occasionally in caves, but show no regressive phenomena. Not only Dysderids, also spiders of the genus *Troglohyphantes,* Leptonetidae and various other groups of cave animals such as cave beetles of the family Bathysciidae are highly diversified on the Balkan Peninsula. Rather than representing a highly aged, relict fauna, these cavernicoles are the testimony that this area has been repeatedly the setting of intense diversification and creative branching and proliferation in the past of animal groups of hygrophilic, cryptic habitats. Whether this area also shelters many old relicts will be revealed only when more data concerning faunas of other geographical areas in the world will be available for comparison.

References

Alicata, P. 1966. Le *Harpactea* (Araneae, Dysderidae) della fauna italiana e considerazioni sulla loro origine. *Atti Acc. Gioenia Sc.Nat.* Serie VI 18: 190-221.

1974. Le *Harpactea* Bristowe (Araneae, Dysderidae) del Nord Africa. *Animalia Catania* 3: 3-24.

Brignoli, P.M. 1974. Ragni di Grecia VI. Specie nuove o interessanti delle isole Ionie e della Morea (Araneae). *Rev. suisse Zool.* 81(1): 155-175.

Deeleman-Reinhold, C.L. in press. Revision of the cave-dwelling and related spiders of the genus *Troglohyphantes* Joseph (Linyphiidae) with special reference to the Jugoslav species. Razprave SAZU Ljubljana.

Kratochvil, J. 1970. Cavernicole Dysderae. *Acta Sc. Nat. Brno.* 4(4): 1-62.

LES POPULATIONS D'ARTHROPODES HYPOGES TERRESTRES: EXEMPLE D'UN INSECTE (COLEOPTERA BATHYSCIINAE)

B. Delay
Laboratoire souterrain du C.N.R.S.
09410 Moulis, France

Terrestrial hypogean arthropods live not only in large caves but also in inaccessible cavities of varying width. The study of a population of *Speonomus longicornis* with a mark-and-recapture method indicates that only 1 to 7% of the total population can be seen in a cave census, and that a "turnover" exists from caves to inaccessible cavities. The author describes a method of calculating this turnover in space and time.

Toute réflexion sur les populations d'invertébrés troglobies, terrestres ou aquatiques, est un corollaire de réflexions sur la nature des habitats souterrains.

La première classification du milieu souterrain proposée en 1907 par E.G. Racovitza, distingue "les grottes accessibles à l'homme" et "les fentes étroites inaccessibles à l'homme". En fait, opposer la notion de grotte à celle de réseau de fentes, peut conduire à des confusions sur la nature exacte des biotopes et nous considérons que le milieu cavernicole est un ensemble de cavités de tailles différentes, présentant des ressources alimentaires, des climats et microclimats différents, une partie seulement de ces cavités étant directement accessible donc observable par l'homme.

Etude des Populations Monospécifiques

1. Les populations directement accessibles

De nombreux travaux portent sur l'évaluation de la taille des populations terrestres par comptage direct dans les grottes; la plupart ont porté sur des Coléoptères, d'autres étudient un Criquet cavernicole *Ceuthophilus cunicularis* et un Ricinuleide *Cryptocellus pelaezi;* (Cabidoche 1966; Racovitza 1968; 1971, 1973 et 1975; Mitchell 1967 et 1970; Barr & Kuehne 1971; Juberthie 1969; Peck 1975; Mitchell 1967, 1969 et 1970;

Les résultats obtenus sur les coléoptères hypogés mettent en évidence des variations saisonnières du nombre d'individus dans les grottes. Les connaissances sur la biologie de certaines formes permettent de penser qu'il s'agit de migrations d'individus entre un volume accessible à l'homme et un volume inaccessible constitué par le "réseau de fentes" et éventuellement des cavités de grande taille inconnues; le volume inaccessible abrite l'ensemble des individus directement observables. Les migrations d'individus d'un ensemble vers l'autre sont dues, selon les auteurs ou les cas étudiés, à des facteurs climatiques nutritionnels ou de reproduction. Les études actuelles sur les organes sensoriels, le comportement et le métabolisme de l'eau des coléoptères hypogés devraient permettre de connaître la nature des stimuli qui entrent en jeu et le seuil de sensibilité des animaux; les résultats devraient conduire à préciser la nature exacte des facteurs climatiques agissant sur la densité des populations directement observables.

Le rôle du facteur reproduction envisagé par Jeannel et qui ferait du réseau de fente le lieu privilégié pour la ponte et le développement, vraisemblable pour certaines espèces, n'est pas démontré pour toutes. Les études en cours sur l'écophysiologie de la reproduction apporteront des éléments de réponse.

La valeur même du réseau de fentes dans l'ensemble de l'habitat de la population n'est pas totalement élucidée; Racovitza (1974) l'assimile à un espace de réserve, la grotte étant le milieu normal, alors que pour *Aphaenops cerberus* Juberthie (1969) pense que les zones de la grotte fréquentées correspondent à une extension du territoire occupé lorsque les conditions climatiques sont favorables.

2. Evaluation des populations totales

L'étude des problèmes de la répartition spatiale des Coléoptères troglobies a rendu nécessaire la quantification de ce que représentent les ensembles d'individus directement observables par rapport aux populations d'un réseau, ou éléments de réseau. Pour cela nous avons utilisé la méthode des marquages et recaptures sur une population de *Speonomus longicornis* (Bathysciinae) troglobie dont le développement ne comprend qu'un stade larvaire. Les éléments composant l'ensemble directement observable de cette population étaient de 10 individus en janvier 1973 et de 2340 individus en juillet 1973.

Nous avons tenté de définir les conditions d'utilisation de la méthode des marquages et recaptures dans le milieu souterrain, puis de l'employer dans une cavité suffisamment petite ($150 m^2$) pour cerner au mieux l'ensemble de la population directement observable.

Nous utilisons ici l'équation de Petersen modifiée par Bailey (Roff 1973)

$$\hat{N} = \frac{M\,(n+1)}{R+1}$$

ou $\hat{N}$ est l'estimation de l'effectif de la population
M est le nombre des animaux marqués à la première prise
n est le nombre des animaux comptés lors des autres prises
R est le nombre des animaux marqués repris.

De facon générale, on peut admettre que cette méthode des marquages et recaptures avec l'utilisation de l'équation de Petersen peut être appliquée aux populations souterraines à condition:

— que les animaux marqués se mélangent de facon homogène avec les animaux non margués
— que la mortalité des animaux marqués soit faible pendant la durée des éxperiences
— que les animaux marqués n'aient pas un comportement particulier.

Les erreurs faites sur M, n est R sont pour chaque facteur toujours dans le même sens et chacune induit une erreur toujours dans le même sens:

— M est toujours surestimé entraînant une surestimation de $\hat{N}$
— n est toujours sousestimé entraînant une sousestimation de $\hat{N}$
— R peut être sousestimé entraînant une forte surestimation de $\hat{N}$
et c'est là la principale cause d'erreur.

Reprenant les conclusions de Roff (1973) nous devons préciser que la méthode des marquages et recaptures doit voir son utilisation limitée à la recherche d'un ordre de grandeur plus qu'à une estimation précise. Son utilisation constitue une première approche, indispensable pour l'estimation des populations terrestres hypogées et l'étude de leur dynamique.

Trois marquages effectués en mars, juin et octobre ont été suivis de reprises successives au cours de l'année.

Lorsque l'estimation apparaît comme la meilleure (12 juillet), l'ensemble des individus en relation avec la cavité est évalué à 55000 individus; 2000 individus soit environ 4% sont donc visibles dans la cavité; si on tient compte de l'intervalle de confiance à 95% ce pourcentage peut varier de 1 à 7%.

Au cours du printemps et du début de l'été on constate une augmentation progressive de N qui passe de 7000 à 52000, il y a là une variation saisonière qui est comparable à celle de n et qui se traduit par un maximum en été et un minimum en hiver.

Trois facteurs sont à envisager pour expliquer une variation saisonnière de N: des rythmes d'activité différents, un rythme de reproduction, un phénomène de migration.

Les rythmes d'activité peuvent avoir une influence sur le "turnover" des individus entre le volume observable et le volume inaccessible; des travaux récents sur les Coléoptères hypogés (Weber *in literis*) ont montré que la phase de repos des cycles d'activité s'allonge lorsque la température s'abaisse.

Le rythme de reproduction saisonnier peut avoir une double origine maximum saisonnier de ponte et (ou) maximum saisonnier de mue imaginale induits par les variations saisonnières de la température (Delay, 1974).

Les migrations peuvent résulter de l'extension du territoire occupé, et jouer en modifiant le nombre d'individus effectivement en rapport avec la grotte, ce qui implique que tous les individus ne soient pas en permanence en relation avec la grotte pour des raisons climatiques, topographiques ou de dynamique des déplacements.

Les Ensembles D'Individus Dans un Massif

Les résultats précédemments exposés nous amènent à proposer la définition d'ensemble d'individus en fonction de la dynamique de leurs déplacements, l'espace et le temps étant pris en consideration.

L'homme peut, au niveau de la grotte, accéder à certains groupements d'individus $n_1, n_2, \ldots\ldots n_x$ occupant des biotopes directement observables. L'ensemble de ces groupements forme "la population" totale n observable dans la grotte, "population" dont la taille varie au cours des saisons.

La méthode des marquages et recaptures permet de calculer la taille de l'ensemble des individus N en rapport avec la cavité étudiée en un temps donné. N est formé de n (déjà défini) et N' (ensemble des individus non directement observables), le faible taux de recapture (moins de 6%) indique un échange important d'individu entre n et N'.

La variation annuelle de N, citée plus haut, peut s'expliquer en partie par des échanges d'individus avec un ensemble S1 dont la taille varie en fonction inverse de N. N et S1 forment l'ensemble P' qui est l'ensemble des individus susceptibles d'être en rapport avec la grotte dans un laps de temps donné.

Il est possible que S1 fasse partie d'un ensemble d'individus S dont, par hypothése, une partie S2 ne sera jamais en rapport avec la grotte au cours d'un temps donné; la taille de cet ensemble S2 qui peut être vide ne peut pas être évaluée par la méthode des marquages et recaptures.

L'ensemble des individus N et l'ensemble des individus S forment la population isolée P1 qui est une des composantes de la population globale P du massif karstique. La distinction des populations $P_1, P_2, \ldots,$ P_4 n'est pas fixe dans le temps mais est une image fonction du laps de temps considéré, les populations isolées évoluant alors indépendamment sous l'effet des facteurs écologiques locaux.

Conclusions

Les résultats actuels sur les études des populations de coléoptères hypogés nous amènent à proposer les conclusions suivantes:

— le milieu souterrain est susceptible d'être peuplé dans sa totalité; la répartition des individus dans l'espace disponible étant fonction des capacités d'expansion de l'espèce, expansion contrôlée par les facteurs du milieu.

— L'ensemble des individus présents dans la cavité à un moment donné est le seul qui nous soit directement accessible; il ne représente qu'une partie, parfois faible, d'un ensemble plus grand dont une partie nous est accessible par la méthode des marquages et recaptures.

Des ensembles d'individus peuvent être définis en fonction de la dynamique de leurs déplacements, l'espece et le temps étant pris en consideration; des échanges numériques importants d'individus existent entre l'ensemble des individus présente dans la cavité à un moment donné et l'ensemble des individus en rapport avec la grotte pendant un laps de temps donné.

L'extention de ces notions à d'autres formes terrestres que les coléoptères est possible et souhaitable mais enconsidérant toujours la possibilité d'existence d'un ensemble individus non directement accessible à un moment donné et en essayant d'évaluer les échanges entre les différents ensembles.

La notion d'abondance d'une population est liée à celle de densité, on ne peut donc dire qu'un animal est abondant ou non que si on précise sa taille, la dynamique des ses déplacements, son comportement territorial sa place dans la chaine trophique et surtout la surface ou le volume étudié; ce dernier point est très délicat à définir avec exactitude dans le monde souterrain. Notons que cette notion de densité est valable également pour les populations de troglobies aquatiques où l'expression d'un nombre brut pour qualifier l'abondance d'une population n'a pas grand sens si on ne précise pas le rôle trophique de l'espèce et le volume d'eau peuplé.

References

Barr, T.C. et Kuehne, R.A. 1971. Ecological studies in the Mammoth Cave ecosystem of Kentucky. II. The ecosystem. *Ann. Speleol.*, 26, 1, p. 47-96.

Carbidoche, M. 1966. Contribution à la connaissance de l'écologie des Trechnae cavernicoles pyrénéens. Thèse Univ., Paris.

Delay, B. 1974. Les conditions thermiques des milieux terrestres dans la zone d'hétérothermie des massifs calcaires et leurs influences sur le développement de *Speonomus longicornis* (Coléoptère, Bathysciinae). *Ann. Speleol.*, 29, 1, p. 121-126.

Jeannel, R. 1926. Faune cavernicole de la France avec une étude des conditions d'existence dans le domaine souterrain. *Encycl. Entom.*, 7, Lechevalier, Paris, 334p.

Juberthie, C. 1969. Relations entre le climat, le microclimat et les *Aphaenops cerberus* dans le domaine souterrain. *Encycl. Entom.*, 24, 1, p. 75-104.

Kane, T.C. et Poulson, T.L. 1976. Foraging by cave beetles: spatial and temporal heterogeneity of prey. Ecology, 57 p. 793-800.

McKinney, T. 1975. Studies on the niche separation in two carabid cave beetles. *Int. J. Speleol.*, 7, p.65-78.

Mitchell, R.W. 1967. Distribution and dispersion and species associations of a mixican cavernicole ricinuleid. *Ciencia*, 27, 2-3, p. 63-74.

Mitchell, R.W. 1969. Population size and dispersion and species associations of a mixican ricinuleid. *Ciencia*, 27, 2-3, P. 63-74.

Mitchell, R.W. 1970. Total number and density estimates of some species of cavernicoles inhabiting fern cave, Texas, *Ann. Speleol.*, 25, 1, p. 73-90.

Peck, S.B. 1975. A population study of the cave beetle *Ptomophogus loedingi* (Coleoptera; Leiodidae; Catopinae). *Int. J. Speleol.*, 7, p. 19-32.

Racovitza, E.G. 1907. Essais sur les problèmes biospéologiques. *Biospelogica* I, *Arch. Zool. exp. gen.*, 4, 6, p. 371-448.

Racovitza, G.H. 1968. La périodicité reproductive chez *Pholenon proserpinae glaciale*, Jeannel (Coleoptera, Bathysciinae). *Centenaire „Emile G' Racovitza"*, p. 446-458.

Racovitza, G.H. 1971. La variation numérique de la population de *Pholenon (Parapholenon moczareji)* de la grotte de Vadu-Crisului. *Trav. inst. Speol. "Emile Racovitza"*, 10, p. 273-278.

Racovitza, G.H. 1973. Quelques aspects de la dynamique des populations de Coléoptères cavernicoles Cinquantenaire de l'Institut de Speologie "Emile Racovita", p. 409-419.

Racovita, G.H. 1974. Apercu d'ensemble sur la systématique, la répartituion géographique, la phylogénie et l'écologie des Bathysciinae cavernicoles. *Ann. Speleol.*, 29, 2, p. 191-211.

Racovitza, G.H. 1975. Recherches sur la biologie de la population de Coléoptères cavernicoles de la *Pestera cu apa din valea Lesului, Ann. Speleol.*, 30, 2, p. 351-363.

Roff, D.A. 1973. On the accuracy of some mark recapture estimators. *Oecologia*, 12, p. 15-34.

SOBRE LA MORFOGENESIS DE CIERTOS CONDUCTOS PSEUDOKARSTICOS

Andrés Aguera Donay
c/o Entenza No. 4, Pral Ia, Barcelona, Spain.

Following the development of karstic solution channels below the surface, the overlying rock collapsed into the caves. The collapse reached the surface and a pattern of channels was formed which had previously been attributed to erosional processes.

Consecuencia de incontadas observacionesrealizadas en distinas cavidades pertenecientes a un mismo karst, ha sido el hallazgo de ciertos cavernamientos, de dimensions reducidas pero de génesis sumamente interesante, que participan plenamente en el reticulo cavernoso dualizando o mixturando la genérica morfologia y procedencia fenomenologica de los conductos.

Aunque estamos convencidos de la generalidad del fenomeno, nos hemos de remitir logicamente al caso o problema concretamente estudiado, aclarando con toda premura las caracteristicas mas determinantes.

Desde un punto de vista morfologica y espeleométrico, previa aclaracion de que describimos un sector no la totalidad del fenomeno, podemos decir que se trata de conductos de seccion ortoaxial oblonga, medidas maximas 10x2 mts. y seccion transversal lenticular cuyo plano axial buza entre 50° y 60°. Aparentemente se trata de una diaclasa ampliada por los clasicos fenomenos de karstificacion, ya que se aprecian algunas morfologias de corrosion sobre la roca encajante (dolomia del Jurasico). Enmascarandolas, se observan incipientes formas qui miolitogénicas axiales ortogeotropas y una sedimentacion acumulada en las zones mas bajas compuesta principalmente por elementos macroclasticos. Un analisis mas detenido del citado elementos macroclasticos. Un analisis mas detenido del citado conducto y las zonas de la caverna directamente relacionadas con él, nos demuestra claramente la gran equivocacion cometia en la previa descripcion morfogenética.

Es inmarginable, para ilegar a une completa comprension del fenomeno, la descripcion del contexto en su actual situacion evolutiva, ya que como se apreciara uno es consecuencia del otro. Las galerias principales presentan un aspecto caotico, consecuencia del proceso subsidente (2) en que se hallan inmersas; el desplazamiento de inmensos bloques liticos solicitados por la gravedad, crea facturas en ciertos puntos de la masa rocosa, al no arrastrar en profundidad la totalidad del diafragma separador, determinadas por la heterogeneidad del conjuncto y efectos mecanicos repartidos con diferencial potencia.

Las citadas fracturas se desarrollan, aunque a nivel superior, paralela o infimamente oblicuas a la galeria principal, entrando en coalescencia con ella y por tanto formando reduidos diverticulos en algun caso dificilmente transitables.

Aparece de esta manera un conducto creado con posterioridad a la cavidad, de la cual forma parte integrante y cuya procedencia no es puramente karstica, aunque dependa directamente de un fenomeno inserto en la evolucion karstica hipogea. Estos neoconductos pseudokarsticos aparecen pues asociados a fenémenos de subsidencia, vienen generados por efectos mecanicos de origen hipogeo y no deben condfundirse con las oquedades interclasticas que con proliferacion aparecen en este tipo de cavidades.

Es de hacer notar el importante papel que desempnan estas formas a la hora de abordar el interesante trabajo de reconstruccion paleomorfologica para las cavidades en fase subsidente, se deduce facilmente que su medicion, previa observacion de todos sus aspectos especiales, puede sernos, en algunos casos, fundamental para el conocimiento de la cinética de bloques.

(2) No especificamos el origen de la subsidencia, que puede ser provocado por efectos tectonicos posteriores a la aparicion de la caverna, o a fenomenos de disolucion junto al nivel de base karstico cuando el paquete calcareo es suficientemente delgado o incoherente, ya que nuestra pretension es plantear el caso lo mas genericamente posible.

Bibliografia

Aguera Donay, A. 1974. El macizo cavernoso de Albinana. III Congreso Nacional de Espeleologia (Madrid)
1976. Sobre una fase de la evolucion senil en cavidades subterraneas. IV Congreso Nacional de Espeleologia (Marbella) peniente de publicacion.

Closas Miralles, J. 1935. Cova fona de Salomo. Sota Terra (Barcelona).

Instituto Geologico y Minero de Espana. 1973. Mapa geologico de Espana. esc 1!50000 Hoja 446 Valls. (Madrid).

LE SYSTEME DE LA RIVIÈRE SAINT VINCENT — KARST DE LA PIERRE SAINT MARTIN (FRANCE — ESPAGNE)

Michel Douat
c/o Lalanne A4 Le Casterot
64170 Artix — France

The aim is not to describe the many caverns of which the Saint-Vincent system is constituted, even though one of them is the deepest cave in the world. It will rather take stock of the most recent discoveries and also show the hopes of the members of ARSIP, which was founded in 1966 for a more efficient exploration of one of the biggest karst systems known.

Les lignes qui suivent n'ont pas pour but de décrire les cavités tributaires du systeme de la Rivière St Vincent — même si l'une d'elles est la plus profonde du monde — mais de faire le point sur les découvertes récentes et les espérances des spéléologues de l'ARSIP, association crée en 1966 pour permettre l'exploration efficace d'un des plus grands karst connus.

La Rivière St Vincent est une des 4 grandes rivières du massif de la Pierre St Martin. Sa résurgence située à 450m d'altitude dans la vallée de Ste Engrâce (Pyrénées atlantiques — France) a un module annuel moyen de 2'37m^3/s correspondant à un bassin d'alimentation de 36 km^2 étagé de 550 à 2500m d'altitude. Elle est la mieux connue et la plus explorée des 4, cepandant nous sommes persuadés n'en connaitre qu'une faible partie.

Le bassin d'alimentation de la Rivière St Vincent est d'une remarquable unité géologique, constitué d'une assise de calcaires crétacés de 300 à 450m d'epaisseur presque horizontale du côte espagnol et plongeant vers le Nord côte francais; comprise entre un niveau collecteur de schistes primaires et un bouclier protecteur de flysh, intact par endroits mais totalement disparu sur la plus grande partie du massif. La fracturation est intense en tous sens avec une dominante des failles Est-Ouest et Sud Ouest-Nord Est.

Trés grossièrement, ce bassin d'alimentation peut être délimité par une surface de 3 à 4 km de large et 8de long, limitée à l'Est par les pics d'Anie (2504m) et de Soum Couy (2315m), barrée à l'Ouest par le pro-

fond ravin d'Ehujarre (1200 à 550m). Au Sud la limite est plus approximative car l'exploration de la Rivière St George commence seuleument et les bassins versants respectifs sont encore peu connus dans cette zone. L'incertitude porte sur une bande de 2km^2 environ où sont situées les deux seules cavités donnant accès à des rivières pouvant être des têtes de réseau du St George. Dans un cas d'extrème extension vers le Sud cette limite pourrait donc être une ligne passant par la Sierra de Analarra (2355m), la Teirola (1824m) et l'extrémité Sud du ravin d'Ehujarre (1200m). Vers le Nord, la limite des bassins d'alimentation des rivières St Vincent et Couey Lotge est connu à quelques centaines de mètres prés et la suite de l'exploration du Gouffre B.3 devrait lever rapidement les dernières incertitudes. On peut néanmoins admettre une limite passant par le Pas de l.Osqu (1900m), la Station de Ski de la Pierre St Martin et la vallée de Ste Engrâce (550m).

Un tel système etait évidement hors de porté d'un groupe de spéléologues même trés actifs et les fondateurs de l'ARSIP ont eu l'idée originale de confier l'exploration du massif à divers groupes qui peu à peu s'intégrent à ses structures assurant ainsi le renouvellement permanent de ses organes directeurs.

L'ARSIP n'est pas un group spéléologique mais l'organisme directeur émmanant de l'ensemble des explorateurs du massif.

Pendant les premières années de son existance, le but essentiel de l'ARSIP a été de trier et synthétiser les informations et découvertes du moment ainsi que celles précedant sa creation; bénéficiant en cela des recherches et archives du Prof. M. Cosyns, explorateur du massif depuis 1930.

Mais depuis quelques années l'ARSIP peut orienter les recherches de facon plus précise et les découver s'accélèrent notablement. On en arrive ainsi à une spéléologie presque expérimentale: chaque découverte globa du système, permettant ainsi de pressentir de nouveaux réseaux qui sont découverts à postériori par des équipe envoyées sur place dans ce but précis. L'ARSIP crée dans une optique de synthèse des travaux est aussi devenu un champ d'expériences pour la conception de l'exploration spéléologique.

A ce jour 54.5km de réseaux souterrains ont été explorés (exception faite des centaines de gouffres de 20 à 320m de denivellation sans developpement horizontal important), répartis dans 8 cavités principales non encore reliées entre elles. Le point haut est situé à 2043m d'altitude, le point bas atteint en plongée à 400m seulement. En 1966 trois de ces huit cavités étaient connues et totalisaient moins de 15km de developpement.

Plusieurs rivières collectées par le lit de schiste primaire imperméable sont donc connues, elles se dirige d'Est en Ouest sensiblement parallèles à peu de distance. Elles résurgent toutes à la Grotte du Bentia sous la dé nomination unique de Rivière St Vincent. Le collecteur souterrain St Vincent n'est pénetrable que sur quelque mêtres à la résurgence et dans deux petites grottes voisines, puis atteint de nouveau 2km en amont dans le Trou du Renard (altitude 585m). De vastes puits noyés y ont éte plongés jusqu'à l'altitude 400m, soit 50m au dessous du niveau de la résurgence sans trouver en amont ou aval une branche remontante.

Plus en amont, le collecteur est inconnu pour l'instant. La pénétration humaine dans les différentes cavités tributaires de ce collectuer butte sur un important fossé tectonique dans lequel les rivières s'enfouissent aprés avoir crevé leur lit de schiste. De grandes salles telles que la Verna et la Styx sont les témoins de ces en-fouissements.

En amont du fossé, vers l'Est, chaque rivière est donc indépendante, du moints les cours actifs, car tout laisse supposer que des cours fossiles encore inconnus relieront entre elles la plupart de ces cavités.

La plus connue de ces cavernes est sans nul doute le Gouffre de la Pierre St Martin dans lequal coule la plus importante des rivières à laquelle nous avons conservé le nom de Rivière St Vincent. Il possede 4 entrées naturelles (Puits Lépineux, Tête Sauvage, Gouffre Moreau, Gouffre de Beffroi) et une artificielle (Tunnel EDF) Avec ses 33km de developpement, ses 1332m de denivellation, ses salles géantes et un potentiel spéléologique à peine entamé il est déjà en soi une des plus importantes cavernes du monde. Pourtant seul son cours actif et ses affluents ont été relativement bien explorés. Une nouvelle phase de son exploration, en cours actuellement, peut amener des developpements considérables.

La deuxième caverne découverte ne possède aucune entrée naturelle, seuls le hasard et un tunnel artificiel y ont donné accès. Il s'agit de la Grotte d'Arphidia òù coule une rivière de faible débit. Mais l'intèret de cette grotte est de donner accès et de s'enfoncer profondement dans le fossé tectonique, permettant en celà de garder tous les espoirs pour la découverte du Collecteur St Vincent. Avec 7.5km de developpement et 665m de denivellation elle est tout de même l'une des plus importantes du massif et pourrait être la clèf des jonctions avec ses voisines puisque elle n'est séparée par endroits que de 30m avec la Pierre St Martin et 90m avec le Gouffre Lonné Peyré.

Ce dernier gouffre possède bien des points communs avec la Pierre St Martin mais à plus petite échelle Long de 8.5 km et profond de 717m, sa rivière (Rivière Lonné Peyré) subit au contact du fossé tectonique (Salle Styx) le même enfouissement que la rivière St Vincent à la Verna. C'est probablement le grand gouffre du massif le moins connu et le moins bien exploré, son amont n'a d'ailleurs jamais été terminé.

D'autres gouffres donnent accès à des rivières de moindre importance, probables affluent des précedentes. Ainsi le Gouffre B.3, situé tout au Nord du bassin d'alimentation St Vincent recèle une rivière dénomée Rivière de Soudet qui peut être un affluent du Lonné Peyré ou le début d'une nouvelle grande rivière qui elle aussi ira se perdre dans le fossé tectonique. Long de 2km, d'une denivellation de 305m, il est en cours d'exploration.

La dernière connue est située en Espagne au Sud de la Pierre St Martin, elle coule jusqu'à 330m de profondeur au fond du Gouffre Mulékéké long de 1.2km.

La particularité de cette rivière est d'être l'affluent présumé d'une autre grande rivière encore inconnu appellée Rivière X, qui doit couler moins d'un kilomètre au Sud de la Pierre St Martin et être collecté à l'Ouest par l'accident tectonique d'Arphidia. L'accès à la Rivière X, qui peut être un ancien cours de la Pierre St Martin, donnera les indications les plus précieuses sur les limites Sud du bassin d'alimentation St Vincent.

D'autres cavités approchent ou atteignent les niveaux de schiste imperméable à des profondeurs variant de 250 à 350 mais ne donnent accès à aucune rivière. Certaines possèdent de grandes verticales (la plus importante du massif étant le Puits Lépineux: 320m): un puits de 220m dans le Gouffre de l'Ours et dans celui du Pas del'Osque, un puits de 240m dans l'Assomoir, un de 196m constitue le Gouffre Sauveur Bouchet. D'autres verticales de 100 à 150m sont fréquentes dans tout de massif.

Mais toutes ces explorations s'accompagnent de désagréments dus à la réputation même du Gouffre de la Pierre St Martin et à son "mythe du record du monde de profondeur". Titre certes enviable même s'il n'a pas grande signification mais qui retarde chaque année d'importantes découvertes, le but avoué de nombreuses équipes étant d'ajouter quelques mètres à la denivellation du réseau, déployant pour celà des sommes considérables d'énergie alors que le potentiel spéléologique du massif est à peine entamé, que ce soit au niveau des resurgences, des immenses lapiazs encore vierges ou à l'intérieur même des cavités connues.

TAXONOMIC STRUCTURE OF CAVE ALGAL FLORA

Stefan Jord Draganov
Faculty of Biology, University of Sofia,
Bulgaria.

This paper summarises the results of investigations on cave algae from the end of the 19th century to the present.

A total of 627 taxa of cave algae have been found including 542 species, 64 varieties and 21 forms, belonging to the following 6 divisions: Cyanophyta, Rhodophyta, Chlorophyta, Chrysophyta, Pyrrophyta and Euglenophyta.

The Blue-green algae predominate over the other divisions — this division includes over 48.5% of all taxa. Orders Hormogonales and Chroococcales as well as families Oscillatoriaceae and Chroococcaceae have the greatest numbers. The Genera *Oscillatoria* Vauch. *Phormidium* Kutz. and *Lyngbya* C. Ag. have the greatest species diversity; next rank *Gloeocapsa* Kutz., *Chroococcus* Nag., *Nostoc* Adanson etc. The greatest number of new species in the division Cyanophyta belong to the new genera: *Baradlaia* Palik, *Geitleria* Friedmann, *Ialomitzia* Gruia, *Palikiella* Claus and *Spelaeopogon* Borzi.

TABLE 1. Number of families, genera, species, varieties and forms of the different divisions, subdivisions and orders of algae, recorded in caves.

Algae	*Families*	*Number of: Genera*	*Species*	*Varieties*	*Forms*
CYANOPHYTA	16	55	269	21	15
Chroococcales	2	14	83	8	1
Pleurocapsales	1	4	7	–	–
Dermocarpales	3	3	5	–	–
Hormogonales	10	34	174	13	14
RHODOPHYTA	4	4	4	–	–
Goniotrichales	2	2	2	–	–
Nemalionales	2	2	2	–	–
CHLOROPHYTA	22	60	88	7	4
EUCHLOROPHYTINA	19	53	82	7	4
Volvocales	4	5	5	1	–
Tetrasporales	2	4	8	–	–
Chlorococcales	7	27	43	6	1
Ulotrichales	1	7	16	–	3
Prasiolales	1	1	1	–	–
Chaetophorales	3	7	8	–	–
Siphonocladales	1	2	1	–	–
ZYGNEMOPHYTINA	3	7	6	–	–
Mesotaeniales	1	2	2	–	–
Zygnemales	1	2	–	–	–
Desmidiales	1	3	4	–	–
CHRYSOPHYTA	19	46	158	35	2
CHRYSOPHYTINA	4	9	18	–	–
Ochromonadales	3	8	17	–	–
Chrysocapsales	1	1	1	–	–
XANTHOPHYTINA	7	13	19	–	–
Pleurochloridellales	1	1	1	–	–
Mischococcales	4	10	14	–	–
Tribonematales	1	1	3	–	–
Vaucheriales	1	1	1	–	–
BACILLARIOPHYTINA	8	24	121	35	2
Coscinodiscales	1	2	5	1	–
Fragilariales	1	5	11	8	–
Eunotiales	1	1	4	1	–
Achnanthales	1	2	8	2	1
Naviculales	4	14	93	23	1

PYRROPHYTA	8	9	9	–	–
Gloeodiniales	1	1	1	–	–
Gymnodiniales	1	1	1	–	–
Peridiniales	3	3	2	–	–
Phytodiniales	1	1	1	–	–
Cryptomonadales	2	3	4	–	–
EUGLENOPHYTA	4	12	14	1	–
Ruglenales	2	7	10	1	–
Peranematales	2	5	4	–	–
TOTAL	73	186	542	64	21

The Diatoms (about 25% of the total number of algae) predominate in the division Chrysophyta in which the orders Naviculales and the family Naviculaceae have the greatest species diversity. The genus *Navicula* Bory has the greatest species diversity followed by *Pinnularia* Ehr., *Nitzschia* Hass., *Cymbella* C. Ag., *Gomphonema* Ag. etc. The golden algae and yellow-green algae contribute only 18 and 19 species respectively.

The greatest number of Green algae belong to the orders Chlorococcales and Ulotrichales.

The Euglenoid algae are presented by 14 species and 1 variety: the Pyrrophyt by 9 spp. and the algae by only 4 spp.

There is no doubt that the list of cave algae will increase as a result of future investigations.

Acknowledgements: I thank my colleague Dr. Ganchovsky for translation from Bulgarian.

DIE LÖSUNGSINTENSITÄT VON BÄCHEN, DIE AUS DEM KRISTALLIN STAMMEN, IN KALKIG-DOLOMITISCHEN KOMPLEXEN

A. Droppa.
Geographisches Institut der Slowakischen Akademie der Wissenschaften, Lipt, Mikulas, Czechoslovakia.

In the crystalline region surface waters display little mineralisation (content less than 0.05 g in litre), however, are highly aggressive (CO_2 content agr. 3 – 4,8 mg in litre). When entering limestone-dolomite complexes they are altered. A sudden increase in calcium or calcium-magnesium bicarbonate constituent is evident. The content of other constituents increases significantly.

These relations were studied at the northern side of the Low Tatra (West Carpathians) in 1974-1976. The average monthly discharges and their chemical analyses were established here. The speed of dissolution of carbonates by surficial streams depends on their temperature and speed of discharge through the karst area. The highest increase in Ca has been shown in the winter months (December – March) when water temperature dropped to 0°C with values of 22-25 mg/l, while the least increase was the spring months (April-June) during floods with values of 10-12 mg/l.

According to present results, the intensity of karst corrosion by surficial streams has been:

	Year 1974	*Year 1975*	*Year 1976*
Demänovská dolina valley	46.7 m^3/km^2	52.8 m^3/km^2	41.16 m^3/km^2
Jánska dolina valley	41.8 m^3/km^2	41.0 m^3/km^2	28.72 m^3/km^2

Die Oberflächenerinne, die aus dem Kristallin zufließen, sind gering mineralisiert (Gesamthärte unter 0,1 g/l), aber hoch aggressiv (3,3 bis 4,8 mg/l freies CO_2). Die Mineralisation dieser Wasser stammt vorwiegend aus hydroltischem Abbau der verschiedenen Silikate, während der CO_2 - Gehalt von Luft, Boden und Vegetation herrührt. Beim Eintritt in das Kalkareal reagieren diese Wässer. Als Ergebnis der Reaktionen steigen die gelösten Kalcium- bzw. Magnesium-Bikarbonate rasch an. Das Volumen der anderen Komponenten ändert sich, besonders in Abhängigkeit von lokalen Bedingungen, wenig.

Diese Beziehungen wurden auf der Nordseite der Niederen Tatra (West-karpaten) studiert. Auf der hydrologischen Erforschung (1974-1976) und den chemischen Analysen der ober - und unterirdischen Wässer im Demänová- und Janskátal aufbauend werde ich zeigen, welchen Einfluß die Korrosionsintensität der Bäche auf die Denudation des dortigen Karstgebietes hat.

Das Quellgebiet der Oberflächengerinne an der Nordseite der Niederen Tatra liegt im kristallinen Kern, der aus Granit und kristallinen Schiefern besteht. Auf beiden Seiten des Zentralkernes befindet sich eine breite Zone mesozoischer Schichten, die in zwei Decken aufliegen. Als verkarstetes Gestein ist Gutensteiner Kalk der Mitteltrias zu nenne, der relativ mächtig vorkommt. Hier gibt es auch stark gefalteten, gut geschichteten und chemisch reinen Kalk (97% $CaCO_3$).

Klimatisch liegt das Karstterrain der Niederen Tatra in der kühlgemäßigten Region mit einem Jahresmittel von 5°C. Das niedrigste Monatsmittel hat der Januar mit – 6°C, das höchste der Juli mit 14°C. Die Jahresniederschlagssumme beträgt 900 - 1023 mm. Am trockensten sind Januar und Februar mit 23 mm, am feuchtesten Juni und Juli mit 150 m.

Die hydrologischen Verhältnisse dieses Karstgebietes sind durch zwei Entwässerungstypen zu charakterisieren: Die kristallinen Bereiche der Täler werden nur durch Oberflächengerinne entwässert, nämlich im Demänovátal durch die drei parallel fließenden Bäche Demänovka, Priečny und Zadná voda, und im Janskátal durch die zwei Bäche Štiavnica und Bystrá. Beim Eintritt in das Karstareal enden sie alle an mehreren Schwinden (Ponoren). Unter Tag durchfließen sie die tiefsten Stockwerke der dortigen Höhlen. Nach 2,5 km langem, unterirdischem Lauf treten sie in einer Sprudelquelle (Vyvieračka) wieder an die Oberfläche und setzen ihren

obertägigen Lauf durch Karstareal fort.

Der Chemismus der Oberflächenwässer ist von den geologischen Verhältnissen abhängig: Die Gerinne des Kristallins haben nur sehr niedrige Total-mineralisation (50 - 69 mg/l). Im Jahre 1975 hatte die Demänovka einen Ca-Gehalt von 9,6 mg/l und einen Mg-Gehlat von 1,75 mg/l, die Štiavnica hatte einen Ca-Gehalt von 12,0 mg/l und einen Mg-Gehalt von 2-3 mg/l. Der Gehalt an freiem CO_2 wurde bei ihnen mit 3,2 - 4,84 mg/l festgestellt. Der höchste freie CO_2-Gehalt war im Mai-Juni (6,6-8,8 mg/l), der niedrigste im Februar (1,3-2,0 mg/l). Den Anstieg des gelösten Ca und Mg beim Durchfließben des Karstes zeigen die Tabellen 1 und 2. Danach außert sich die Korrosionsfähigkeit eindrucksvoll in den Wintermonaten Januar-Februar in Ca-Werten von 28,3 mg/l und Mg-Werten von 9,6 mg/l, während die Frühlingsmonate (April-Juni) mit Ca-Werten von 4, 7 mg/l und Mg-Werten von 0,65 mg/l am niedrigsten sind.

Berechnung der Korrosionsintensität

In Karstgebieten bestimmt man die Korrosionsintensität von Oberflächenwässern durch Messung der abgetragenen Kalke und Dolomite in m^3/km^2/Jahr. Es gibt verschiedene mehr oder weniger genaue Methoden: J. Corbel 1959, P. Williams 1963, M. Pulina 1968, I. Gams 1969, A.G. Tchikischew 1972 u.A. Genauer läßt sich die Korrosionsintensität feststellen, wenn von der Menge der am Ausgang des Karstareals gelösten Karbonate (Gewichtseinheit in der Zeiteinheit) die Menge der am Eintritt in das Karstareal gelösten Karbonate (ebenfalls Gewichtseinheit in der gleichen Zeiteinheit) abgezogen wird. Für diese Berechnung stellen wir die Formel auf:

$$C = \frac{11{,}68/Vv\text{-}Vp/ - 10{,}87/Dv\text{-}Dp/.R}{P}$$

C — jährliche Korrosion in m^3/km^2, oder in mm/1000 Jahre,
Vv — gelöster $CaCO_3$-Gehalt in g/sec am Ausgang des Karstareals, Vv = Q.m
Q — Abfluß in m^3/sec, m — gelöster $CaCO_3$-Gehalt in mg/l
Vp — gelöster $CaCO_3$-Gehalt in g/sec beim Eintritt in das Karstareal,
Dv — gelöstes $MgCO_3$ in g/sec im Wasser am Ausgang des Karstareals, Dv = Q.n.
Q — Abfluß in m^3/sec, n — gelöster $MgCO_3$-Gehalt in mg/l
Dp — gelöster $MgCO_3$-Gehalt in g/sec beim Eintritt in das Karstareal,
R — Reduktionsfaktor, einzusetzen bei allochthonen Gerinnen, weil zeitweise hohe Abflüsse die Härte temporär herabsetzen,
P — Fläche des verkarsteten Entwässerungsgebietes in km^2.

Nach dieser Formel bringt die beiliegende Tabelle die Korrosions-intensität der Oberflächengerinne und der Sprudeln:

Örtlichkeit	*Fläche in km^2*	*Jahr*	*Abfluss m^3/sec*	*Ca und Mg in mg/l*		*Abtrag in m^3/km^2 $CaCO_3$ $MgCO_3$*	*Totalmineralisation*
Demänovka beim		1974	0.330	10,9	3,81	13,67	–
Eintritt in das	10,0	1975	0,327	8,08	1,56	8,26	9,16
Karstareal		1976	0,230	9,0	2,13	6,68	11,61
1025 m ü.M							
Priečnybach beim		1974	0,090	11,60	4,64	11,57	–
Eintritt in das	3,3	1975	0,069	11,66	2,45	7,19	9,73
Karstareal		1976	0,040	13,08	4,78	5,96	10,52
920 m ü.M.							
Zadnábach beim		1974	0,540	11,15	3,44	11,74	–
Eintritt in das	16,9	1975	0,498	8,58	1,52	6,15	6,44
Karstareal		1976	0,388	8,58	2,83	7,58	13,90
907 m ü.M.							
Sprudelquelle		1974	0,652	24,67	11,83	55,50	–
Demänovka	10,0	1975	0,641	25,16	7,71	51,97	94,51
787 m ü.M.		1976	0,536	26,00	10,48	45,87	87,13
Demänovka am		1974	1,398	23,34	9,06	46,80	–
Ausgang des	16,4	1975	1,373	25,91	5,99	52,88	77,15
Karstareals		1976	0,946	25,83	8,70	41,16	58.89
715 m ü.M.							
		Janskátal:					
Štiavnica beim		1974	0,535	10,30	3,42	8,10	–
Eintritt in das	20,0	1975	0,579	12,08	2,17	8,77	12,03
Karstareal		1976	0,383	11,25	3,65	6,30	10,91
879 m ü.M.							
Bystrábach beim		1974	0,232	12,66	4,68	9,55	–
Eintritt in das	9,5	1975	0,307	14,33	3,45	14,46	16,35
Karstareal		1976	0,193	14,00	4,66	9,34	13,56
870 m ü.M.							

Sprudelquelle		1974	0,700	18,00	6,12	20,27	—
Štiavnica	11,2	1975	0,740	18,58	4,35	21,15	35,73
774 m ü.M.		1976	0,594	18,33	7,05	20,05	29,60
Štiavnica am		1974	1,799	28,66	10,28	43,59	—
Ausgang des	32,8	1975	1,555	32,16	8,12	41,03	67,14
Karstareals		1976	1,022	31,50	10,71	28,72	34,39
648 m ü.M.							

Das Karbonatvolumen im Karstgebiet enthält auch einen Anteil von Kalken und Dolomiten aus der Vertikalzirkulation. Um diesen Anteil abzugrenzen. lässt sich die Korrosionsleistung von Gerinnen, die aus Kristellin kommen, gestimmen. Im Jahre 1976 hat die oberirdische Štiavnica auf der Strecke des Durchflusses durch das Kastareal, also auf 1,8 km Länge, ein Volumen von 9,34 m^3 an Karbonaten abgetragen, was in der Gerinnesohle/9000 m^2 /1,03 mm ausmacht.

References

Bögli, A. 1964. Mischungskorrosion – ein Beitrag zum Verkarstungsproblem. Erdkunde, B.18, S.83-92, Bonn.

Corbel, J. 1959. Erosion en terrain calcaire. *Annales de Géographie*, H. 68, p.97-120, Paris.

Droppa, A. 1976. Corrosion Intensity of Karst Waters in Demänová Valley, *Slovenský kras*, 14: 3-30, Martin.

Gams, I. 1969. Zur Ergänzung der vergleichenden Forschungen der Karst-korrosionsintensität *Abh. des 5. Int. Kongress f. Spelaologie*, B-2.

Laptev, F.F. 1939. Agressivnoje dejstvije vody na karbonatnyje porody, gipsy i betony. M.-L., 1939.

Pulina, M. 1966. Zjawiska krasowe w Zachodnim Kaukazie. *Czas geograf.* 37, 4 Wroclaw.

Tchikischew, A.G. 1972. Karst Valdajskej vozvyšennosti. Karst v karb. porodach T.47, p.94-114, Moskva.

Williams, P. 1963. An Initial Estimate of the Speed of Limestone Solution in County Clare, *Irish Geogr.* V-4, 6, Dublin.

MICROCLIMATE OF KARST CAVITIES OF THE MOUNTAIN CRIMEA

V.N. Dubljanski & L.M. Sockova
Simferopol University,
U.S.S.R.

The underground microclimate determines the thermodynamic conditions for karst processes such as the formation of cave sedimentations. The hydrogeologic features of the karst massif, the conditions of existing speleofaunaes and man's stay under the ground for a long period and the possibilities of the economic use of caves also depend on the microclimate. In spite of its importance, the problem of the formation of the microclimate is one of the less worked out in the theoretical karst science (5,6).

In the Crimea during the period 1958-1975 over 800 karst cavities, having lengths up to 13 km and depths up to 500m were opened and studied. The morphogenetic classification was worked out (3) and the hydrogeology and the microclimate were studied (1). Before 1958 only a few examples of the measurement of temperature in 12 caves of the Crimea were found in the literature (4). At the present time about 200 cavities are being observed. More than 2000 measurements in cavities, and also more than 7000 daily records of the changes of temperature, humidity and pressure of air were made. This gives the possibility to distinguish average microclimatic features for cavities of different types and classes (Table).

TABLE 1. Microclimatic characteristics of the karst cavities of the mountain Crimea (warm period)

Genetic class and morphological type of cavity	*Amount of studied objects*	*Average t.°C*	*c,mm of Hg*	*r.%*	*l, time/day*	*Gaseous composition of air*
Corrosively-gravitational						
jointly well, mine	6	9.9	7.2	97	37.5	Equilibrates to atmospheric
Nivally-corrosive						
well	27	10.4	8.3	89	2.0	The content of CO_2
mine	85	5.3	6.7	97	3.0	(to 0.5%)
Corrosively-erosional						
mine-sinkhole	16	6.2	6.8	97	19.7	The content of CO_2
cave-sinkhole	6	6.8	8.0	93	1.4	(to 4.5%); near fracture) dislocations
laid-bare cave	48	5.2	6.5	95	1.3	to 3% CH_4
cave-source	10	9.5	7.8	88	1.2	

The temperature and humidity of air. In any karst cavity, excluding shallow nival-corrosive wells, there are entrance "equilibrating" and "neutral" zones. In the "equilibrating" zone the temperature and humidity of air vary widelv in response to the daily, monthly and seasonal changes of microclimate elements on the surface. In the "neutral" zone microclimatic parameters are stable and they have only a yearly motion. There is a close relation (r=0.3-0.9), of the form $y=ax^b + c$, between the temperature and vapour pressure of air under the ground (y, °C or mm of Mg) and the distance from the entrance, x. The value "c" determines the temperature or humidity in the "neutral" zone. "c" is similar for cavities in the same morphological types and situated in similar geomorphological conditions. For example, the temperature distribution in caves – sinkholes with narrow entrances is described by the equation $y=98X^{-1.3}+ 9.1$. For broad entrances the relation is: $y=98X^{-1.3}+ 4,6$. So, the temperature of air in the karst cavities depends not on the value of the aerial thermic stage and the cavity's elevation (5,7), but on its morphology and location's conditions (1).

The temperature of air in the "neutral" part of the karst cavities of the Crimea varies from +5.3 up to +10.4° (Table). The corresponding range of mean annual temperatures at the cave elevations is 5,7 – 7,2°. This makes it possible to separate climatic subtypes: warm (temperature underground above that on the surface) and cold (temperature underground below that on the surface).

Considerable amounts of snow and ice accumulate at the entrance of cold cavities. Snow and ice in the caves play a small role in the water balance in spite of their considerable effect on the cave's and mine's microclimate.

The high relative humidity (95-100%) is maintained by the infiltration moisture entering the cavity and by the presence of underground channels and reservoirs. Lowest relative humidity values (88-90%: See Table) occur only in well warmed nivally-corrosive wells and in small caves with intermittent channels. Vapour pressures vary from 6.5 to 8.3 mm of Hg. In warm cavities underground is greater than surface while in cold cavities underground is less than surface. These inequalities determine whether evaporation or condensation takes place.

Movement of air. The changes in the underground atmosphere, being excited by pressure differences between entrances, are usually rhythmical and they respond to the daily, monthly and yearly cycles of the atmospheric elements on the surface. In a cold period, when air movement is from lower to higher entrances, the maximum speed of the movement of air is observed when the surface temperature is a minimum. The opposite effect occurs during warm periods with maximum downward flow at times of maximum external temperature.

Synoptic relationships of the movement of air under the ground are often masked or modified by the effect of the secondary factors – the effect of rarefaction, the difference in the specific weight of dry and damp air, evaporation and condensation. In complex, labyrinthed caves, connected with the surface by narrow tunnels, one finds an irregular pulsation of air in speed and direction ("spelean breath").

The speed of the movement of air in karst cavities of the Crimea varies over very wide ranges: from 0.003 to 8.0 m/sec. A new concept, the airchange coefficient is introduced: this is the ratio of the volume of air flow over one day to the cave's volume (I). At $I < 5$ to the dynamic types (Table). The study of the changes of the atmospheric pressure on the surface and under the ground gives the possibility of estimating the sizes and the character of unknown cavities.

The condensation of moisture. Condensation in the cavities of all types is observed only in the warm period (2). The amount of condensationed moisture, forming in the jointy-karst containers, is determined from the relation

$$Q = V \cdot T \cdot I\,(\rho\ \text{surface} - \rho\ \text{underground}),\ \text{where}$$

V – the total volume of cavities, m^3
T – airchange span (in days)
I – airchange coefficient

ρ surface and ρ underground – absolute humidity of air g/m^3. About 50 mln.m^3 of moisture may form in the warm period in the upper part of zone of aeration. This would lead to a condensational run-off of 1.8 1/sec. km^2. Condensation apparently plays a significant role in water balance. It is equivalent to 7.3% of the difference between precipitation and evaporation. In warm periods the run-off is supported by the condensational waters. This conclusion is confirmed by balance and hydrological methods for the hydrological region of Krasnopestchezsk.

The geothermic conditions of the karst regions. The geothermic field of the mountainous Crimea is upset by the influence of karstification. The depth of occurrence of the layer of constant temperatures is equal to 250-300 m, and the configuration of its surface depends on the rate of jointing and karsting of the mountain rocks. All karst cavities are surrounded by cooled zones of different width. Microclimatic research gives the possibility to calculate the thermal balance of separate karst massifs and to determine the value of the conductive component of the thermal stream ($8.4.10^{-5}$ kkal./cm^2.sec.).

The gaseous composition of air of the karst cavities. It was noted in the laboratory the considerable concentration of CO_2 up to 0.5%), connected with the decomposition of organic material. This was noted by testing of air in 200 cavities and by gas analysis of more than 100 tests. Near the fractural breaks an increase of the content CO_2 (up to 3-7.5%) is observed. A considerable increase in the content of N_2 (from 76 to 82%) and the appearance of CH_4 (from traces to 6.7%), C_2H_6, C_3H_8, C_4H_{10} (from traces to 1.1%), is also observed. The gas displays of N_2-CO_2, CO_2, CO_2-CH_4, N_2-CO_2-CH_4, CH_4-N_2 content are probably connected with the entering of dry streams of gas from zones of fractural dislocations. The partial pressure CO_2 in air of karst cavities is 10 to 100 times higher than its pressure in atmospheric air. It determines the activity of corrosive processes in different parts of the section.

The microclimatic conditions of karst cavities of the Crimea in the whole are favourable for long speleological and medical scientific researches. The degree of discomfort can be determined by the categories "cold, damp" and "cold, very cold" (7). The high content of CO_2 in air may have an influence on the artificial isolation of the cave's part for the underground camp or laboratory.

The main problems of studying the cave's and mine's microclimate of the Crimea are the creation of microclimatic hospitals; the working out of mathematical models of karst cavities of different types; increasing the precision of the thermodynamical calculations, possibly using the methods of mining meteorology, and the use of diagrams of the humid air's state.

Literature

1. Dubljanski. V.N. 1957. The temperatural regime of carbonaceous rock mass of the main range of the Crimean mountains. Book. "Works of MINHIGP". Issue, 67. Moscow.
2. Dubljanski. V.N. 1972. The condensation of moisture in the fracturally-karst collectors of the Mountain Crimea. Book. "Hydrogeology and Engineering geology of the arid zone of the USSR" No. 6, M., "Mineral Resources".
3. Dubljanski. V.N. 1974. Classes and types of karst cavities on some mountain structures of the Alp's folded region. Book. "Materials of the VIII and IX congresses of Karpato-Balkan geological Association". Kiev, "Naukova dumka",
4. Kruber, A.A. 1915. Karst region of the mountain Crimea. M.
5. Maksimovich, G.A. 1963. Principles of karst. Perm. vol. 1.
6. Trimmel, H. 1968. Die Hohlenkunde, Braunschweig.
7. Trombe, F. 1952. Traité de spéléologie. Paris.

OLIGOCHAETA FROM CAVES IN THE TATRA MTS WITH REFERENCES TO ANOMALIES IN THEIR STRUCTURE

Elzbieta Dumnicka
Section of Underground Alpinism
Kmieca 20/9, 30-014 Krakow
Poland

The fauna of Polish caves is very little known. The oldest investigations were concerned with the fauna of Sudeten caves. Of the Oligochaeta the occurrence of 3 species of the family Lumbriculidae was noted as well as 6 species of the family Enchytraeidae, including 1 species dubia. The data found in the literature are only concerned with the occurrence of those species, their biology and ecology being wholly unknown. In Poland Chodorowski was the first who noted the presence of Oligochaeta in bodies of cave water. Several species were identified by Kasprzak from the Dziura cave (the Valley Ku Dziurze) where he collected samples in a pile of fallen leaves. There he found *Fridericia ratzeli, Mesenchytraeus armatus, Bryodrilus ehlersi* and *Enchytraeus buchholzi.*

In the years 1972-1976 samples were collected during sporting expeditions, organized by the Section of Underground Alpinism, with the aim of investigating the qualitative composition and distribution of Oligochaeta. The investigations were carried out in the following caves: Zimna, Mietusia, Kasprowa Nizna, Szczelina Chocholowska, Bandzioch, Kalacka and Goryczkowa. Table 1 contains short descriptions of these caves. In the Szczelina Chocholowska cave samples were collected in the underground sector of the Chocholowski stream: in Mietusia and Kasprowa collections were also from water habitats (small pools and a stream). In the Zimna and Bandzioch caves samples were collected from the bottoms of water bodies as well as from dry ground. In the small caves Kalacka and Goryczkowa no constant water bodies occur, therefore the samples were only collected from a clay sediment.

During the investigations in the Tatra caves 16 species of Oligochaeta from 3 families — Naididae, Enchytraeidae and Lumbriculidae — were recorded (Table 2).

Naididae occurred only in an underground sector of the Chocholowski stream, in typical cave waters no representatives of this group were noted, thus they are trogloxenic organisms which, washed into the cave, may live there for a certain period. It seems that *Propappus volki* (Enchytraeidae) belongs to this group of organisms.

Two species of the family Lumbriculidae also occurred only in the underground stream while a juvenile specimen was found in the pool in the Zimna cave.

The remaining species are not typical representatives of the aquatic fauna (perhaps with the exception of *Cernosvitoviella tatrensis* which has not been found in a land environment yet). They are land or amphibious species, though some of them occur almost exclusively in water. Apart from the Szczelina Chocholowska where in two samples as many as 7 species and 2 genera occurred: the number of species is proportional to the number of samples.

In cave water bodies the two most frequently encountered species were of the genus *Cernosvitoviella: C. atrata* and *C. tatrensis,* and also *Marionina riparia.* In the water sink of the Zimna cave a new species was found: *Cernosvitoviella parviseta.* In the land environment the most frequent species were *Enchytraeus buchholzi* and *Henlea perpusilla. E. buchholzi* is an exceptionally frequent species in the cavesof Europe.

The greatest number of species was found in the caves where the samples were collected from water bodies as well as from unflooded sectors of tunnels. The water bodies in the caves lie above the level of surface

waters, hence direct "Flowing-in" of animals to the caves is not possible. It is most pronounced in the Bandzioch cave, where *Cernosvitoviella atrata* was noted, an amphibious species but closely connected with the aquatic environment. This cave has two entrances both lying outside the range of stream waters, nevertheless, near the upper entrance, situated almost on the ridge, this species was encountered on the bottom of a lake in a meander. Water in this lake comes from rain water filtering in from the surface. It seems that the population of this species is wholly or almost wholly isolated from the surface population. Under such conditions the appearance of new forms, sub-species or even species is possible.

On the basis of material from the caves of Poland and of neighbouring countries (Czechoslovakia, Hungary) it may be claimed that the majority of Oligochaeta species living in caves are common forms, frequently encountered in other environments as well. Even some new species described from caves were later found on the surface e.g. *Fridericia semisetosa.* Infiltration into the cave is not difficult for soil species, therefore the fauna of land Oligochaeta is represented by a greater number of species.

During the identification of samples originating from Tatra caves as well as from the caves of the Krakow – Czestochowa Upland, specimens with certain deviations from the normal structure were found. Most often a reduction of septal glands was encountered, the degree of reduction varying from the total atrophy of all pairs to diminished dimensions, most frequently noted in the third pair (Figs. 1 - 3). This phenomenon was observed in *Fridericia* sp., *Enchytraeus* sp., and *E. polonicus.* Sometimes cases of the duplication

Table 1. Short characteristic of the investigated caves

cave	valley	altitude a.s.l.	length (m)	change of level (m)
Zimna	Kościeliska	1125	4000	+100
Chochołowska	Chochołowska	1050	3000	-
Szczelina		1070		
Kalacka	Kondratowa	1220	360	-
Goryczkowa	Goryczkowa	1260	260	-
Miętusia	Miętusia	1330	6000	-200
Kasprowa	Kasprowa	1235	1500	-

Fig.1. Animal with normal septal glands

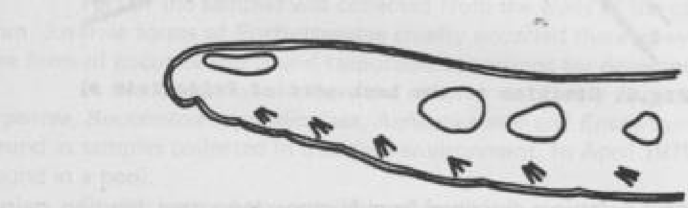


Fig.2. Animal with reduced septal glands

Fig.3. Animal without septal glands

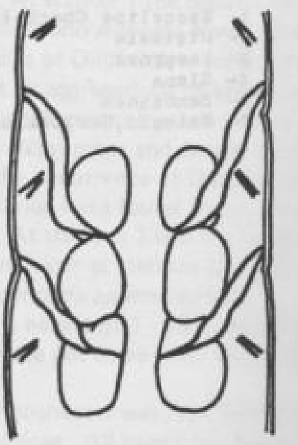


Fig.4. Enchytraeus polonicus with duplicated spermathecae

Table 2. List of oligochaete species found in the caves of Tatra Mts

species	1	2	3	4	5	6
Naididae						
Chaetogaster sp. von Baer 1827	+					
Nais communis Piguet 1906	+					
Enchytraeidae						
Propappus volki Michaelsen 1916	+					
Mesenchytraeus sp. Eisen 1878	+					
Cernosvitoviella atrata (Bretscher) 1903	+			+	+	
-"- tatrensis (Kowalewski) 1916	+			+		
-"- parviseta Gadzińska 1974				+		
-"- sp. Kiel et Christ 1959	+			+		
Henlea perpusilla Friend 1911				+	.	+
-"- sp. Michaelsen 1899						+
Buchholzia appendiculata (Buchholz) 1862					+	
-"- sp. Michaelsen 1887					+	+
Fridericia bulbosa (Rosa) 1887					+	
-"- maculata Issel 1905					+	
-"- sp. Michaelsen 1889				+		
Enchytraeus buchholzi Vejdovsky 1879				+	+	
-"- dominicae Dumnicka 1976					+	
-"- sp. Henle 1837				+		
Marionina argentea (Michaelsen) 1889				+	+	
-"- riparia Bretscher 1899	+	+		+		
Enchytraeidae juv. non det.	+			+	+	+
Lumbriculidae						
Lumbriculus variegatus (Müller) 1774	+					
Stylodrilus heringianus Claparede 1862	+					
Lumbriculidae juv. non det.	+			+		

1- Szczelina Chochołowska
2- Miętusia
3- Kasprowa
4- Zimna
5- Bandzioch
6- Kalacka, Goryczkowa

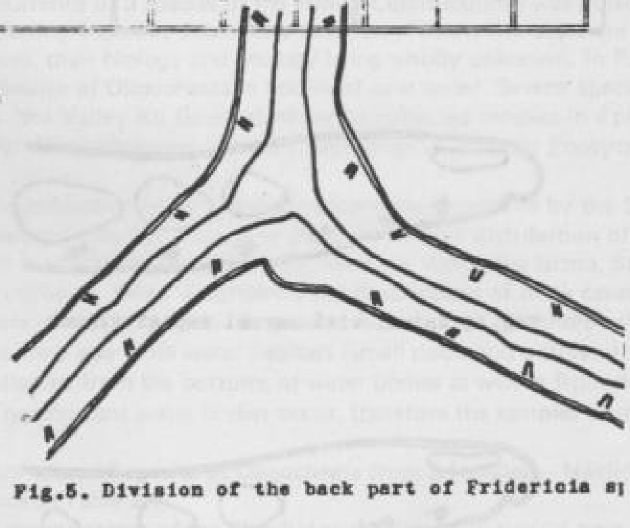


Fig.5. Division of the back part of Fridericia s[

of organs were observed. The species *Enchytraeus polonicus* described from Nietoperzowa cave, has two pairs of spermathecae, where normally only 1 pair occurs (Fig. 4).

The occurrence of detached parcels of setae in the coelomic cavity was previously noted in some representatives of the genus *Fridericia* only. In the material from Tatra and Krakow-Czestochowa Upland caves such parcels were also encountered in *Buchholzia* sp., *Enchytraeus dominicae* and *E. polonicus*. The reasons for, and mechanisms of, the formation of these parcels is not yet explained, therefore one cannot conclude what contributed to their formation in the Oligochaeta occurring in caves.

Another deviation was the reduction of mature specimens, particularly well seen in *Fridericia bulbosa*. One specimen of this species was bifid for one third of the animal's length (Fig. 5), this injury evidently being mechanical.

A few specimens were also noted with irregular formation of characters significant from the point of view of taxonomy. The changes consisted of translocations of individual organs or of their excessive development, e.g. with some specimens of *Achaeta eiseni* spermathaecae reach to segment VIII, or even to IX, while in typical specimens they end in segment VII.

Sometimes the observed irregularities also appear in Oligochaeta from surface waters or soil, but their frequency is many times less. The reasons of the changes discussed may be unfavourable environmental conditions in the cave: under extreme cave conditions only the best adapted organisms can survive. Thus one may suggest that the observed irregularities did not diminish the adaptability of the organisms.

ANNUAL CHANGES OF OLIGOCHAETE FAUNA IN A CAVE OF THE KRAKOW-CZESTOCHOWA UPLAND

Elzbieta Dumnicka
Section of Underground Alpinism
Kmieca 20/9, 30-014 Krakow
Poland

The numerous caves in the Krakow – Czestochowa Upland are usually small, mostly not exceeding 100m in length. The fauna of these caves was investigated by Demel, Szymczakowski and Stach. However, no data on Oligochaeta are to be found in their works only *Dendrobaena* sp. (Lumbricidae) from the Nietoperzowa Cave being mentioned by Demel.

In the present work two caves, greatly differing from each other, were included: The Nietoperzowa and the Kryspinowska Cave. In the Nietoperzowa Cave four stations were selected for the present study (Fig. 1). At all stations, except No. 1, aggregations of bat excrement, most abundant in the Main Chamber, were noted. At stations 3 and 4 much of the walls was covered by clay and humus, which had filtered in with water from the surface.

In the Kryspinowska Cave the samples were collected at several points which may be grouped into 3 stations (Fig. 2). The bottom is covered with clay and in some places a thin layer of humus occurs.

In the Nietoperzowa Cave year-round investigations were carried out from November 1975 to November 1976, the samples being collected at about one-month intervals. In the Kryspinowska Cave the samples were collected in April, May and June 1976.

The occurrence of 9 species of Oligochaetes was noted in the two caves investigated: two species are new to science; *Enchytraeus dominicae* and *E.polonicus*, and they have been described elsewhere. The remaining Oligochaeta are already known from the caves of Europe.

On the basis of the investigations it is possible to determine seasonal changes and periods of sexual reproduction of individual species. It is also possible to study the allegiance of a species to the habitat.

In the Nietoperzowa Cave 8 species of Oligochaetes of the family Enchytraeidae and 1 species of the family Lumbricidae (*Dendrobaena rubida*, det. A. Wendorff) were found. At station 1 the occurrence of 4 species was noted: *Enchytraeus dominicae, E. buchholzi, Henlea ventriculosa* and *Achaeta eiseni*. The density was low and amounted to 25 - 225 specimens/m^2. At station 2 seven species of Oligochaeta were noted. They were most numerous in bat excrement. However, it was observed that not all aggregations of excrement are inhabited by Oligochaeta. In spite of variations brought about by uneven settlement of guano layers, seasonal changes were distinctly visible in the numbers of Oligochaeta (Table 1). In November and January, when a decrease in the number of Oligochaetes was noted, in some aggregations the occurrence of Diptera larvae was observed, and in the following months (February, March, April) pupal exuviae were found there. Thus, it is possible that Diptera are competitve organisms in relation to Oligochaeta. At stations 3 and 4 a total of 5 not very numerous species was found: *Fridericia bulbosa* and *Enchytraeus dominicae* at stations 3 and 4, *Enchytraeus polonicus* only at station 3, and at station 4 *Achaeta eiseni* and *Buchholzia appendiculata.*

Part of the samples was collected from the walls of the cave at the height of 1 - 1.5m above the bottom. Juvenile forms of Enchytraeidae chiefly occurred there; they could have got there from the surface in the form of cocoons and found favourable conditions for development.

In the Kryspinowska Cave the occurrence of only 4 species of Oligochaetes was recorded: *Marionina argentea, Buchholzia appendiculata, Achaeta eiseni* and *Enchytraeus dominicae.* All specimens were also found in samples collected in a surface environment. In April 1976 only empty cocoons of Oligochaetes were found in a pool.

On the basis of the material collected it is possible to claim that the variability and number of Oligochaeta chiefly depend on the amount of accessible food, and in a smaller measure, on the distance from the entrance.

Cocoons, juvenile and adult specimens were found throughout the year, thus indicating that no periodicity occurred in reproduction. This feature was also noted in other groups of animals. At the same time, the absence of periodicity suggests that no dependence occurs between the cave and surface populations, since the cocoons found in winter had to be laid in the cave, as none might be found on the surface in this season of the year.

The frequency of species in the samples was calculated (Table 2). In the Nietoperzowa Cave juvenile forms (Enchytraeidae juv.) were most frequent. The species *Fridericia bulbosa* and immature specimens of this genus were fairly frequent (24% of samples). *Enchytraeus* sp. was most often represented by *E. dominicae,* rarely by *E.buchholzi,* and the occurrence of *E.polonicus* was noted three times only.

In the Kryspinowska cave juvenile specimens were most frequently encountered: as well as *Buchholzia appendiculata* and *Buchholzia sp. Marionina argentea* was relatively frequent, though this species was not

Fig.1. Plan of the Nietoperzowa Cave.

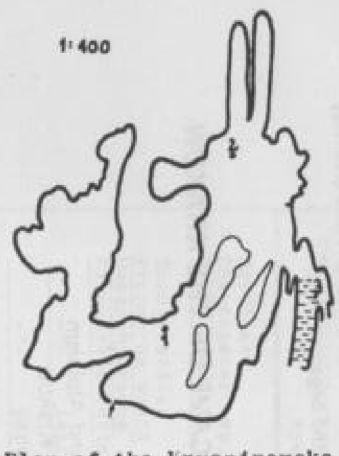


Fig.2. Plan of the Kryspinowska Cave.

Table 1. Station 2 – number of Oligochaeta found in the bat's excrements during a year

months / species	XI	I	II	III	IV	V	VI	VII	VIII	X	XI
Fridericia sp.	1	10	1	2	1	-	61	no samples	4	130	-
-"- bulbosa	2	4	11	-	-	-	129		76	152	-
in general	16	24	103	26	4	-	431		135	446	14

Table 2. Frequency of species in the samples from Nietoperzowa and Kryspinowska caves / % /

species	Nietoperzowa Cave	Kryspinowska Cave
Achaeta eiseni Vejdovsky 1877	18	7
-"- sp. Vejdovsky 1877	11	7
Henlea ventriculosa (d'Udekem) 1854	2	-
-"- nasuta (Eisen) 1878	2	-
-"- sp. Michaelsen 1889	2	-
Buchholzia appendiculata (Buchholz) 1862	7	7
-"- sp. Michaelsen 1887	13	20
Fridericia bulbosa (Rosa) 1887	24	-
-"- sp. Michaelsen 1889	24	-
Enchytraeus buchholzi Vejdovsky 1879	11	-
-"- dominicae Dumnicka 1976	18	7
-"- polonicus Dumnicka 1977	7	-
-"- sp. Henle 1837	13	7
Marionina argentea (Michaelsen) 1889	-	13
Enchytraeidae juv. non det.	78	53
Samples without animals	12	40

Table 3. Frequency of species in the different substrata (%)

species	bat's excrements	clay with humus	clay
Fridericia bulbosa	28	30	-
-"- sp.	36	26	-
Buchholzia appendiculata	14	4	-
-"- sp.	21	9	8
Enchytraeus buchholzi	21	9	-
-"- dominicae	43	17	8
-"- polonicus	14	-	8
-"- sp.	21	9	8
Achaeta eiseni	-	26	17
-"- sp.	-	17	8
Henlea nasuta	-	-	8
-"- ventriculosa	-	-	8
-"- sp.	-	-	8

Table 4. Chemical properties of different types of sediments in the caves

	Nietoperzowa			Kryspinowska	
	bat's excrements	clay with humus	clay	clay	clay
pH	4,7	8,6	8,4	8,3	8,2
%N	9,66	0,369	0,182	0,056	0,049
% organic matter	65,17	6,310	2,017	0,776	0,207

noted in the Nietoperzowa cave. On the other hand, an insignificant share of the species of the genus *Fridericia* was observed; neither were representatives of the genus *Fridericia* encountered in this cave. In a relatively large number of samples (40%) Oligochaetes did not occur, while in the Nietoperzowa cave this applied to only 12% of the samples. Thus the fauna of the Kryspinowska cave is poorer and shows a greater proportion of small forms, which may more easily live in a habitat rather poor in organic matter.

In the Nietoperzowa cave the samples were collected from 3 habitats: clay, clay with humus and bat excrement. The frequency of species and of some selected forms in these types of habitat was calculated and differences in their occurrences were determined (Table 3). *Fridericia bulbosa* and juvenile specimens of this genus were found equally frequently in the excrement and in the clay with humus, while in pure clay no specimens were encountered. *Buchholzia appendiculata* and juvenile forms of this genus are still more strongly connected with guano. The species of the genus *Enchytraeus* are most frequent in guano, more rare in the clay with humus, and only sporadic in the clay. The occurrence of *Achaeta eiseni* and juvenile specimens of this genus is connected with clay habitat while they were never found in the aggregations of bat excrement. The species of the genus *Henlea* also occur in clay only, but since they were only recorded three times, it is not

possible to draw conclusions of their allegiance to this habitat.

It seems a rule that the larger a species is, the more frequently it occurs in habitats rich in organic matter, but the distribution of *Achaeta eiseni* does not agree with this generalisation. Maybe the pH value of the sediment plays a role here, being distinctly acid in the excrement (Table 4).

The material presented shows that Oligochaeta are a permanent constituent of the cave fauna and that the next investigation should lead to the explanation of their role in simple communities living in this environment.

THERMAL PROPERTIES OF ABSEILING DEVICES

Andrew J. Eavis
5 Sycamore Close, Selby,
N. Yorks, England.

Once the abrasion and strength advantages of keeping nylon rope dry were appreciated, (Eavis 1974) the importance of descender temperature was realised. It was decided to do a simple series of experiments to find the temperatures involved. Various types of descenders and two different types of rope were therefore taken to Malham Cove, as well as 300 feet of strong electric cable, a thermocouple and a box of electronics that had previously been shown to give the temperature of a point on a descender to an accuracy of a few degrees Centrigrade. The temperature of a point as close as possible to that of maximum heat was recorded at five seconds intervals for seven descents. In addition, the caver stopped at the 200 foot mark just above the ground, and the temperature was taken every five seconds for a couple of minutes giving cooling curves of the device in a rest situation.

Although it might not seem immediately apparent, the curves for each test are essentially similar and take the form of Fig. 1. The descending device is the main element in a system into which heat enters primarily from friction with the rope, and exits by transference to various bodies, i.e. atmosphere, rope carabiner, cavers'

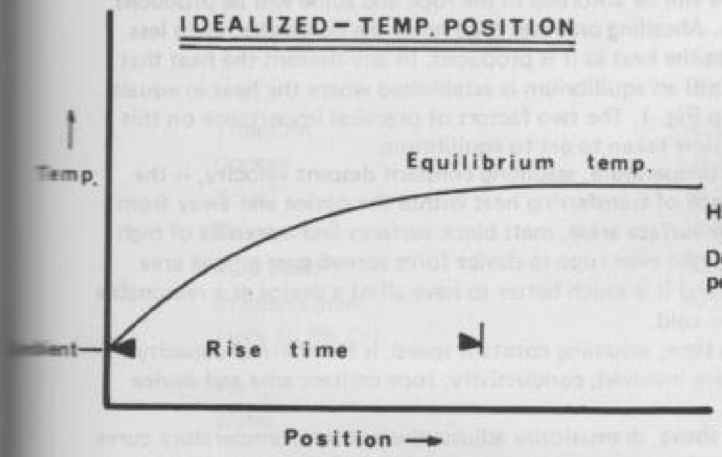


FIG. 1

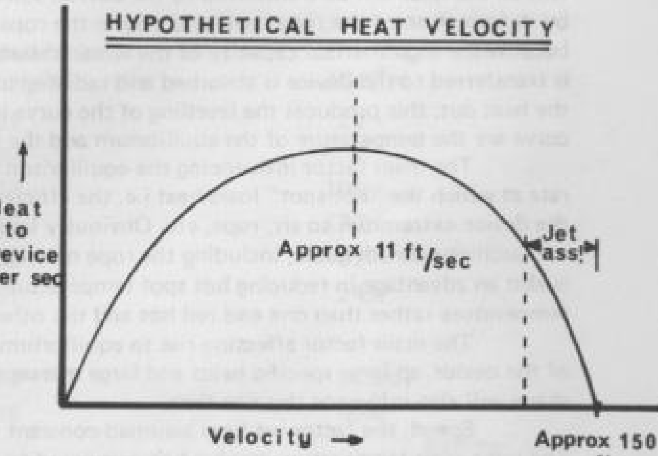
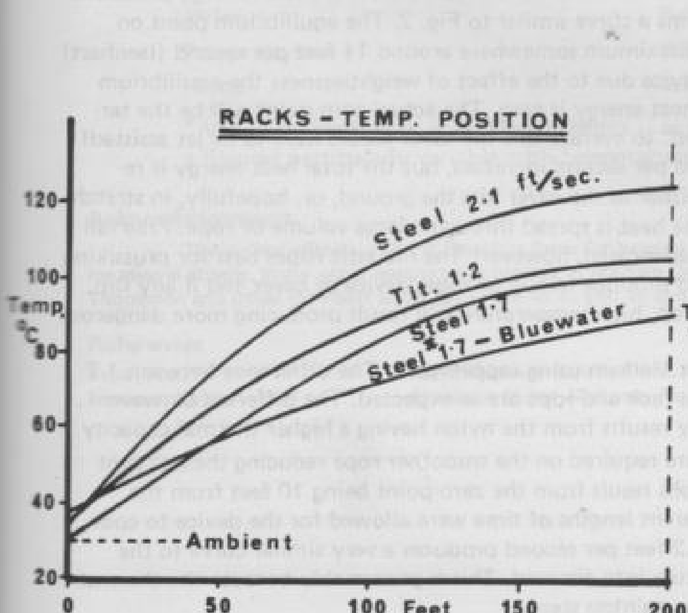


FIG. 2



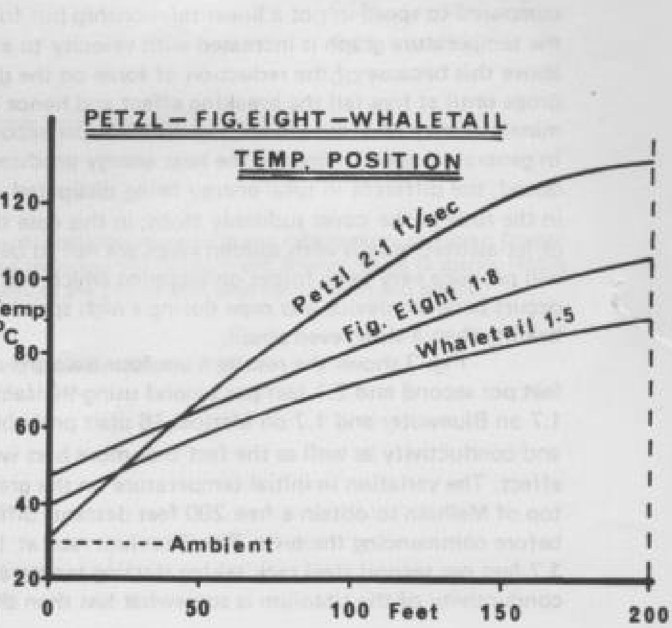


FIG. 3

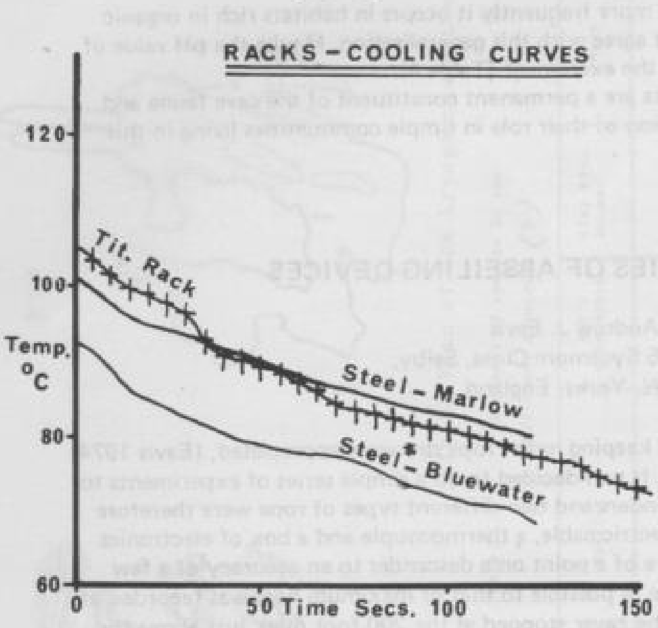


FIG. 5

FIG. 4

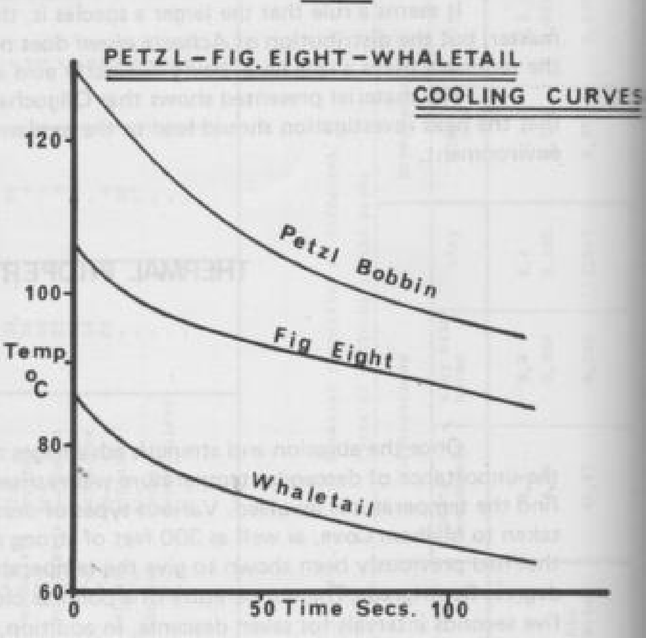


FIG. 6

N.B all tests on 10 m.m. marlow 16 plait terylene except where shown *

hands, etc. Now if two cavers of similar weight descend at the same speed using different devices, the same amount of heat energy per second is involved, but different devices will reach entirely different temperatures. Not all the heat will be transferred to the device; some will be absorbed in the rope and some will be produced by deformation of the rope itself and stay in the rope. Abseiling on a wet rope heats the descender much less because the high thermal capacity of the water absorbs the heat as it is produced. In any descent the heat that is transferred to the device is absorbed and radiated until an equilibrium is established where the heat in equals the heat out; this produces the levelling of the curve in Fig. 1. The two factors of practical importance on this curve are the temperature of the equilibrium and the time taken to get to equilibrium.

The main factor influencing the equilibrium temperature, assuming constant descent velocity, is the rate at which the "hot spot" loses heat i.e. the efficiency of transferring heat within the device and away from the device extremities to air, rope, etc. Obviously large surface areas, matt black surfaces and materials of high conductivity are advisable, including the rope material. An even rope-to-device force spread over a large area is also an advantage in reducing hot spot temperature and it is much better to have all of a device at a reasonable temperature rather than one end red hot and the other cold.

The main factor affecting rise to equilibrium time, assuming constant speed, is the thermal capacity of the device, so large specific heats and large masses are involved; conductivity, rope contact area and device shape will also influence this rise time.

Speed, the factor we have assumed constant above, dramatically adjusts the position/temperature curve. The large scale temperature graph when compared to a time/position graph showed remarkable agreement; a slight increase in velocity was coincidently noticeable on the temperature curve. Now the heat energy produced compared to speed in not a linear relationship but forms a curve similar to Fig. 2. The equilibrium point on the temperature graph is increased with velocity to a maximum somewhere around 11 feet per second (Isenhart) above this because of the reduction of force on the device due to the effect of weightlessness the equilibrium drops until at free fall the breaking effect and hence heat energy is zero. The actual zero point will be the terminal velocity of a caver in air, say 150 feet per second: to average this the caver would have to be jet assisted! In general, as speed increases the heat energy produced per second increases, but the total heat energy is reduced, the different in total energy being dissipated either as the caver hits the ground, or, hopefully, in stretch in the rope as the caver suddenly stops; in this case the heat is spread through a large volume or rope. Free fall or jet-assisted abseils with sudden stops are not to be advocated, however! The inelastic ropes best for prussiking will produce very large forces on stopping which could produce failure of rope, device or caver and if any slip occurs between device and rope during a high speed stop, high temperature will result producing more dangerous heating than a slow, even abseil.

Fig. 3 shows the results from four descents at Malham using rappel racks. The difference between 1.7 feet per second and 2.1 feet per second using the same rack and rope are as expected. The different between 1.7 on Bluewater and 1.7 on Marlow 16 plait probably results from the nylon having a higher thermal capacity and conductivity as well as the fact that more bars were required on the smoother rope reducing the hot spot effect. The variation in initial temperature on the graphs result from the zero point being 10 feet from the top of Malham to obtain a free 200 feet descent; different lengths of time were allowed for the device to cool before commencing the tests. The Titanium rack at 1.2 feet per second produces a very similar curve to the 1.7 feet per second steel rack taking starting temperature into account. This is presumably because the thermal conductivity of the titanium is somewhat less than the stainless steel.

Fig. 4 shows the effect of thermal capacity; the whaletail and figure-of-eight get nowhere near their equilibrium. The Petzl bobbin has a low thermal capacity without an enormous surface area; the result of the speedy abseil produces 130°C. Under these conditions polypropylene rope would probably have failed and nylon or terylene been damaged, not to mention the effect on any skin touching it.

The cooling curves Figs. 5 and 6. show the heat losing ability of the device with the caver remaining stationary at the 200 foot mark just above the ground. The cooling curves for the racks have undulations probably resulting from the effect of the complicated heat flow from the monitored hot spot through the bar, then the rack sides to other bars. The rack on Bluewater cooled with a curve slightly diverging from the rack on Marlow, so again suggesting faster heat flow to Bluewater. Although the titanium rack got hotter, it also cooled down faster presumably because of the lower thermal capacity of the thermally more isolated bar.

The effect of the ratio of thermal capacity to surface area is shown in Fig. 6. The whaletail cooled rather faster than expected, possibly partly due to the large rope to device contact.

Conclusion

High thermal capacity gives a slow rise to equilibrium; good conductivity reduces the hot spot effect which is greatly effected by abseil speed. Large thermal capacity, however, does produce a large energy source that could enable a rope to be melted through before the device cools and of course tends to increase device weight.

Low equilibrium temperature is achieved by dissipating heat within the rope or transferring heat from the device to its surroundings.

Speed plays a very important role in increasing equilibrium temperature up to about 11 feet per second, then the equilibrium temperature reduces.

From the accompanying table, thermally the best device material is duralumin having the highest thermal capacity and second highest conductivity. If size and surface area are then taken into account from purely thermal considerations a device like a whaletail is best preferably with an increased surface area. The racks with their low equilibrium temperature were a close second, reasonably large duralumin bars being advisable.

The best thermal properties for rope material from the table and experiments seem to be those of nylon.

	Specific Heat *KJ/Kg°K*	*Thermal Conductivity* *J/MS°K*	Melting Point.
Titanium	0.61	22	
Copper	0.39	403	
Brass*	0.38	105	
Duralumin*	0.88	170	
Mild Steel*	0.46	52	
Stainless Steel* (18% Ni 8% Cr)	0.51	24.5	
Air	1.00	0.026	
Water	4.19	0.60	
Terylene +	0.3	0.14	260°C
Nylon +	0.5	0.25	250°C
Polypropylene +	0.5	0.21	170°C
Hemp	0.35	0.21	–

* Very variable figures for different alloys – as near mean as possible quoted.
\+ Figures particularly variable with temperature.

Acknowledgements

The author wishes to thank Brendon Brew for helping with obtaining equipment and information, and John Forder for several abseils. Many other people were present at Malham Cove including Sid Perou, Frank Binney, Steve Crabtree, Robin Thompson and other members of ULSA – thanks to you all and also to the people who gave information and advice.

References

Eavis, A.J. 1974. Ropes in S.R.T. *Trans. Brit. Cave Res. Assoc.* 1 (4).
Isenhart, Kyle. Article in *Nylon Highway*, No. 4, U.S.A.

KARST MORPHOLOGY IN SUBARCTIC SWEDEN

Leif Engh,
Lunds Universitet Naturgeografiska Institutionen,
Dept. of Physical Geography, Univ. of Lund,
Sölvegatan 13, S-223 62 Lund, Sweden.

Limestone, mostly of Silurian and Ordovician age occurs in many places in Sweden. The largest concentrations are situated in the two big islands in the Baltic, Öland and Gotland. The karst phenomena here are few, and except for the Lummelunda cave (1350 m) only small caves are known. This is also the case in all limestone areas in the southern and middle Sweden. The large limestone areas in the northern part of the country (the mountains excluded) are little investigated and only a few caves are known from those areas.

In the last ten years, members of the Swedish Speleological Society have concentrated their work in the Caledonian range, where there are many, but small limestone areas. The mountains are wilderness areas and the quality of the geological maps is often very poor. Therefore the exploration, which is made on foot, backpacking, first is concentrated on finding limestone. Where limestone is found, mostly some kind of karst phenomena is found. In this way many new karst areas and a lot of big caves have recently become known.

The author has been working with cave exploration in the mountains during 1968-1974. The work in the last three years has been concentrated on the surface morphology of karst areas in the subarctic parts of Scandinavia and on Spitsbergen. The investigation, which mainly deals with morphometrical analyses will be finished in 1978. The intention of this paper is to give the reader an idea of the karst morphology in the Swedish part of the investigated areas.

Climate and vegetation

All examined karst areas are situated above the timber line in the Caledonian range, Lapland, Northern Sweden. The climate is, according to the classification system of Köppen (1936), of the ET(H) tundra type. The annual mean temperature is less than -2.0°C in all areas, but no permafrost does exist. The annual average precipitation varies from 800 mm/year to 1900 mm/year. Most of the precipitation is in the form of snow, which covers the ground from the end of September to the beginning of June. Large and deep karst depressions sometimes hold snow all the year round.

Most of the examined karst areas are situated just above the edge of the timber line, and none is more than 200 m above it. This means that all areas are situated below the ancient timber line of the post glacial warm periods.

Where no thick soil cover exists, the vegetation is scanty, mostly grass and peat, while there is a rich vegetation when soil conditions are favourable.

Karst areas are known below the timber line, but the thick and high undervegetation in the birch forest during the summer makes exploration difficult.

Types and morphology of karst areas

According to the classification of Sweeting (1972) the landscapes are of the Glacio-Nival karst type, subdivision high mountain type. This is true as far as we only consider the large scale forms in the landscape that have been formed by the ice. But a closer look at some of the karst areas will show that most of the karst forms there are true solutional forms. In other areas the surface karst forms could be built up predominantly by frost and fluvial processes. Therefore it would not be wrong to use Cvijic's old definition, holokarst and merokarst, to distinguish the two main types of karst landscape in the subarctic parts of Sweden.

Until 1977 there are only 14 known areas of *holokarst,* larger than 0.5 km^2. The limestone here is mostly crystalline and the content of non-carbonate minerals is less than 10%. All areas are oblong and small, none larger than 3.5 km^2, due to the folding of the Caledonian mountains.

Where a soil cover does not exist, or is thin, karstification is very intense, and joint dolines, enlarged kluftkarren, are the most common karst forms. In some areas there can be more than 900 per km^2, and they vary in size from 0.5 - 30 m in length, 0.2 - 2.7 m in width and 0.3 - 8 m in depth. Less frequent are the normal solutional dolines and collapse dolines. Along the dividing line between limestone — not limestone, kotlici often occur.

Because of the folding, exposed horizontal layers of limestone are rare, but where they occur schichttreppenkarst with pavements are formed. Bowl-shaped solutional dolines and alluvial dolines are the most frequent forms where the ground is covered by till. They seldom exceed 30 m in diameter and a few metres in depth. If the carbonate content in the soil is high and the soil cover is thick (more than 1 m), surface karst forms are rare. Where the soil cover is thick and of glacifluvial origin, the alluvial dolines are the only observed forms. They grow to a size of more than 100 m in diameter (very big for Scandinavia) and then they tend to form uvalas.

In the holokarst other traditional karrenforms than kluftkarren are rare. Rinnenkarren can occur on the edge of joint dolines or on inclined rocks. On all exposed rocks, joints and bedding planes are widened by solution. Those voids, "strukturkarren", are very frequent and they are seldom more than a few cm deep and wide, and they seldom exceed one metre in length.

Hardly any surface water exists in those areas. Allogenic streams disappear in swallets at the limestone limit or just inside it, and reappear as springs at the downhill limestone lime. Dyetests show that there is not normally any homogeneous karst water surface, but in two areas there are more springs than swallow holes.

Glacio-Nival holokarst in the subarctic parts of Sweden

Glacio-Nival Holokarst in den subpolaren Teilen Schwedens

Glacio-Nival merokarst in the subarctic parts of Sweden

Glacio-Nival Merokarst in den subpolaren Teilen Schwedens

Caves have been found in all areas, and three cave systems are explored for more than 1.5 km in length.

The bedrock in the *merokarst* areas mostly consists of impure limestone or schistose limestone with an almost vertical dip. Most of the limestone in the Caledonian mountains are mixed up with other minerals and shows few karst forms. Even if there is no soil cover, the karst features are few and small. The frost is

the main agent and the solutional processes are of less importance. Kotlici are the most frequent dolines, but joint and sometimes collapse dolines occur. The dolines seldom exceed 10 m in diameter and a few metres in depth. Karren are rare except for the above described "strukturkarren". A soil cover more than 1.5 m thick is almost a guarantee that no surface karst feature will be seen.

Streams and small lakes occur on the surface and existing underground passages are short, at the most a few hundred metres. Dyetests show that each investigated swallow hole is connected to only one spring. The caves in those areas are small and narrow and mainly developed by streaming water.

In this type of karst there can occur beds or lenses of pure crystalline limestone, which increase the number of karst forms per km^2. Normally there are less than 150 (longer than 0.5 m) per km^2. A common feature is an irregular stonecovered surface that is a consequence of the frost action on the limestone.

IONIC MIGRATIONS IN A KARSTIC ENVIRONMENT

Adolfo Eraso
Dpto. de Cristalografi y Mineralogia, Universidad Complutense de Madrid
Presidente de la Comision de Fisico-Quimica del Karst (UIS)

Presentation of the problem

On the foothills of the Western Pyrenees about 20 km to the North of Pamplona there is an outcrop of dolomites of Namurian Age, which presents varied chalcopyrite paragenesis. Copper has been mined in the past by the Romans, and we find numerous artificial pits and tunnels or caves once used but now abandoned.

In these dolomites a karstic drainage net is represented by different caves, generally of small size, except one which reaches a length of 0.7 km in two stages. This cave is named Basajaunetxea (the house of the man in the forest in the Basque language).

In Basajaunetxea there are speleothems with very peculiar features, contrasting with these normally found in these latitudes, which form a remarkable exception with a special beauty. They have varied colourations of which the green and blue in different intensities are the most remarkable and abundant. Eccentric forms of speleothems dominate and seem to defy laws of gravity. More classic speleothems are also unusual, since on the fractured surface we do not find the normal calcite rhombohedrons but a fibre-like texture rather like aragonite.

However, the ecological conditions of Basajaunetxea, characterised by a temperature of 7 - 9°C and a relative humidity of practically 100%, are more appropriate for the existence of calcite speleothems.

Some metres away from Basajaunetxea at a higher level, opens the main tunnel of the Roman mine, named Ayerdi IV, about 100 m long, and at its end we can find chalcopyrite filling a vertical fissure in the form of nodules. These chalcopyrite nodules are subject to weathering by high environmental humidity and on their margins there are coloured concentric aureoles with this sequence: brown-yellowish, green-bluish and white, very like the colours in the speleothems.

In order to estimate the possible interrelation between the proper weathering characteristics of the chalcopyrite and the speleothems, a research programme directed by the author has been prepared, including some M.Sc. theses in the Crystallography and Mineralogy Department of the Geological Science Faculty of the Complutense University in Madrid, with the cooperation of the Diputacion Foral of Navarra (administrative body of the area concerned).

The present paper is a summary of the results obtained so far.

Results

The geological environment has been examined by thin sections of the lithologic column studied by polarizing light microscope techniques. The dominant mineral is *dolomite, quartz* appears as accessory and *chalcopyrite* and *graphite* in minor quantities.

The opaque minerals have been examined employing reflecting microscope techniques, and *chalcopyrite* is dominant; *goethite* is accessory.

In both rock samples and speleothems, X-ray fluorescence has revealed the following cations: Ca, Mg, Sr, Cu, Mn, Fe and traces of Ti.

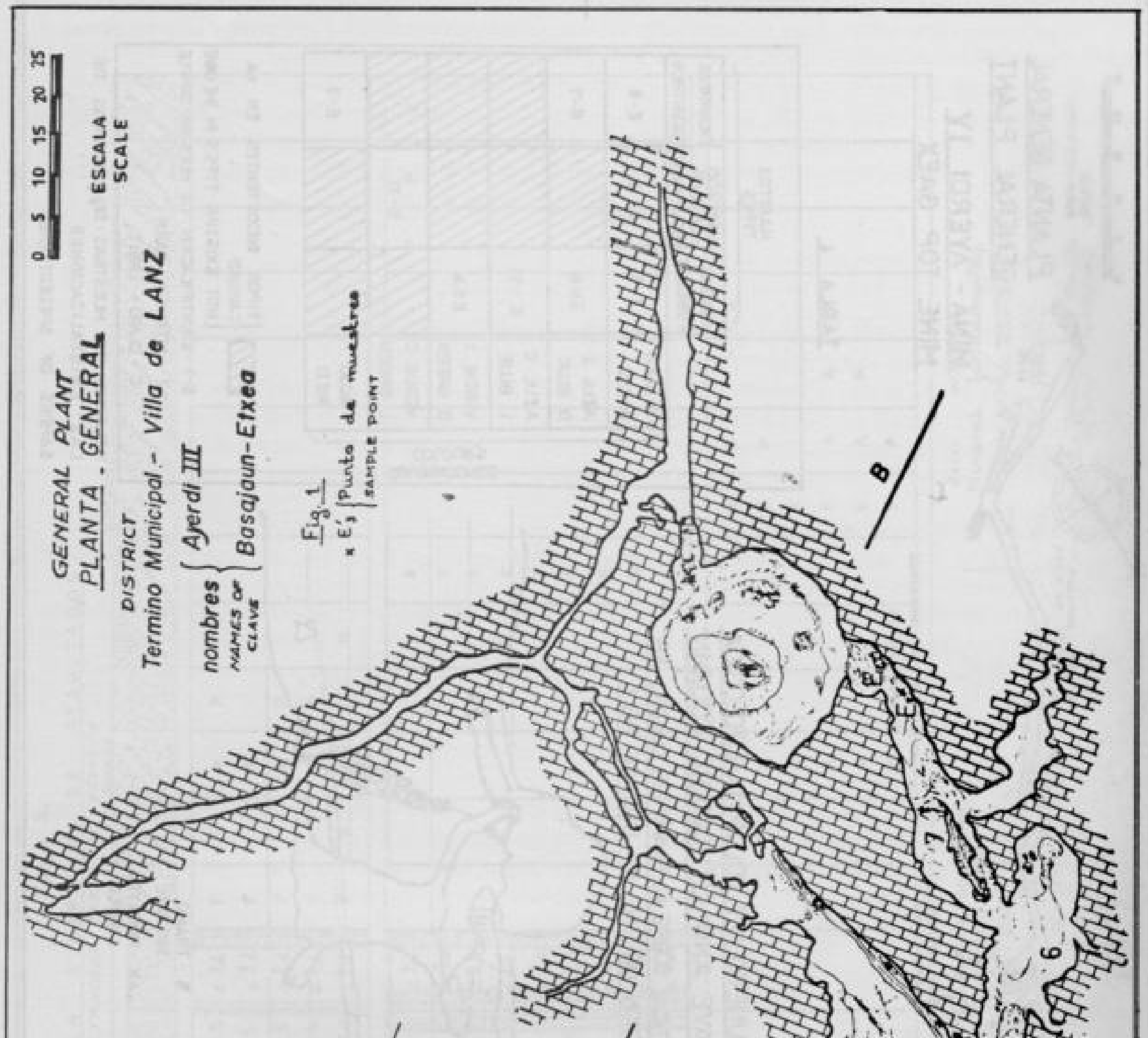
These cations have been examined quantitatively with the following techniques:

a) by compleximetry:	Ca and Mg
b) by atomic absorption:	Mg, Sr, Cu and Mn
c) by photocolorimetry:	Fe and Ti

The following have also been detected *aragonite, gypsum, brochantite, malachite, calcite* and possible *langite.*

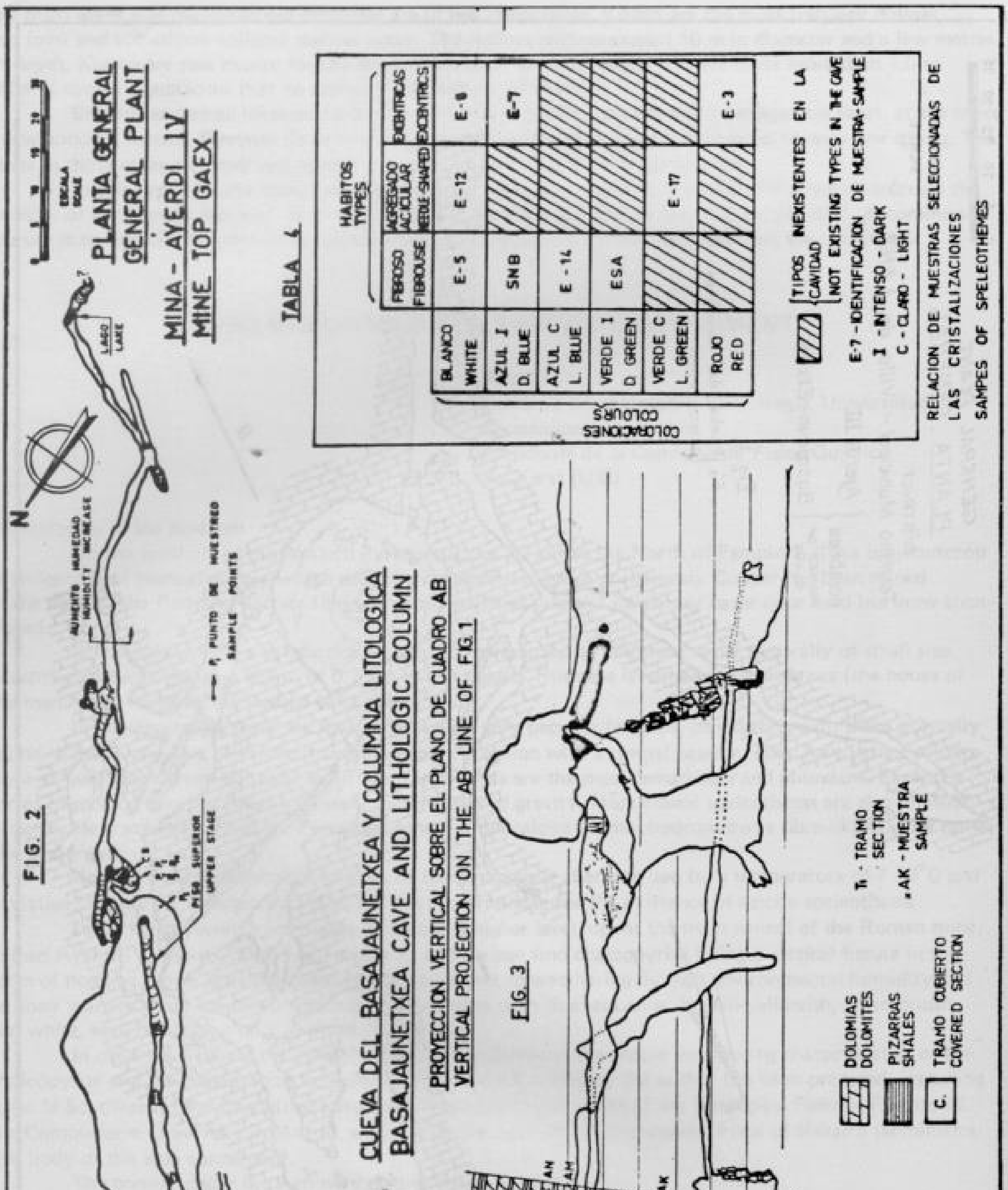
Discussion

The action of weathering on dolomite rock containing chalcopyrite, produces both karstification and chalcopyrite weathering.



Both processes are simultaneous in an interrelated way, resulting (1) that weathering products of chalcopyrite fix selectively on speleothems, producing the remarkable colours and (2) that the mineralogical character of these speleothems is unusual, since aragonite dominates instead of calcite, contrasting with other caves at these latitudes or with similar climatological conditions.

The results of this interrelation allow us to establish two main groups of conclusions:



COLORACIONES / COLOURS	FIBROSO / FIBROUSE	AGREGADO ACICULAR / NEEDLE-SHAPED	EXCENTRICAS / EXCENTRICS
BLANCO / WHITE	E-5	E-12	E-8
AZUL I / D. BLUE	SNB	▨	E-7
AZUL C / L. BLUE	E-14	▨	▨
VERDE I / D. GREEN	ESA	▨	▨
VERDE C / L. GREEN	▨	E-17	▨
ROJO / RED	▨	▨	E-3

▨ TIPOS INEXISTENTES EN LA CAVIDAD / NOT EXISTING TYPES IN THE CAVE
E-7 - IDENTIFICACION DE MUESTRA - SAMPLE
I - INTENSO - DARK
C - CLARO - LIGHT

RELACION DE MUESTRAS SELECCIONADAS DE LAS CRISTALIZACIONES
SAMPES OF SPELEOTHEMES

Detected ionic migrations

Calcium, present in the rock with an average concentration of 234213 ppm, appears in the speleothems with a remarkable higher average concentration of 395616 ppm. In the speleothems calcium is the only cation existent in quantity, whereas in the rock it is comparable with magnesium.

Magnesium, present in the rock with an average concentration of 147320 ppm, appears with a much

Table 3.

TABLA SINOPTICA DE RESULTADOS
SIMULTANEOUS TABLE OF RESULTS

	MUESTRA *SAMPLE*	Ca	Mg	Sr	Cu	Mn	Fe	Ti	Dolomita	Calcita	Cuarzo *QUARTZ*	[illegible]	[illegible]	[illegible]	Yeso *GYPSUM*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					p p m																
LITOLOGIAS *ROCKS*	AN	279.062	171.148	101	< ld	1.038	5.923	< ld	F		A	P									
	AM	244.179	154.215	71	< ld	1.301	6.315	< ld	F		A										
	AK	219.263	142.119	85	< ld	1.226	6.228	< ld	F		A	P									
	AE	204.313	133.048	112	< ld	839	3.484	< ld	F		A	P									
	O	224.246	136.072	60	< ld	1.432	3.876	< ld	F	P	A		P								
CRISTALIZACIONES *SPELEOTHEMES*	SNB	378.727	17	1.198	532,5	< ld	52	< ld						F	[illegible]				P	P	P
	E_{14}	380.720	28	283	191	< ld	44	< ld						F							
	E'_7	413.610	66	171	592	< ld	87	< ld						F							
	ESA	388.694	11	279	196	< ld	52	< ld						F							
	E_{11}	405.151	51	261,5	200,5	< ld	44	< ld						F							
	E_9	385.704	91	320	< ld	< ld	52	< ld						F							
	E_{12}	408.627	3	328	< ld	< ld	61	< ld						F							
	E_8	394.674	36	310	< ld	< ld	52	< ld						F							
	E'_3	404.640	4.240	65	41	< ld	52	< ld		F											
PARAGENESIS *PARAGENESIS*	C_8										A		F		A	P		A			
	P_3										A				F	P					
	P_2										A				F						
	P_8										A				F	A	A	P			
	P_4										A				F	A	P				
	P_{10}										P				F	P					

Microscopía *MICROSCOPY*: de luz transmitida *POLARIZING LIGHT*; de luz reflejada *REFLECTING LIGHT*

Fluorescencia de rayos X *X-RAY FLUORESCENCE*

Complexometría *COMPLEXIMETRY*

Absorción atomica *ATOMIC ABSORPTION*

Fotocolorimetria *PHOTOCOLORIMETRY*

Difracción de rayos X *X-RAY DIFFRACTIONS*

F — Mineral fundamental *BASIC MINERAL*

A — " accesorio *ACCESSORY MINERAL*

P — " posible *POSSIBLE MINERAL*

< ld — Inferior al límite de detección *BEYOND DETECTION LIMIT*

smaller concentration in the speleothems, 38 ppm in those of aragonite and 4240 ppm in those of calcite. Its rejection from speleothems, in particular those of aragonite, is evident.

Strontium, present in the rock with an average value of 86 ppm, appears in the speleothems differentially as 65 ppm in calcite and the notable average value of 394 ppm in aragonite.

Copper, not detected in the rock but locally concentrated as chalcopyrite is found in speleothems, but only in aragonites coloured green and blue, where it appears with an average concentration of 342 ppm.

Its concentration is proportional to the colour intensity.

Manganese, diffused through the rock with an average concentration of 1167 ppm, does not appear in any of the speleothems studied. Its geochemical behaviour responds to different laws.

Iron, present in the rock with an average concentration of 5165 ppm, appears in the speleothems about 1000 times less concentrated (55 ppm average), without showing any specific behaviour. Its geochemical character could be similar to manganese; in any case it differs from all the other ions studied.

Titanium, detected as a rare element by X-ray fluorescence, could not be quantified by photocolorimetry.

Observed mineralogical components

We applied the X-ray diffraction technique with the following conditions:

A. *Basic minerals* are considered those which appear in the diagrams with the major part of their peaks, corresponding to the expected intensities.

B. *Accessory minerals* are considered those with only their main peaks present in the diagrams.

C. *Possible minerals* are considered those which present in the diagrams at least a principal reflection, being masked by the principal peaks of the basic minerals. The followed criterion is therefore based on the fact, that the existence of these minerals cannot be proved or disproved.

Alterations in the paragenetic sequence

The chalcopyrite cores C_8 present successive concentric aureoles, P_3 and P_2 are brown and yellowish, P_5 and P_1 green and finally P_{10} white.

In these weathered aureoles *gypsum* has been detected in any case as a basic mineral and *brochantite* and *malachite* as accessory in the greenish halos. Also brochantite, malachite and goethite appear as possible minerals in the different halos, accompanying gypsum, which proves that in the subterranean environment S'', Fe^{++} and Cu^{++} of the chalcopyrite, by weathering, appear stable in the ionic forms of SO_4'', Fe^{+++} and Cu^{++} respectively.

Speleothems

They are a result of recrystallizations of all the dissolved ions, by action of karstic water, on dolomite of the rock as well as in speleothems. The statistically dominant mineral is *aragonite,* independent of its colours; but the sensitivity of the X-ray diffraction method does not allow detection of the existence of other minerals. The speleothem SNB_x, with a dark blue colour and high Cu and Sr concentration, contains *langite* as a possible mineral.

Other conclusions

From the foregoing, we can deduce the following conclusions:

The existence of aragonite as the dominant mineral in the speleothems, in spite of an environmental temperature of 7-9°C, can be attributed to various reasons:

a) To the presence of Mg^{++} in karstic water, since this cation prevents the formation of the calcite lattice.
b) To the existence of Cu^{++} and/or Sr^{++} in karstic water, since any of these cations favours the formation of the aragonite lattice.

These reasons are well known by mineralogists and confirmed by numerous experiments in laboratories. However, and this is in our opinion the importance of this research work, this is the first time, at least as far as we know, that these facts have been proved in nature.

The tendency of Mg^{++} for the calcite net and of Sr^{++} for the aragonite net in speleothems corresponding to the fact that the respective carbonates, magnesite and strontianite, belong to the isomorphic series of calcite or aragonite. Therefore we think that these cations are contained in the respective nets replacing the Ca^{++} cation in some of its positions.

With regard to the coloured cations the situation is not as clear. With exception of *langite,* we cannot prove the existence of mineralogical structures with these cations, as to whether they are replacing Ca^{++} ions in the aragonite net, or on the contrary appear only absorbed in it.

References

Charlot, G. 1954. Teoria y Metodo nuevos de Quimica Analitica Cualitativ 1 Vol. 443 p. Ed. Aguilar Madrid.

Dragone, D., Duval, F. Garreau, J. Girou, A. Humbert, L. Jacquin, C. Roques, H. 1975. Genese Experimentale et Naturelle des Carbonate de Calcium. Etude Bibliographique Project A.R.T.E.P. – I.N.S.A. Toulouse, I.G. Bordeaux I.F.P. 1 Vol. 185 + 81 p + 3 Ann. Ref. I.F.P. 23354 Juillet.

Dragone, D. Duval, F. Garreau, J. Girou, A. Humbert, L. Jacquin, C. Roques, H. 1975. Genese experimentale et naturelle des carbonates de calcium. Mise au point sur les connaissances actuelles. Ier Symposium International de la Physico-Chimie du Karst Granada, Sept. 1975. Ann. Speleol. 1975, 30, 4 p. 629-641.

Eraso, A. 1975. Le rôle des facteurs physico-chimiques dans le process de la karstification (Conférence inaugurale). Ier Symposium Intern. de la Physico-Chimie du Karst Ann. Spéléol. 30, 4, p. 567-580.

Glasstone, S. 1953. Tratado de Quimica Fisica. 1 Vol. 1180 p. Ed. Aguilar, Madrid.

Graf, D.L. & Bradley, W.F. 1963. The Crystal Structure of Huntite, $Mg_3 Ca (CO_3)_4$ Acta Crystallographica Vol. 15, Part 3. Denmark.

Kern, R. & Weisbrod, A. 1964. Thermodynamique de base pour Minéralogistes, Pétrographes et Géologues. 1 Vol. 243 p. 80 fig. Ed. Masson Paris.

Lippmann, F. 1973. Sedimentary Carbonate Minerals, 1 vol. 228 p. 54 fig. Springer Verlag New York.

Lopez-Acevedo 1976. Estudio mineralogico de los productos de alteracion de calcopirita y condiciones de estabilidad en medio karstico. Tésis de Licenciatura. Depto. Cristalografia y Mineralogia. Facultad de Ciencias Geologicas. Universidad Complutense. 1 Vol. 76 p. 18 fig. 16 tab. Madrid.

Rankama, K. & Sahama, Th. G. 1954. Geoquimica. 1 Vol. 862 p. Ed. Aguilar Madrid.

APPLICATION DE L'ANALYSE CANONIQUE A LA SYSTEMATIQUE DES BATHYSCIINAE (COL. CATOPIDAE)

O. Escola
Museu Zoologia
Apartat 593, Barcelona (5).
Espagne.

C.M. Cuadras
Seminario Matematico (C.S.I.C.)
Univ. Barcelona
Espagne.

The application of canonical analysis to the taxonomy of *Bathysciinae (Col. Catopidae)* on a sample of 14 *taxa* populations shows reasons to discriminate, or to join, some forms, e.g. *Speophilus fonti* from *S.fonti schuttei; Troglocharinus espanoli* from *T.espanoli mateui* and *T. espanoli pinyareti* and also *Speophilus schibii, Speophilus kiesenwetteri andresi, Speophilus patracoi* and *Troglocharinus hustachei*, from all the others. Remarkable is the strong separation of *Troglocharinus ferreri* from *T.ferreri jeanneli*. The forms *Speophilus kiesenwetteri castellsaperai* and *S. kiesw. sanllorensi* show a big overlap with *S.kiesenwetteri;* they cannot be considered as independent forms, and this confirms the impressions of morphological taxonomy.

The canonical analysis is a technique method designed to distinguish groups or populations applying the Mahalanobis statistical distance, relating observable variables and representing them on 2 or 3 canonical axes.

Bathysciinae sont bien connus à partir Jeannel, 1911, 1924. Après, un seul travail d'ensemble pour faune mondiale (Laneyrie 1967, 1969). On a connu beaucoup de formes nouvelles. Un problème grave dans *Troglocharinus* et *Speophilus:* on est arrivé à supprimer presque tous les caractères différentiels et il y a des formes que l'on ne sait pas trop bien situer dans l'un ou l'autre *taxa.*

L'utilité de l'analyse canonique pour la systématique est démontrée dans quelques travaux récents (Prunus et Lefebvre 1971; Louis et Lefebvre 1971; Rostron 1972; Petitpierre et Cuadras 1977).

Material et Methodes

Exemple de 14 populations (14 taxa: 7 spp. de 2 gen: *Troglocharinus* Reitt, *Speophilus* Jeann.) de 14 grottes de Catalogne (Espagne), provinces de Barcelona (B), Tarragona (T) et Lleida (L). Soumises à l'analyse canonique. Localisation, taxa et renseignements: Appendix et fig. 1. Analyse sur des mâles (plus de caractères biométriques: protarses dilatés p.e.).

On prend 18 données biométriques de chaque exemplaire. Echantillons de 20 mâles. Mesures dans fig. 2, prises avec oculaire micrométrique:

Caracteres	*Grossissement*	*Echelle*	
1,2,3,4,5,9,10,11	100 X	1 division	= 0,015 mm
6,7,8	40 X	"	= 0,036 mm
12,13,14,15,16,17,18	200 X	"	= 0,01 mm

On n'a pas pris d'autres caractères utilisables en taxonomie (forme carène mésosternale, ponctuation pronotum, striolation élytres) qui ne sont pas facilement homologables aux mesures quantitatives. On n'a pas trouvé de caractères quantitatifs utilisables dans les oedéages (nombre de soies des styles, etc.)
Schéma de Catalogue avec situation des stations: fig. 1.

Analyse canonique de populations

Technique satatistique destinée à différencier k groupes ou populations, en utilisant la distance statistique de Mahalanobis en relation à p variables observables. Représentées sur 2 ou 3 axes canoniques qui doivent absorber la dispersion maximale entre les populations.

Il est necessaire pour l'analyse canonique: 1) Les matrices de variances-covariances Σ_1, Σ_2, Σ_1 ne doivent pas être significativement différentes. Cette hypothèse se démontre par le test d'homogeneité de Bartlett. 2) Si l'on peut accepter l'homogeneité et Σ est la matrice de varianes-covariances communes, on doit tester l'hypothèse que les valeurs moyens p-dimensionels $p_1, \ldots, p_k$ sont significativement différents, en utilisant le U statistique de Wilks. 3) Finalement, s'il y a homogeneité et des différences entre les valeurs moyens des populations, on projette sur les premiers vecteurs propres de la matrice Σ_e (covariabilité entre populations) par rapport à Σ (covariabilité dans les populations). Le représentation canonique, en 2 dimensions, donne une interprétation facile de la proximité et les différences entre groupes.

Fig. 1. 1) Avenc d'Ancosa, Plana d'Ancosa, Pontons (B) (Troglocharinus espanoli Zar.); 2) Cova del Garrofet, Montagut, Querol (T) (Troglocharinus espanoli mateui Zar.); 3) Avenc de Pinyarets de Baix, Aiguaviva, Montmell (T) (Troglocharinus espanoli pinyareti Zar.); 4) Avenc de la Solana, Pla d'Ancosa, Pontons (B) (Speophilus schibii Españ.) 4) Esquerda Olla de Ferro, Querol (T) (Speophilus schibii Españ.); 5) Avenc del Cataplanell, Montanissell (L) (Speophilus fonti Jeann.); 6) Cova Font Mentidora de Perauva, Ortoneda de la Conca (L) (Speophilus fonti scuttei Españ.); 7) Avenc d'En Roca, Ordal-Garraf (B) (Troglocharinus ferreri Reitt.); 8) Avenc Grallera, Montsec de Rubies, Tremp (L) (Troglocharinus hustachei Jeann.); 9) Cova Fou Montaner, Ordal-Garraf, (B) (Troglacharinus ferreri jeanneli Zar.); 10) Cova Salitre, Montserrat (B) (Speophilus kiesenwetteri Dieck.); 11) Avenc Castellsapera, Serra Obac, Terrassa (B) (Speophilus kiesenwetteri castellsaperai Zar.); 12) Avenc del Davi, Sant Llorenc del Munt, Terrassa (B) (Speophilus kiesenwetteri sanllorensi Zar.); 13) Avenc Montserrat, Sant Salvador Espases, (B) (Speophilus kiesenwetteri andresi Escolà); 14) Cova del Patracó, Olesa (B) (Speophilus patracoi Zar.).

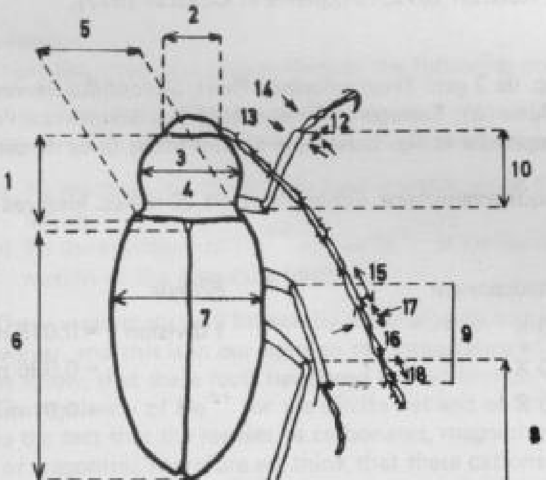


Fig. 2. Troglocharinus et Speophilus.

1. Longueur pronotum
2. Largeur bord antérieur pronotum
3. Largeur maximale pronotum
4. Largeur sinusosité pronotum
5. Largeur bord posterieur pronotum
6. Longeur élitres
7. Largeur maximale élitres
8. Longeur tibia postérieure
9. Longeur tibia intermédiaire
10. Longeur tibia antérieure
11. Longeur premier article tarse postérieur
12. Longeur premier article tarse antérieur
13. Largeur sommet tibia antérieure
14. Largeur premier article tarse antérieur
15. Longeur article VII de l'antene
16. Longeur article VIII de l'antene
17. Largeur article VIII de l'antene
18. Longeur article X de l'antene

Cette technique, adaptée de l'analyse de corrélation canonique de Bartlett (1938), fut développée par Rao (1948, 1952). Un exposé complet peut être trouvé dans Seal (1964), qui explique en plus la facon de trouver des régions confidentielles approximées pour avoir une vision du degré de coincidence entre deux ou plusieurs populations. Malgré tout, dans ce travail on a calculé les régions confidentielles exactes pour chaque population, selon la méthode décrite par Cuadras (1974).

Les résultats peuvent être appréciés dans les fig. 3, 4' La différence entre populations fut significative avec $p < 10^{-6}$. Les deux premiers axes canoniques représentent le 74% de la dispersion entre les populations. Les régions confidentielles, représentées par des cercles, ont été calculées avec un cofficient de confiance du 90%.

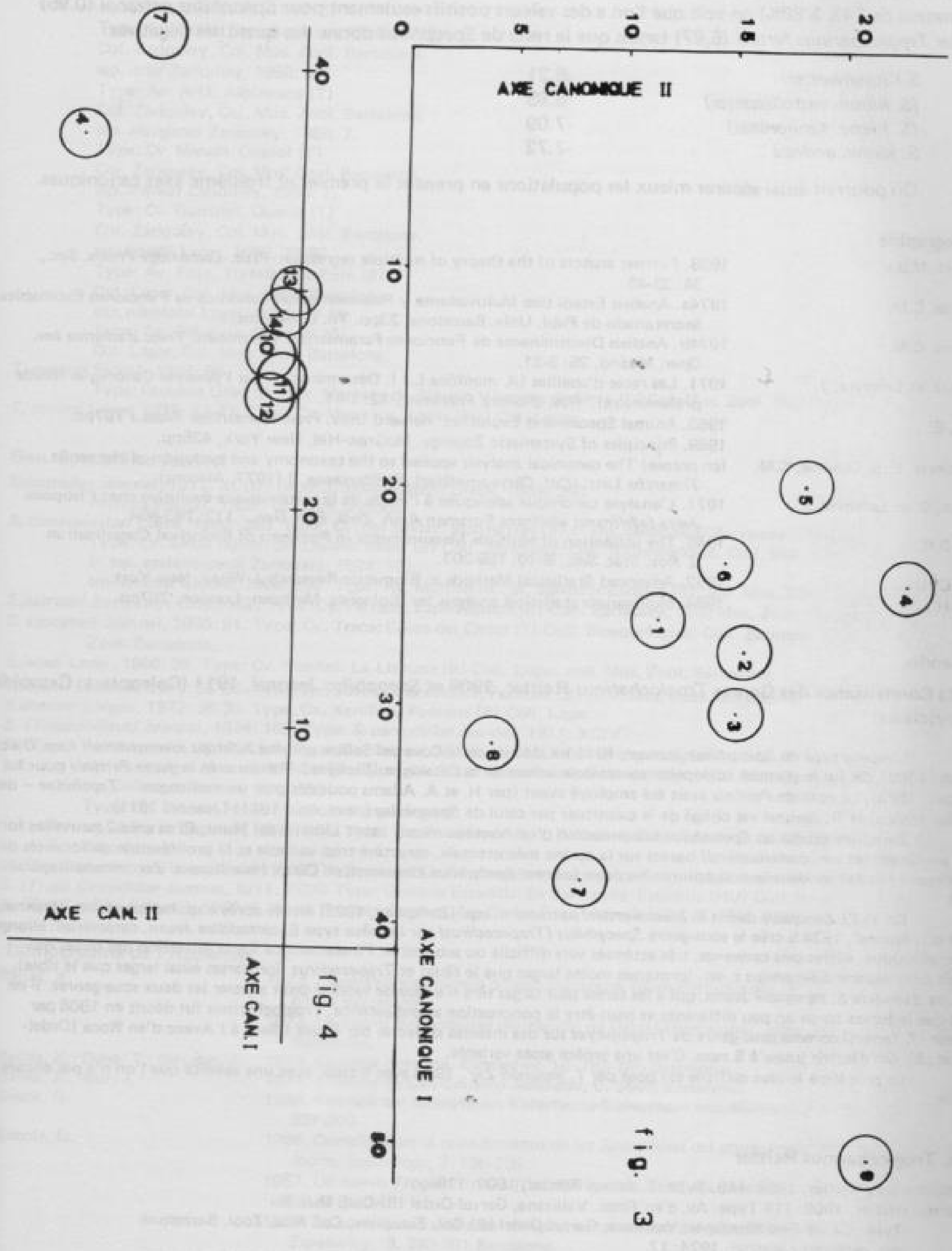


fig. 4

fig. 3

Resultats

L'analyse canonique n'est q'une des lignées de recherche de celles qui permettront, toutes à la fois, la solution du problème entre les deux genres.

Résultats dans figs. 3, 4. Représentation bidimensionelle. (degré discrimination 74%).

Fig. 3 démantre que *Troglocharinus espanoli* Zar. s.str. séparé, mais près, de *T. espanoli mateui* (2) et *T. espanoli pinyareti* (3). Coincidence avec les résultats morphologiques (mais *T. espanoli pinyareti* est peut-être la plus isolée des 9sspp. de l'espèce).

Speophilus schibii (4) et *Troglocharinus hustachei* (8) nettement séparés. *Speophilus fonti* Jeann. (5) es différent de *S.fonti schuttei* Espan. (confirmation validité de cette ssp. qui semblait être mise en doute). *Troglocharinus ferreri* Reitt, s.str. (7) est séparé de facon remarcable de *T. ferreri jeanneli* Zar. (9).

Fig. 4 démontre que *Speophilus kiesenwetteri* Dieck s.str. (10) se superpose avec les formes *castellsaperai* Zar. (11) et *sanllorensi* Zar. (12) (ca semble confirmer la suppression des deux taxa). *Speophilus kiesenwetteri* andresi (13) est plus séparé, dans un extrême. *S. patracoi* (14) avec une morphologie qui semble com-

mencer un timide rapprochement de celle de *Troglocharinus*, donne un cercle qui chevauche entre *S. kiesenwetteri* et *S, kiesenw. andresi*, mais avec le 3° axe canonique (qui fait passer le pourcentage accumulé de discrimination de 74% à 88%) on voit que l'on a des valeurs positifs seulement pour *Speophilus patracoi* (0.95) et pour *Troglocharinus ferreri* (5,97) tandis que le reste de *Speophilus* donne des quantités négatives:

S.Kiesenwetteri	-6.21
(S. kiesw. castellsaperai)	-6.88
(S. kiesw. sanllorensi)	-7.09
S. kiesw. andresi	-7.72

On pourrait aussi séparer mieux les populations en prenant le premier et troisième axes canoniques.

Bibliographie

Bartlett, M.S. — 1938. Further aspects of the theory of multiple regression. *Proc. Cambridge Philos. Soc.*, 34: 33-40.

Cuadras, C.M. — 1974a. Analisis Estadi tico Multivariante y Representacion Canonica de Funciones Estimables. Secretariado de Publ. Univ. Barcelona, 23pp. Th. D.Resumé.

Cuadras, C.M. — 1974b. Analisis Discriminante de Funciones Paramétricas Estimables. *Trab. stadistica Inv. Oper.* Madrid, 25: 3-31.

Louis, J. et Lefervre, J. — 1971. Les races d'abeilles (*A. mellifica* L.) I. Détermination par l'Analyse Canonique (étude préluminaire). *Rev. Biomet. Praximet.*, 12: 1-41.

Mayr, E. — 1963. Animal Species and Evolution. Harvard Univ. Press. Cambridge (Mass.) 797pp.
1969. Principles of Systematic Zoology. McGraw-Hill, New York, 428pp.

Petitpierre, E. & Cuadras, C.M. — (en prense) The canonical analysis applied to the taxonomy and evolution of the genus *Timarcha* Latr. (*Col. Chrysomelidae*).*Mediterranea*, 2 (1977. Alacant).

Prunus, C. et Lefebvre, J. — 1971. L'analyse canonique appliquée à l'étude de la systématique évolutive chez l'Isopode *Jaera (albifrons) albifrons* Forsman *Arch. Zool. Exp. Gen.*, 112: 793-804.

Rao, C.R. — 1948. The utilisation of Multiple Measurements in Problems of Biological Classification. *J. Roy. Stat. Soc.*, B-10: 159-203.

Rao, C.R. — 1952. Advanced Statistical Methods in Biometric Research J. Wiley, New York.

Seal, H.L. — 1964. Multivariate statistical analysis for Biologists. Methuen, London, 207pp.

Appendix

Sur la Connaissance des Genres *Troglocharinus* Reitter, 1908 et *Speophilus* Jeannel, 1911 (Coleoptera: Catopidae, Bathysciinae)

L'espèce type de *Speophilus* Jeannel, 1911 fut décrite de la Cova del Salitre comme *Adelops kiesenwetteri* n.sp. Dieck (Dieck, 1869). Ce fut le premier coléoptère cavernicole connu de la Catalogne (Espagne). Reitter créa le genre *Perrinia* pour lui (Reitter, 1885). Le nom de *Perrinia* avait été employé avant (par H. et A. Adams pour désigner un mollusque — *Trochidae* — de l'Océan Indien) et R. Jeannel est obligé de le substituer par celui de *Speophilus* (nom. nov. 1911) (Jeannel 1911).

Zariquiey étudia les *Speophilus kiesenwetteri* d'un nouveau massif (sont Llorenc del Munt, B) et créa 2 nouvelles formes (ssp. *sanllorensi* et var. *castellsaperai*) basées sur la carène mésosternale, caractère trop variable et la prolifération de localités de maintenant fait penser de mieux supprimer les deux formes: *Speophilus kiesenwetteri* Dieck (=*sanllorensi* Zar., =castellsaperai *Zar.*).

En 1922 Zariquiey décrit *S. kiesenwetteri patracoi* n. ssp. (Zariquiey, 1922) élevée après a sp. indépendante (Jeannel, 1924 b.). Jeannel, 1924 b crée le sous-genre *Speophilus (Trapezodirus)* sur l'espèce type S. *carrodillae* Jeann. caractérisé: allongement, elliptique, élitres peu convexes, très atténués vers difficile ou subjective. Finalement ce fut la dilatation des tarses qui servait pour séparer *Speophilus* s. str. (protarses moins larges que le tibia) et *Trapezodirus* (protarses aussi larges que le tibia). Mais on découvre S. *espagnoli* Jeann. qui a les tarses plus larges tère n'a plus de validité pour séparer les deux sous-genres. Il ne reste que la forme corps un peu différente et peut-être la ponctuation et pubescence. Troglocharinus fut décrit en 1908 par Reitter (*T. ferreri*) comme sous-genre de *Troglophyes* sur des insectes collectés par Faura I Sans à l'Avenc d'en Roca (Ordal-Garraf, B). On décrivit jusqu'à 5 sspp. C'est une espéce assez variable.

Le problème le plus difficile est posé par *T. espanoli* Zar., 1950 avec 9 sspp. avec une validité que l'on n'a pas encore résout.

Gen. Troglocharinus Reitter

Troglocharinus Reitter, 1908: 116. Type: *T. ferreri* Reitter, 1908: 116.
T. ferreri Reitter, 1908: 116 Type: Av. d'en Roca. Vallirana, Garraf-Ordal (B) Coll. Mus. Bu
Type: Cv. de Fou Montaner. Vallirana, Garraf-Ordal (B) Col. Zariquiey, Col. Mus. Zool. Barcelona
ssp. *zariquieyi* Jeannel, 1924: 17.
Type: Av. de la Funiosa. Garraf (B) Col. Zariquiey, Col. Biospeologica, Col. Mus. Zool. Barcelona.
ssp. *fonti* Zariquiey, 1924: 17. Type: Av. del Vermell. Garraf (B). Col. Zariquiey, Col. Biospeologica, Col. Mus. Zool. Barcelona.
ssp. *codinai* Zariquiey, 1917: 291.
Type: Cv. Fosca de Gavà. Garraf (B).
Col. Zariquiey, Col. Biospeologica, Col. Mus. Zool. Barcelona.
ssp. *pallaresi* Bellés, 1973: 45-49.
Type: Av. Can Montmany. La Palma de Cervello, Garraf-Ordal (B). Col. Bellés, Col. Mus. Zool. Barcelona.
T.hustachei Jeannel, 1911: XCVI. Type: Forat del Gel. Montsec de Rubies, Vilanova de Meià (L) Col. Biospeologica.
T.impellitierii Espanol, 1955: 270. Type: Cv. Palomera de Taus. Boumort, Castells-Taus (L) Col. Mus. Zool. Barcelona.
T.espanoli Zariquiey, 1950: 191-202.
Type: Av. Ancosa. Pontons (B)
Col. Zariquiery, Col. Mus. Zool. Barcelona.
ssp. *pinyareti* Zariquiey, 1950: 4.
Type: Av. Pinyarets. Montmell (T)
Col. Zariquiey, Col. Mus. Zool. Barcelona.
ssp. *ollai* Zariquiey, 1950: 5.

Type: Cv. de l'Olla. Montmell (T)
Col. Zariquey, Col. Mus. Zool. Barcelona
ssp. *portai* Zariquiey, 1950: 6.
Type: Cv. Bolet. Sant Quinti de Mediona (B)
Col. Zariquiey, Col. Mus. Zool. Barcelona.
ssp. *arlai* Zariquiey, 1950: 6.
Type: Av. Arlà. Albinyana (T)
Col. Zariquiey, Col. Mus. Zool. Barcelona.
ssp. *elongatus* Zariquiey, 1950: 7.
Type: Cv. Mandil. Querol (T)
Col. Zariquiey, Col. Mus. Zool. Barcelona.
ssp. *mateui* Zariquiey, 1950: 7.
Type: Cv. Garrofet. Querol (T)
Col. Zariquiey, Col. Mus. Zool. Barcelona.
ssp. *roselli* Lagar, 1952. 77-80.
Type: Av. Foix. Torrelles de Foix (B)
Col. Lagar, Col. Mus. Zool. Barcelona.
ssp. *olerdolai* Lagar, 1952, 77-80.
Type: Av. Olèrdola. Olèrdola (B)
Col. Lagar, Col. Mus. Zool. Barcelona.

T. senenti Escolà, 1967: 85.
Type: Querant Gran de Paus. Montsec de Rubies, Vilanova de Meià (L) Col. Mus. Zool. Barcelona.

T. rovirai Lagar, 1975: 41-47. Type: Cv. Macarius. Baells (Hu) Col. Lagar.

Gen. Speophilus Jeannel

Speophilus Jeannel, 1911. XCIII. Type: *S. kiesenwetteri* Dieck, 1869: 350.
Perrinia Reitter, 1885, 16 (nom praeocc).

S. kiesenwetteri Dieck, 1869: 350. Type: Cv. del Salitre: Montserrat (B) (= ssp. *sanllorensi* Zariquiey, 1924: 10.
Type: Cv. Santa Agnès: St. Llorenç Munt (B) Coll. Zariquiey, Coll. Biospeologica, Coll. Mus. Zool. Barcelona).
(= ssp. *castellsaperai* Zariquiey, 1924: 10).
ssp. *andresi* Escolà, 1966: 200. Type: Av. Montserrat: St. Salvador Espases (B) Coll. Mus. Zool. Barcelona.

S.patracoi Zariquiey, 1922: 162. Type: Cv. Patraco: Esparreguera (B) Coll. Zariquiey, Coll. Mus. Zool. Barcelona.

S. espagnoli Jeannel, 1930: 91. Type: Cv. Traca: Cabra del Camp (T) Coll. Biospeologica, Coll. Zariquiey, Coll. Mus. Zool. Barcelona.

S.jacasi Lagar, 1966: 29. Type: Cv. Rondes: La Llacuna (B) Coll. Lagar, coll. Mus. Zool. Barcelona.

S.schibii Espanol, 1972: 55-60. Type: Av. Solana: Pla Ancosa, Pontons (B) Coll. Mus. Zool. Barcelona.

S.abenzai Langar, 1972: 38-39. Type: Cv. Xerolina: Pontons (B) Coll. Lagar.

S. (Trapezodirus) Jeannel, 1924: 169. Type: *S. carrodillae* Jeannel, 1911: XCIV.

S. (Trap). fonti Jeannel, 1910: CLX. Type: Cv. Ormini: Montanissel (L) Coll. *Biospeologica*
ssp. *zariquieyi* Jeannel, 1924: 170. Type: Cv. Guils: Mata Rossa, Guils del Canto (L) Coll: Zariquiey, Coll. *Biospeologica*
ssp. *infernus* Jeannel, 1911: 364.
Type: Cv. Diablo, Novés (L) Coll. *Biospeologica*
ssp. *schuttei* Espanol, 1955: 268. Type: Cv. Font Mentidora: Boumort, Ortoneda de la Conca (L) Coll. Mus. Zool. Barcelona.

S. (Trap) quadricollis Jeannel, 1911: XCIV. Type: Lo Grallé: Castellet, Espluga de Serra (L) Coll. *Biospeologica*

S. (Trap) Carrodillae Jeannel, 1911: XCIV Type: Grallera Estadilla: Sa Carrodilla, Estadilla (HU) Coll. *Biospeologica*

S. (Trap) subilsi Espanol, 1966: 5. Type: Grallera Cambris Av. Obaga Grau: Alinyà (L) Coll. Mus. Zool. Barcelona.

Bibliographie de l'Appendix

Bellés, X. — 1973. Localizaciones nuevas o poco conocidas sobre *Bathysciinae* catalanes. *Ildobates*, 3-4: 61-64 Barcelona.
1973. Un nuevo *Bathysciinae* del macizo de Garraf (Barcelona). *Misc. Zool.*, 3 (3): 45-49. Barcelona.

Bellés, X.: Cune, T.: Serrano, J. — 1972. La Cova Xerolina. *Espeleoleg*, 16: 783-785 Barcelona.

Bellés, X., Mor, J. — 1974. L'Avenc de Can Castellvi *Ildobates*, 6: 24-26 *Barcelona*.

Dieck, G. — 1869. Beitrage zur subterranen Kaferfauna Sudeuropas und Marocos. *Berl. ent. Zs.*, 13: 337-360.

Escola, O. — 1966. Contribucion al conocimiento de los *Speophilus* del grupo *kiesenwetteri* Dieck. *Int. Journ. Speleology*, 2: 195-205.
1967. Un nuevo *Troglocharinus (Col. Catopidae)* del Prepirineo catalan. *Misc. Zool*,, 2 (2): 85-87 Barna.
1969. La contribucio dels espeleolegs al coneixement del gènere *Troglocharinus* Reitt. *Espeleoleg*, 8. 293-301 Barcelona.
1970a. Catalogo espeleologica del Montsec *Espeleoleg*, 11-12: 453-538 Barcelona.
1970b. Coleopteros cavernicolas del Montsec y zonas limitrofes. *Espeleoleg*, 11-12: 539-541. Barcelona.
1970c. Algunes dades sobre el Forat del Gel o "Espluga de Correis" *Espeleoleg*, 11-12: 542-547. Barcelona.
1974. Los *Bathysciinae* de Aragon. *Com. IV Simp. Bio-Espel.* Barcelona: 13-19.
(En prensa) La Poblacion cavernicola pirenaica (coleopteros) entre el Llobregat y el Noguera Ribagorcana (Catalunya, Espana).
Actas VII Congr. Intern. Est. Pirenaicos. 1974. Seu d'Urgell .

Espanol, F. — 1934. Contribucio al coneixement dels coleòpters cavernicoles del massis de Sant Llorenc del Munt. *Arx. Centr. Excurs. Terrassa*, 16 (91): 70-74' Terrassa.
1950. Coleopteros cavernicolas (troglobios) de la provincia de Tarragona. *Speleon*, 1 (2): 41-58. Oviedo.
1953. Sobre *Bathysciitae* ibericos: adiciones a la ultima revision del Prof. Jeannel (1924). *Speleon*, 4(1): 37-48. Oviedo.
1954. Los *Bathysciinae* catalanes. *Act. II Congr. Intern. Etud. Pyren.* t.3: 109-123. Luchon-Pau.

1955. Nuevos datos sobre la entomofauna cavernicola de la provincia de Lerida. *Eos,* 31(3-4): 261-273. Madrid.
1961. Catalogo Espeleologico de la provincia de Barcelona, I Fauna cavernicola: I. Invertebrados. pp: 29-47 Excma. Diput. Barcelona.
1966. A sobre *Bathysciinae* catalanes. *Int. Journ. Speleology,* 2: 1-8.
1966b. Dos anos de actividades biospeleologicas en el noreste de Espana *Graellsia* 22: 13-23 Madrid.
1972. Un nuevo *Speophilus* del grupo *kiesenwetteri (Col. Catopidae). Misc. Zool.,* 3 (2): 55-60 Barcelona.

Jeannel, R. 1911a. Nouvelles espéces de *Bathysciinae* cavernicoles (Coléoptères) *des Pyrenees espagnoles.* espagnoles. *Arch. Zool. Exp. Gen.,* 8, N — R: XCIII
1911b. Revision des *Bathysciinae. Biospeologica,* 19; *Arch. zool. Exp. Gen.,* 7: 1-641.
1924a. Coléòptères nouveaux de Catalogne. *Trab. Mus. Cienc. Nat. Barcelona* 4 (8): 3-18.
1924b. Monographie des *Bathysciinae. Arch. Zool. Exp. Gen.,* 63: 1-436.
1930. *Bathysciinae nouveaux d.Espagne. Butll. Inst. Catalana Hist. Nat.,* 10 (6): 90-91.

Lagar, A. 1952. Dos nuevas razas de *Troglocharinus espanoli* Zar. *Speleon,* 3 (1-2): 77-80 Oviedo.
1954. Los *Bathysciinae (Col. Catopidae)* de la provincia de Barcelona. *Speleon,* 5 (4): 247-260 Oviedo.
1966. Una nueva especie de *Speophilus* de la provincia de Barcelona. *Graellsia.* Madrid, 22: 29-32.
1972. Nueva especie de *Speophilus (Col, Catopidae). Senderos* (Bol. U.E.C.) 166: 38-39 Barcelona.
1975. Los nuevos coleopteros troglobios de la provincia de Huesca. *Espeleosie* 17: 41-47 Barcelona.

Laneyrie, R. 1967. Nouvelle classification des *Bathysciinae (Col. Catopidae), Ann Speleol.,* 22 (3): 585-645.
1969. Addenda et corrigenda à la "Nouvelle classification des *Bathysciinae". Ann. Speleol.,* 24 (4): 733-736.

Reitter, E. 1885. Bestimmungstabellen der europaischen Coleopteren. XII *Necrophaga. Verh. natf. Ver. Brunn.,* 23, 122pp.
1908. Dichotomische Uebersicht der blinden Silphiden Gattungen. *Wiener ent. Ztg.,* 27: 103-118.

Zariquiey, R. 1917. Sobre el género *Troglocharinus (Ins. Col.) Publ. Inst. Cienc. Treb. Inst. Catalana Hist. Nat.* Barcelona, vol. 1917: 283-294.
1922. *Bathysciinae* catalanes *(Col. Silphidae). Butll. Inst. Catalana Hist. Nat.,* (2 ser.) 2 (no. 9): 159-162.
1924. Contribucion al estudio de los *Bathysciinae* catalanes. *Treb. Mus. Ciene. Nat. Barcelona,* 4 (7): 3-18.
1940. Nuevos *Bathysciinae* catalanes. *VI Congr. Intern. Entom.* Madrid. 1935, t.2: 529-534
1950. Nueva especie del género *Troglocharinus. Speleon,* 1 (1-4): 191-202.

LES STAPHYLINIDAE (COLEOPTERA) CAVERNICOLES DE LA MÉDITERRANÉE OCCIDENTALE

F. Español
Musée de Zoologie de Barcelone
Apartado 593,
Barcelone 3, Spain.

The Staphylinidae are a large and important group of beetles of which few have adopted a truly cavernicolous existence. However, in the Western Mediterranean region, nine species in five genera representing two sub-families may be regarded as troglobites. Illustrated keys for their identification, notes on distribution, and a bibliography are presented.

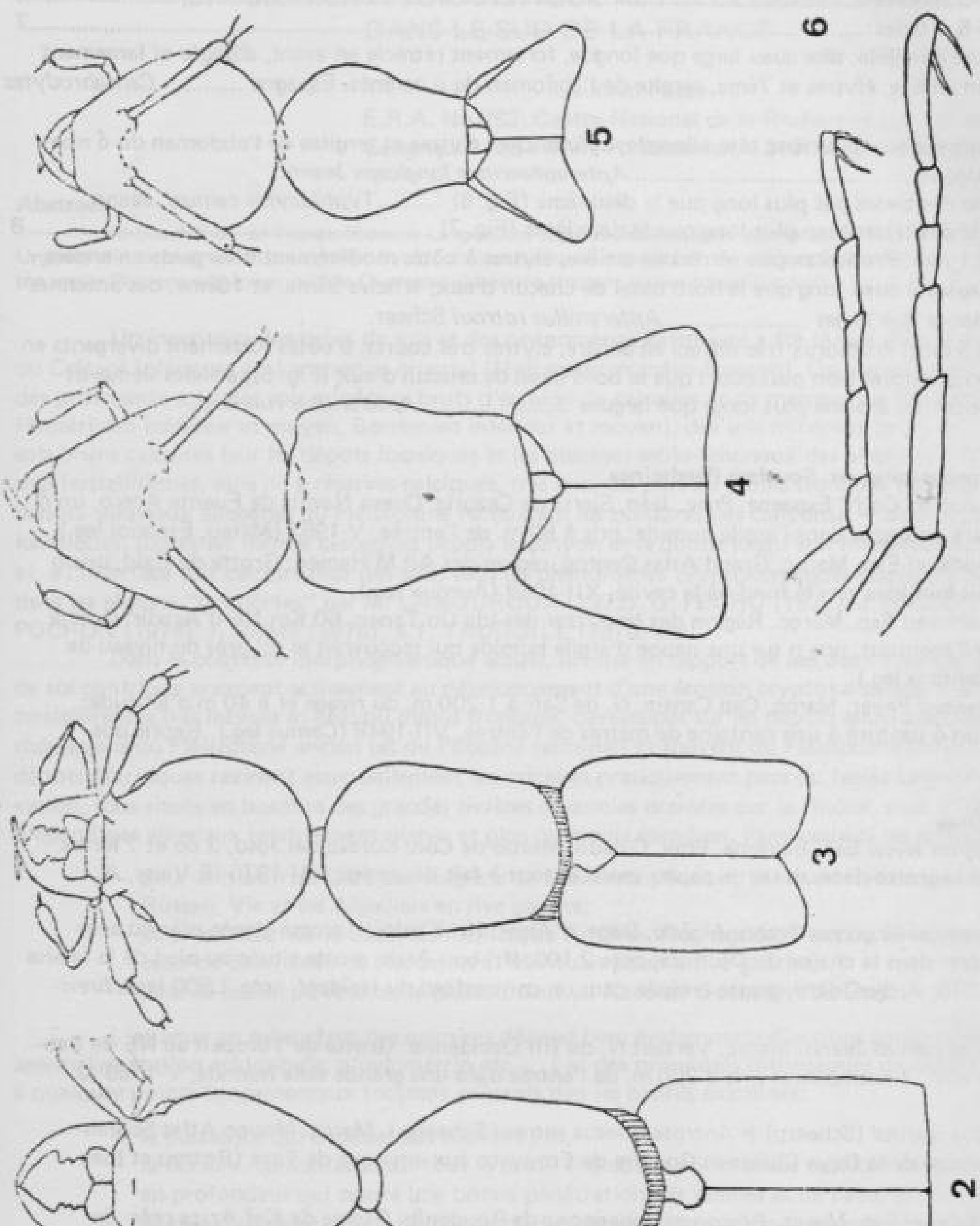
Les données réunies jusqu'à présent sur les coléoptères cavernicoles de la Méditerranée occidentale nous montrent la proportion élévé de staphylins troglobies propres à cette région, particularité fort intéressante car en dépit de leur importance numérique les Staphylinidae ont donné très peu de vrais cavernicoles.

Ces staphylins troglobies se rangent dans deux sousfamilles: les *Aleocharinae* avec les genres *Cantabrodytes* Esp., *Apteraphaenops* Jeann., *Apteranillus* Fairm. (=*Antrosemnotus* Scheerp.) et *Typhloziras* Jeann., et les *Paederinae* avec seulement le genre *Domene* Fauv., étant donné que certains *Lathrobium* Grav., *Medon* Steph., *Paraleptusa* Peyer. et gentres voisins qui pénètrent volontairement dans les grottes appartiennent plutôt au domaine endogé.

Mais voici que la plupart de ces cavernicoles sont fruit de découvertes récentes et que leurs descriptions restent dispersées dans plusieurs revues Ce que fait nécessaire une mise au point de nos connaissances à ce sujet et justifie la publication de la présente note dans laquelle l'auteur énumère ces troglobies, précise leurs caractères distinctifs, leurs localisations géographiques et les sources bibliographiques les concernant.

Clé de détermination des Staphylinidae troglobies de la Méditerranée occidentale.

1 — Antennes insérées au nivea du bord antérieur de la tête (sousfam. Paederinae) 2
— Antennes insérées sur le front (sousfam. Aleocharinae) 5
2 — Long. 5 - 6 mm. Cavernicole peu modifié ayant les caractères des espèces endogées. Espagne ....
Domene cavicola Coiff.
— Long. 10 - 14 mm. Cavernicoles très évolués (Figs. 1-3) Maroc 3



F. ESPANOL Staphylinidae

1. Domene auroxi Esp. 2. D. cantonsi Esp. 3. D. camusi Peyer - avant-corps
4. Apteranillus rotroui (Scheerp.) 5. A. ruei Esp. - avant corps
6. Typhlozyras camusi Jeannel. 7. Apteranillus ruei Esp. tarse intermediaire.

3 — Tête grosse, bien plus large que le prothorax, pédonculée; yeux à peu près nuls; épaules effacées (Fig. 1) ....*Domene aurouxi* Esp.

— Tête à peine plus large que le prothorax, non pédonculée; yeux petits, aplatis, dépigmentés, mais bien distincts; épaules arrondies, mais manifestes 4

4 — Tête fortement rétrécie en arrière; prothorax rétréci en avant ....*Domene cantonsi* Esp. (Fig. 2)

— Tête largement arrondie en arrière; prothorax élargi en avant ....*Domene camusi* Peyer. (Fig. 3)

5 — Tarses de 4-4-5 articles 6
— Tarses de 4-5-5 articles 7
6 — Forme générale parallèle; tête aussi large que longue, fortement rétrécie en avant, abrégée et largement arrondie en arrière; élytres et 7ème. tergite de l'abdomen du ♂ carénés. Espagne .... *Cantabrodytes vivesi* Esp.
— Forme générale élargie en arrière; tête allongée, cylindrique; élytres et tergites de l'abdomen du ♂ non carénés. Algérie ....*Apteraphaenops longiceps* Jeann.
7 — Prémier article des tarses pas plus long que le deuxième (Fig. 6) ....*Typhlozyras camusi,* Jeann.
— Prémier article des tarses bien plus long que le deuxième (Fig. 7) 8
8 — Long. 4,9 - 5,1 mm. Prothorax peu rétréci en arrière; élytres à côtés modérément divergents en arrière et à bord sutural aussi long que le bord basal de chacun d'eux; articles 9ème. et 10ème. des antennes bien plus longs que larges ....*Apteranillus rotroui* Scheer.
— Long. 3,3 - 3,5 mm. Prothorax très rétréci en arrière; élytres très courts, à côtés fortement divergents en arrière et à bord sutural bien plus court que le bord basal de chacun d'eux (Fig. 5); articles 9éme. et 10éme. des antennes à peine plus longs que largues ....*Apteranillus ruei* Esp.

Leurs localisations geographiques. Sousfam Paederinae

Domene cavicola Coiff' Espagne. Prov. Jaén, Sierra de Cazorla: Cueva Navilla de Fuente Acero, un ♂ sous une grosse pierre enfoncée dans l'argile humide; pris à 80 m. de l'entrée, V-1953 (Mateu, Espanol leg.).

Domene aurouxi Esp. Maroc. Grand Atlas Central, région des Ait M'Hamed: Grotte du Caid, une ♀ errante sur les parois humides vers le fond de la cavité, XII-1968 (Auroux leg.).

Domene cantonsi Esp. Maroc. Région des Imouzzer des Ida Ou Tanan, 60 Km.NE d'Agadir: Grotte de Wit Tamdoun, à Tazentout, une ♀ sur une nappe d'argile humide qui recouvrait le sol près du niveau de l'eau, VIII-1971 (Cantons leg.).

Domene camusi Peyer. Maroc. Cap Cantin, N. de Safi à 1.200 m. du rivage et à 40 m.d'altitude: Grotte de Gorane, un ♂ capturé à une centaine de mètres de l'entrée, VII-1948 (Camus leg.). Repris postérieurement.

Sousfam. Aleocharinae

Cantabrodytes vivesi Esp. Espagne. Prov. Oviedo, Mestas de Con: Cureva del Josu, 3 ♂♂ et 7 larves à l'extrême fond de la grotte dans un tas de papier moisi et tout à fait désagrégé, VII-1975 (E.Vives, A. Serra leg).

Apteraphaenops longiceps Jeann. Algérie. Dept. d'Alger: Ifri Khaloua, grotte glacée près du sommet du Djebel Heidzer dans la chaine du Djurjura, cote 2.100; Ifri bou-Arab, grotte située au pied de la falaise de Heidzer, cote 1.210; Ardjer-Idkhi, grotte creusée dans un contresford du Heidzer, cote 1.500 (ssp. *brevicornis* Peyer.).

Typhlozyras camusi Jeann. Maroc. Versant N. du Rif Occidental: Grotte de Torobeit au NE de Bab-Taza, alt. 1.800 m. env., 2 exemplaires pris à 200 m. de l'entrée dans une grande salle humide, V-1959 (J. Camus leg.).

Apteranillus rotroui (Scheerp) (= *Antrosemnotus rotroui* Scheerp.). Maroc. Moyen Atlas Septentrional: Grande caverne de la Daya Chiker et Gouffre de Frouyato aux environs de Taza (Rotrou et bien d'autres).

Apteranillus ruei Esp. Maroc. Région présaharienne de Boudenib: Grotte de Kef Aziza près de Tazzouguert, 6 exemplaires entre 1.000 et 1.500 m. de l'entrée errants sur des bancs d'argile au bord de l'eau, VIII-1968 (Exp. C.E.C. de Barcelona).

References

Coiffait, H. — 1954. Un nouveau *Domene* cavernicole de l'Espagne, indice paléogéographique. *Notes Biospeol.*, 9: 17-20.

Espanol, F. — 1969. Un nuevo *Apteranillus* cavernicola de la region de Boudenib, Marruecos presahariano (Col. Staphylinidae). *Ann. Speleol.*, 24(1): 171-176.

Espanol, F. — 1970. Algunos coleopteros cavernicoles del Gran Atlas Central, Marruecos. *Ann. Speleol.* 25(2): 370-372.

Espanol, F' — 1970-72. Coleopteros cavernicolas de Marruecos. *Comun. Primer Congr. Nac. Espeleol.* Barcelona: 115-121.

Espanol, F. — 1972. Un nuevo *Domene* cavernicola de la region de Agadir, Marruecos (Col. Staphylinidae). *Misc. Zool.*, 3(2): 51-54.

Espanol, F. — 1975. Un nuevo *Aleocharinae* cavernicola del norte de Espana (Col. Staphylinidae). *Speleon*, 22: 131-138.

Jeannel, R. — 1907. Diagnose d'un Staphylinidae cavernicole nouveau de l'Algérie (Col.) *Bull. Soc. Ent. Fr.*, 76: 111-114.

Jeannel, R. — 1959. Un Staphylinide cavernicole nouveau de Maroc. *Bull. Soc. Sci. Nat. Maroc.*, 39: 205-211.

Peyerimhoff, P. de. — 1911. Nouveaux coléoptères du Nord-Africain (12 note). Faune cavernicole du Djurjura. Col. *Staphylinidae Bull. Soc. Ent. Fr.*, 80: 88-91.

Peyerimhoff, P. de. — 1949. Diagnose d'un *Domene* cavernicole du Maroc: *Domene camusi. Rev. Fr. d'Ent.*, 16: 81-83.

Scheerpeltz, O. — 1935. Un genre nouveau et une espèce nouvelle de Staphylinides troglodytes du Maroc (Col.). *Bull. Soc. Sci. Nat. Maroc.*, 15: 238-248.

EROSION CRYPTOKARSTIQUE ACTUELLEMENT ACTIVE DANS LE SUD DE LA FRANCE

Guilhem Fabre
E.R.A. No.282, Centre National de la Recherche Scientifique, Institut de Géographie, 29 avenue R. Schuman, 13100 Aix en Provence, France.

Abstract

In South East of France (Eastern Languedoc) cryptokarstic erosion is, at present, mainly efficient on the pure Urgonian limestones which are covered by allochtonous alluvial deposits of the ancient Quaternary (and in some places of the upper Pliocene and lower middle Quaternary) bearing strongly lessive fersiallitic soils.

Un inventaire des types de sols et des phénomènes karstiques a été réalisé dans le cadre des calcaires du Crétacé inférieurs du Languedoc oriental (Midi méditerranéen français). On a ainsi reconnu: — au niveau des principaux sols: des sols minéraux bruts d'érosion de calcaires et de marnes (sur Berriasien, Valanginien, Hautérivien inférieur et moyen, Barrémien inférieur et moyen), des sols minéraux bruts (sur l'Urgonien), des sols bruns calcaires (sur les dépots losssiques et les placages sablo-limoneux des plateaux d'érosion), différents sols fersiallitiques, sans ou à réserves calciques, très lessivés, plus ou moins tronqués (sur l'Urgonien et les dépots alluviaux allogènes du Pléistocène recouvrant les bordures des canyons). — au niveau des phénomènes karstiques: toutes les formes classiques depuis le canyon et la doline jusqu'aux microformes (micros lapiés) et, à l'interface toit calcaire-mur des sols, tous les phénomènes cryptokarstiques classiques décrits surtout dans les régions "tempérées" par M. LAMOUROUX (1972), G. PEDRO (1972), J. NICOD (1975), M. POCHON (1976), I. GAMS (1976), S.T. TRUDGILL (1976) etc. . .

Dans le contexte morphogénétique actuel, la mise en rapport de ces deux niveaux révèle qu'un type de sol contribue vraiment activement au développement d'une érosion cryptokarstique. Il s'agit des sols fersiallitiques très lessivés et plus ou moins tronqués, développés sur les dépots alluviaux allogènes cévenols et rhôdaniens du Pléistocène ancien (et du Pliocène terminal) et souvent du Pléistocène moyen inférieur. Ces dépots détritiques ravinent essentiellement les calcaires pratiquement purs du faciès Urgonien. Les sites d'observation, tous situés en bordure des grandes rivières cévenoles drainées par le Rhône, sont d'anciennes zones d'épandages alluviaux relativement planes et plus ou moins étendues. Pami ceux-ci les principaux sont:

— pour le bassin du Gard, les méplats de Boucoiran, Sauzet, Dions en rive droite et ceux de Ners, Russan, Vic et les Aigadiers en rive gauche;
— pour le bassin de la Cèze, les méplats de Rivières, Rochegude, Dent du Serret en rive droite et ceux de Saint Jean de Maruejols et Montclus pour la rive gauche;
— pour le bassin du Rhône, le plateau situé au Nord de Rochefort du Gard.

L'attaque en subsurface des calcaires dépend bien évidemment d'actions combinées de nombreux agents (végétation acidophyle, pluviométrio etc. . .) et des propriétés intrinsèques de ces sols. Elles se résument à quelques points fondamentaux toujours présents dan les profils examinés:

— la puissance qui dépasse tres souvent I m,
— la texture, caillouteuse sur tout le profil englobant une matrice sableuse en surface et sablo-argileuse en profondeur qui assure une bonne pénétration des racines et de l'eau, et une relative rétention de cell-ci dans les horizons inférieurs chargés en montmorillonite gonflante où se décèlent localement des marques d'endohydromorphie, comme sur les méplats de Dions et de Tharaux,
— l'acidité de l'ensemble du profil (ph inférieur à 6,5) due à l'absence de calcaire et à l'abondance de matériaux siliceux présents avec plus de 95°/∘ de quartzs (surtout), des schistes cristallins (séricíteux), des grès et des granites pourris pour les éléments grossiers et 98% de quartzs pour les éléments fins, comme le signale par exemple P. DEMANGEON (1959) à Rivières.
— une longue évolution pédologique, illustrée entre autres choses par la très forte altération, voire la disparition plus ou moins complète des éléments non quartzeux.

Ainsi au niveau de ces types de sols toutes les principales conditions favorables à la formation d'un "pansement humide" corrosif (E. COULET, 1975) plus ou moins permanent au contact des calcaires sont requises. Toutefois en Languedoc oriental, la faiblesse relative des précipitations brutales et saisonnières (900 mm de moyenne de 1936 à 1965), le ruissellement et surtout la forte évapotranspiration dépassant souvent 50%, en particulier au moment de la pleine activité biologique de la végétation, font que l'érosion cryptokarstique actuelle est plus ralentie, et par là, moins efficace à bien des égards que dans certaines régions tempérées comme le Jura ou à plus fortes raisons le karst yougoslave.

References

Coulet, E. 1975. Morphologie des plaines et garrigues du Languedoc méditerranéen. *Thèse docto. d'état lettres, Inst. Géog. Uni. P. Valery Montpellier,* 6 vol., 2042 p, 117 fig., 17 Phot., I carte h.t.

Demangeon, P. 1959. Contribution à l'étude de la sédimentation détritique dans le Bas Languedoc pendant l'ère Tertiaire. *Thèse docto. d'état sciences, Inst. Géol. Fac. Sciences Montpellier, Naturalia Monspeliensa, Géol.,* mém. No. 5, 394p, 50 phot. et pl. h.t.

Fabre, G. 1976. Influence des roches sur la karstification en Languedoc oriental. *Etu. Vauclus.* No. 16, p. 9-14.

Gams, I. 1976. Forms of subsoil karst. *Actes 6° cong. intern. de Speleo*, Olomouc, CSSR, 1973, Acad. Praha, T2, Ba 017, p. 169-179.

Lamouroux, M. 1972. Etude des sols formés sur roches carbonatées. Pédogenèse fersiallitique au Liban. *Thèse docto. d'état sciences, mêm. O.R.S.T.O.M.* no.56, 266 p.

Nicod, J. 1975. Corrosion de type crypto-karstique dans les karsts méditerranéens. *Bull. Assoc. Géog. Fra.*, no. 428, p. 289-297.

Pedro, G. 1972. Les sols développés sur roches calcaires. Nature, originalité et cadre général de leur évolution à la surface du globe. *Science du Sol*, no. I, p. 5-18.

Pochon, M. 1976. Les processus d'alteration de quelques types de calcaire dans les sols du Haut Jura Suisse. *Bull. Soc. Géol. Fra.*, (7), t 18, no. I, p. 33-39.

Trudgill, S.T. 1976. Limestone erosion under soil. *Actes 6° cong., intern. de Spéléo.*, Olomouc, CSSR, 1973, Acad. Praha, T2, Ba 044, p. 409-422.

VARIATIONS DE L'AGRESSIVITE DES EAUX DE SOURCES KARSTIQUES PROVENCALES

Guilhem Fabre et Jean Nicod
Attaché de Recherche, Central National de la Recherche Scientifique, 21, rue colbert, 30000 Nimes, France
(1) E.R.A. no. 282, Centre National de la Recherche Scientifique, Institut de Géographie, 29 avenue R. Schuman, 13100 Aix En Provence, France

Abstract

108 water samples (1971 - 1975) of four karstic springs of Provence (South East of France) are studied in regard of their agressivity (H. ROQUE's curves). All during hydrologic cycle they are slightly aggressive especially two springs which have regular discharge (dolomitic basin) and one which has a great and complex limestone basin. The water aggressivity generally comes up with great discharges and on the contrary saturation appears with feeble discharge, especially during spring and summer.

Au Nord des Maures, on a effectué 108 prélèvements d'eau sur quatre sources des plateaux varois, Argens (Seillons) le Pavillon (Pontevès), la Saint Rosaire (Tourtour) et Saint Martin (Cotignac)*. Elles sont pérennes à l'exception de celle du Pavillon. L'une est très importante, c'est la source d'Argens dont le module moyen sur les II dernières années est de 5661/s. Tous ces exutoires drainent des impluvioms calcaro — dolomitiques, localement gypsifères, boisés et recevant en moyenne moins de 900 mm d'eau par an. Ils sourdent au contact d'accidents tectoniques jouant plus le rôle de barrage que de drain (failles, bordures de synclinaux bourrés de matériaux argilo-marneux imperméables etc. . .)

Les opérations d'echantillonnage systématique ont été conduites de 1971 à 1975. Parmi les différents paramètres relevés on a analysé l'agressivité générale de ces eaux calée sur les débits respectifs mesurés aux griffons. Etant donné que ces sources sont froides (classification de H. SCHOELLER, 1962), nous avons utilisé les courbes d'équilibre de H. ROQUES (1968) qui permettent la meilleure approche théorique de ce probème, aux températures relevées.

Dans l'ensemble et au long du cycle hydrologique, les eaux étudiées placées sous leur courbe respective de température sont faiblement agressives (p11). Le fort regroupement permanent des valeurs sur les diagrammes des sources pérennes d'Argens, du Saint Rosaire et de Saint Martin le met bien en évidence. Cette belle régularité apparaît dans plus de 90% des échantillons où le pH se situe entre 7 et 7,5 et le tH (degrés francais) entre 28,5 et 33. Pour le Saint Rosaire et Saint Martin elle est liée au très faible coefficient de variabilité du à l'existence d'impluviums essentiellement dolomitiques. A l'Argens où les débits sont plus irréguliers elle s'explique par l'importance et la complexité du réservoir plus calcaire que dolomitique.

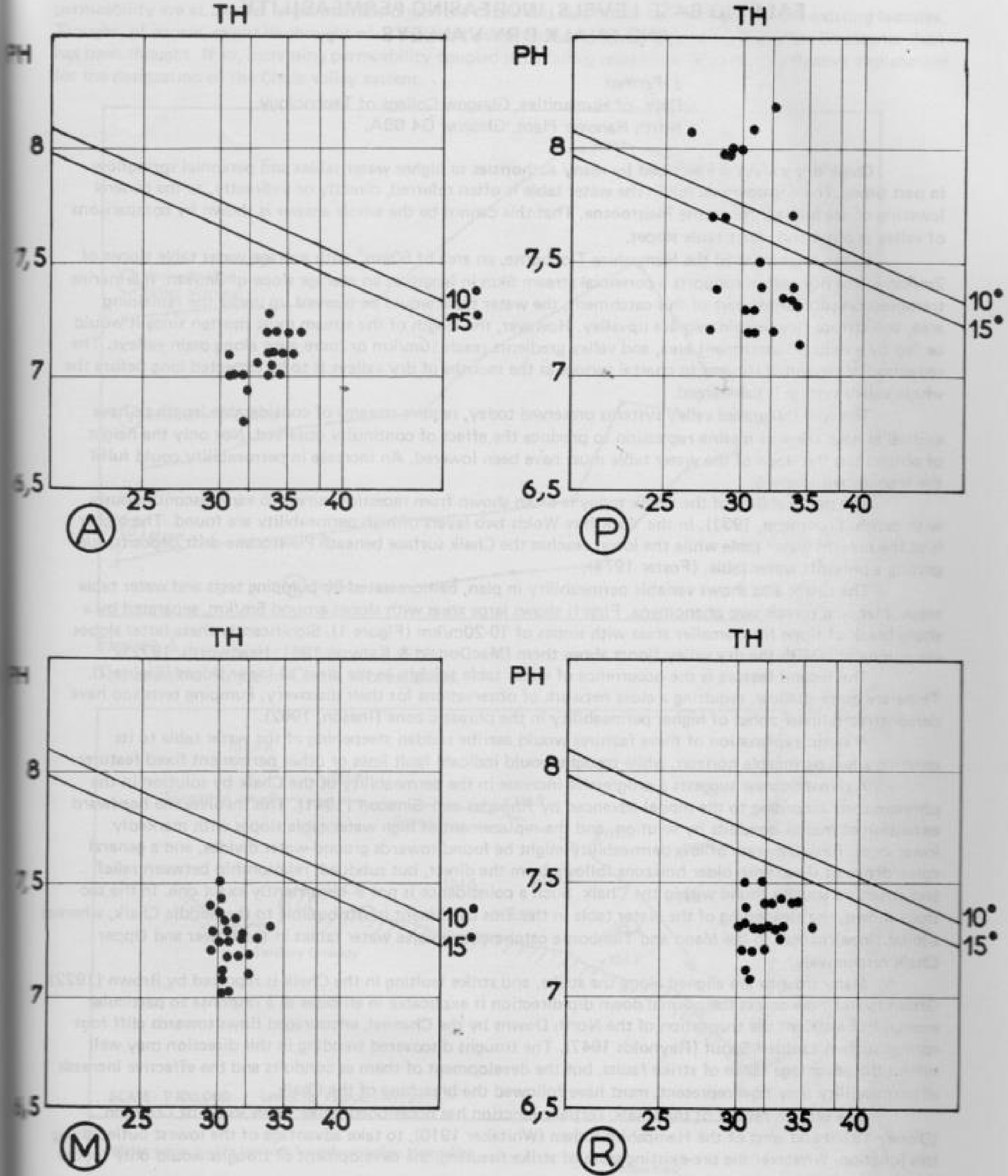
Des nuances spatio-temporelles s'observent toutefois. Dans l'espace, la saturation intervient généralement vers l'aval à l'air libre, avec l'augmentation de la basicité du pH (supérieur à 8) consécutive à la disparition de l'anhydride carbonique dissous dans l'eau. Ce fait est très net à la source temporaire du Pavillon échantillonnée pour des raisons pratiques aux griffons principal amont et secondaires aval.

Dans le temps, avec les fluctuations du débit, plus importantes au niveau des sources calcaires et temporaire, la saturation est loin d'être atteinte, en particulier quand il y a eu de fortes preécipitations en automne, un fort gonflement hivernal des réservoirs aquifères, et un débit soutenu en été. C'est le cas que l'on a observé par exemple à Argens pendant la période 1971-1972. Par contre sur cette même source la saturation a été frôlée en 1964-1965 à la suite d'un stockage hivernal particulièrement déficient (J. NICOD, 1976).

En conclusion, au niveau des griffons pérennes et pour la période considérée, les eaux sont théoriquement agressives présentement. Toutefois, toutes proportions gardées, cette agressivité est nettement moins efficace dans l'attaque des roches que celle des autres agents érosifs. Elle explique peut-être en partie que la morphologie actuelle des exutoires karstiques est singulièrement incipiente comparée à celle des réseaux hypogés auxquels elles sont connectées.

En fait si on se place sur un plan zonal et sans tenir compte des différents éléments intervenant dans l'agressivité d'une eau (température, CO_2 etc. . .) on se rend compte que la "dissolution karstique" est toujours la plus forte avec des nuances dans les zones à pluviométrie très élevée, qu'elles soient en domaines froid (Nord Ouest de l'Europe), tempéré (Yougoslavie) ou tropical (Amérique centrale, Madagascar, Chine du Sud)' Grande quantité d'eau disponible — efficacité de l'érosion.

*Plus de reseignements et notamment la bibliographie sont donnés dans: J. Nicod (1967, 1976) et G. Fabre, B. Hakim et J. Nicod (1976).



Equilibre des eaux des sources provencales, 1972-1975 (abaques de H.Roques).
A = Source d'Argene; P = Source de Pavillon; M = Source de St. Martin;
R = Source de St. Rosaire. (tH en degres francais).

References

Fabre, G., Hakim, B. et Nicod, J. 1976. Etudes hydrologique et hydrochimique sur quelques sources de Basse Provence. Tavaux 1975-1976, no. 5, E.R.A. 282, C.N.R.S., *Inst. Géog. Aix en P.,* p. 1-40.

Nicod, J. 1967. Recherches morphologiques en Basse Provence calcaire. Thèse docto. E. Lettres, Inst. Géog. Fac. Lettres Aix en P., imp. L. JEAN, Gap, 557 p + annexes.

Nicod, J. 1976. Relations débit-teneurs et débit-érosion dans les karsts méditerranéens. Actes 99° Cong. Soc. Savantes, Besançon 1974, Sect. Géog. p.115-124.

Roques, H. 1968. Chimie des carbonates et hydrogéologie karstique. Mém. et doc. C.R.D.C.G. Phénomènes karstiques I, 1967, 4 ed. C.N.R.S. p. 113-141.

Schoeller, H. 1962. Les eaux souterraines. Ed. Masson, Paris, 642p.

FALLING BASE LEVELS, INCREASING PERMEABILITY AND CHALK DRY VALLEYS

J. Fermor
Dept. of Humanities, Glasgow College of Technology,
North Hanover Place, Glasgow G4 0BA.

Chalk dry valleys are ascribed by many authorities to higher water tables and perennial springflow in past times. The considerable fall in the water table is often referred, directly or indirectly, to the general lowering of sea levels through the Pleistocene. That this cannot be the whole answer is shown by comparisons of valley profiles and water table slopes.

In the catchment of the Hampshire Tichborne, an area of $50km^2$ with average water table slopes of 2m/km in the dry season supports a perennial stream 5km in length at an average slope of 3m/km. If a marine transgression submerged part of this catchment, the water table would be buoyed up under the remaining area, and stream flow would migrate upvalley. However, the length of the stream must shorten since it would be fed by a reduced catchment area, and valley gradients reach 10m/km or more even along main valleys. The reduction of perennial streams to coastal springs at the mouths of dry valleys is to be expected long before the whole valley system is submerged.

The well integrated valley systems preserved today, require streams of considerable length to have existed at each stage of marine regression to produce the effect of continuity observed. Not only the height of outlets but the slope of the water table must have been lowered. An increase in permeability could fulfil the second requirement.

The permeability of the Chalk today is often shown from recession curves to vary discontinuously with depth. (Thomson, 1931). In the Yorkshire Wolds two layers of high permeability are found. The higher is at the present water table while the lower reaches the Chalk surface beneath Pleistocene drift deposits, suggesting a pre-drift water table. (Foster 1974).

The Chalk also shows variable permeability in plan, demonstrated by pumping tests and water table maps. Mapping reveals two phenomena. First it shows large areas with slopes around 5m/km, separated by a sharp break of slope from smaller areas with slopes of 10-20m/km (Figure 1). Significantly these latter slopes are comparable with the dry valley floors above them (MacDonald & Kenyon 1961; Headworth, 1972).

The second feature is the occurrence of water table troughs in the areas of lower slopes (Figure 2). These are quite shallow, requiring a close network of observations for their discovery. Pumping tests too have demonstrated linear zones of higher permeability in the phreatic zone (Ineson, 1962).

A static explanation of these features would ascribe sudden steepening of the water table to its entering a less permeable horizon, while troughs would indicate fault lines or other permanent fixed features.

A dynamic view suggests a progressive increase in the permeability of the Chalk by solution in the phreatic zone according to the model advanced by Rhoades and Sinacori (1941). This involves the headward extension of master conduits by solution, and the replacement of high water table slopes with markedly lower ones. Residual areas of low permeability might be found towards ground-water divides, and a general coincidence of these with older horizons follows from the direct, but subdued, relationship between relief and structure usually found within the Chalk. Such a coincidence is not a consistently exact one. In the sections shown, the steepening of the water table in the Ems catchment is attributable to the Middle Chalk, whereas similar slope changes in the Meon and Tichborne catchments involve water tables in the Lower and Upper Chalk respectively.

Many troughs are aligned along the strike, and strike faulting in the Chalk is reported by Brown (1922). Groundwater flow across the normal down dip direction is explicable in all cases as a response to particular events. In East Kent the truncation of the North Downs by the Channel, encouraged flows towards cliff foot springs such as Lydden Spout (Reynolds 1947). The troughs discovered trending in this direction may well reflect the advantage taken of strike faults, but the development of them as conduits and the effective increase in permeability they now represent, must have followed the breaching of the Chalk.

The uneven retreat of the Chalk-Tertiary junction has occasioned strike flows south of Croydon (Dewey 1915) and west of the Hampshire Itchen (Whitaker 1910), to take advantage of the lowest outlet along this junction. Whatever the pre-existing state of strike fissuring, the development of troughs would only follow this uneven retreat.

The troughs in the Hamble catchment focus upon the culmination of plunge of the Forest of Bere syncline (Day 1964). The present outlets occur beyond this syncline, a belt of overlying Tertiaries occurring in the syncline itself. Trough directions reflect the general focussing of flow towards the easiest path for confined water under the Tertiaries, a path that will only have been used since falling sea levels allowed the Bedhampton springs, at 8m OD, to become effective competitors with former springs at the Chalk-Tertiary junction north of the syncline. This suggests a late development for the troughs.

Troughs reported beneath dry valleys (Ireson 1962; Fermor 1969) may result from the widening of joints by pressure release as the valleys are excavated, or may reflect a common origin using a pre-existing line of weakness. The Upper Meon follows a syncline so that pre-existing wide fissures are not likely. The coincidence of a trough with this perched river course, is then the more likely to indicate a developing permeability.

The association, in the Yorkshire Chalk, of higher permeability with past and present positions of the water table bears an intriguing resemblance to Sweeting's (1950) correlation of near horizontal cave systems and intermittently falling base levels in the Carboniferous Limestone of Ingleborough. The zones of greater

permeability are at a lower angle than the dip of the Chalk and can hardly be attributed to pre-existing features. Troughs, of course, might be thought of as incipient caves. Perhaps the Chalk is more like other limestones than has been thought. If so, increasing permeability coupled with falling outlets can provide an effective explanation for the desiccation of the Chalk valley system.

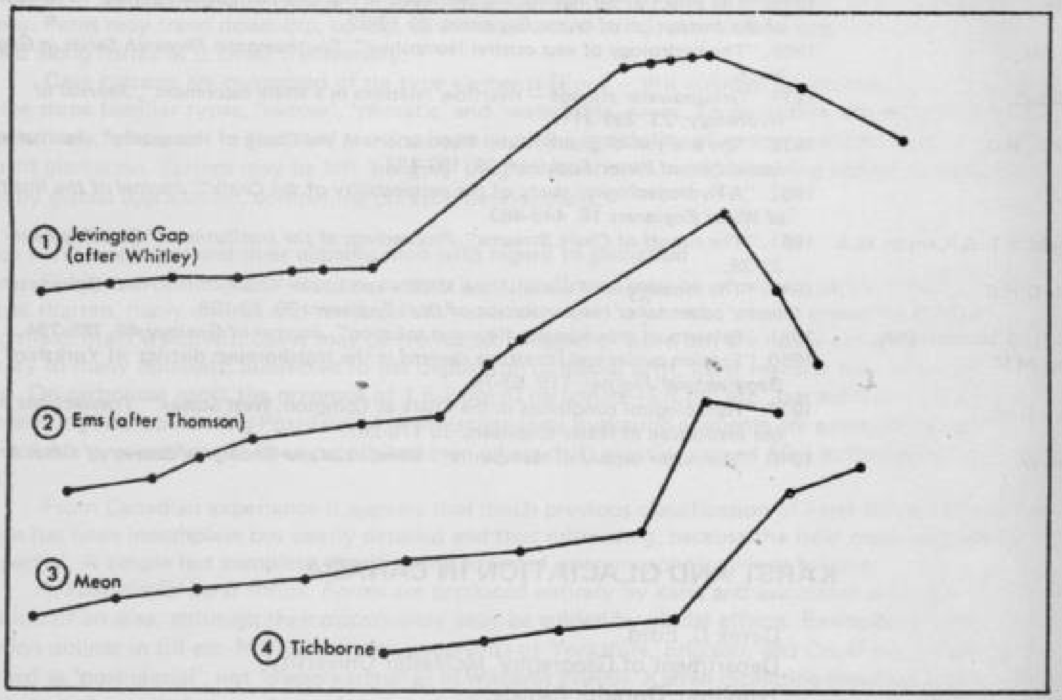


Figure I.

The break of slope in Chalk watertables.

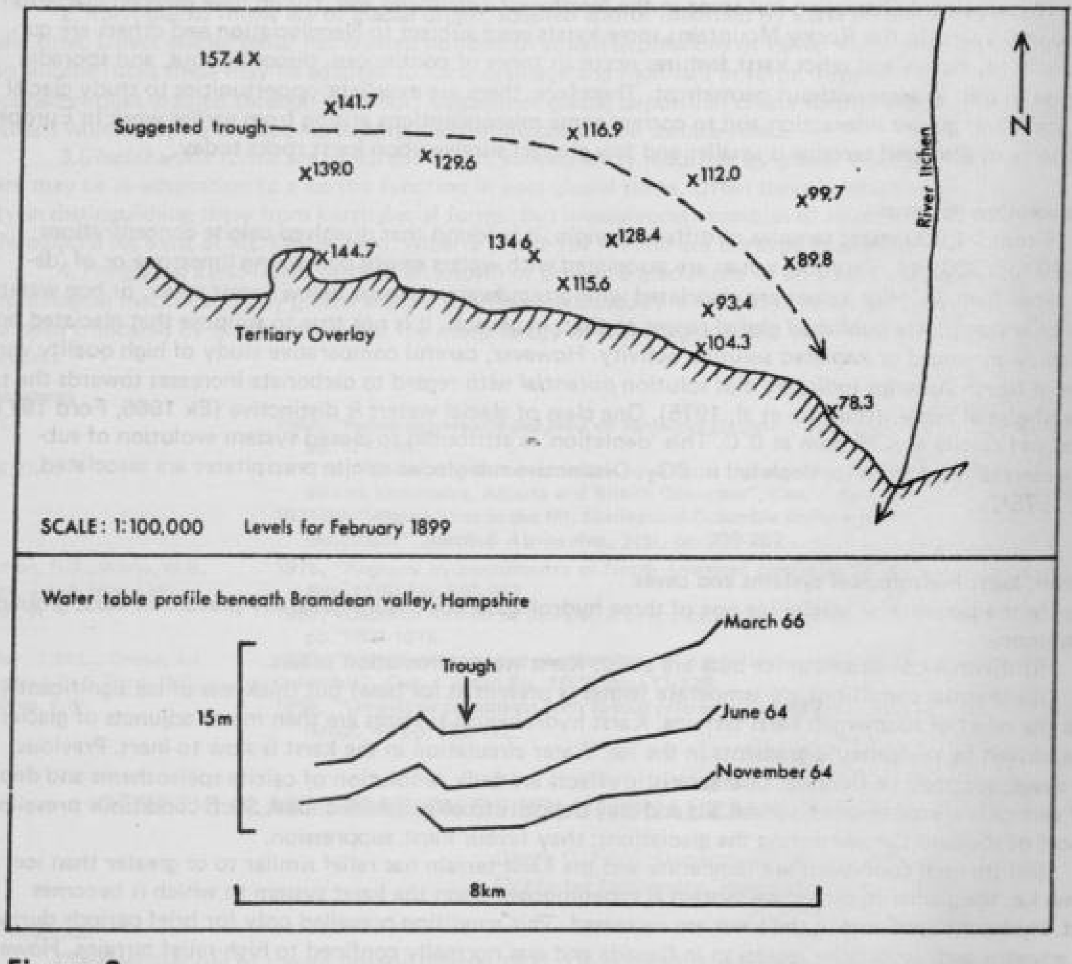


Figure 2.

Water table troughs

References

Brown, E. 1922. "Underground water in the Kent coalfields". Minutes of Proceedings of the *Institute of Civil Engineers,* 215. 59-60.

Day, J.B.W. 1964. "Infiltration into a groundwater catchment and the derivation of Evaporation." Water Supply Papers of the *Geological Survey of Great Britain,* No.2.

Dewey, H. 1915. "The effect of springs upon water levels in the Chalf of Eastern Surrey". *Transactions of the Institution of Water Engineers.* 20 12-32.

Fermor, J.H. 1969. "The hydrology of east central Hampshire". *Southampton Research Series in Geography.* No. 5.

Foster, S.S.D. 1974. "Groundwater storage – riverflow relations in a chalk catchment". *Journal of Hydrology,* 23. 299-311.

Headworth, H.G. 1972. "The analysis of groundwater fluctuations in the Chalk of Hampshire". *Journal of the Institution of Water Engineers 26.* 107-124.

Ineson, J. 1962. "A hydrogeological study of the permeability of the Chalk". *Journal of the Institution of Water Engineers* 16. 449-463.

MacDonald A.T. & Kenyon W.J. 1961. "The runoff of Chalk Streams". *Proceedings of the Institution of Civil Engineers* 19. 23-38.

Reynolds D.H.B. 1947. "The movement of water in the Middle and Lower Chalk of the River Dour catchment". *Journal of the Institution of Civil Engineers* 29. 73-108.

Rhoades R. & Sinacori M.N. 1941. "Patterns of groundwater flow and solution". *Journal of Geology* 49. 785-794.

Sweeting, M.M. 1950. "Erosion cycles and limestone caverns in the Ingleborough district of Yorkshire". *Geographical Journal,* 115. 63-78.

Thomson, D.H. 1931. "Hydrological conditions in the Chalk at Compton, West Sussex". *Transactions of the Institution of Water Engineers.* 36 176-207.

Whitaker, W. 1910. "The water supply of Hampshire". *Memoirs of the Geological Survey of Great Britain.*

KARST AND GLACIATION IN CANADA

Derek C. Ford.
Department of Geography, McMaster University,
Hamilton, Ontario, Canada.

Exposed in Canada are approximately 1,100,000kms^2 of carbonate rocks and 77,000 kms^2 of sulphate rocks, distributed across the land and between Lats. 44 and 82° N. Most outcrops were glaciated during the Last (Wisconsinan) Glaciation but some in the Northwest Territories and Yukon have escaped glaciation for >350,000 years. In the Rocky Mountains some karsts were subject to Neoglaciation and others are currently glaciated. Active and relict karst features occur in zones of continuous, discontinuous, and sporadic permafrost as well as areas without permafrost. Therefore, there are excellent opportunities to study glacial effects, karst and glacier interaction and to correct some misconceptions arising from earlier work in Europe where choice of glaciated terrains is smaller and few glaciers survive upon karst rocks today.

Modern solution patterns

From >1,000 water samples of differing origin, it is found that dissolved calcite concentrations range <10 to >300 mgl. Very low values are associated with waters newly contacting limestone or of 'depleted' types (below). High values are associated with groundwater seepage below forest cover, or bog waters. This range encompasses published global ranges so that, in general, it is not true to suppose that glaciated terrains display enhanced or depleted solution activity. However, careful comparative study of high quality water analyses in North America indicates that solution *potential* with regard to carbonate increases towards the tropics and out of glacial range, (Harmon et al. 1975). One class of glacial waters *is* distinctive (Ek 1966, Ford 1971); this saturates wrt calcite at <25 ppm at 0°C. This 'depletion' is attributed to closed system evolution of subglacial waters derived from ice depleted in CO_2. Distinctive sub-glacial calcite precipitates are associated, (Hallet 1975).

Glaciation, karst hydrological systems and caves

In the presence of glacier ice one of three hydrological conditions generally prevails in karst groundwater system:—

(i) thermal conditions at ice base are polar. Karst water circulation ceases.

(ii) thermal conditions are temperate (water is present at ice base) but thickness of ice significantly exceeds the relief of submerged karst terrains. Karst hydrological systems are then minor adjuncts of glacier systems, driven by piezometric gradients in the ice. Water circulation in the karst is slow to inert. Previous vadose caves, etc. may be flooded. Characteristic effects are bulk re-solution of calcite speleothems and deposition of vertically discontinuous, varved silt and clay deposits from suspended load. Such conditions prevailed over most of lowland Canada during the glaciations; they favour karst suppression.

(iii) thermal conditions are temperate and the karst terrain has relief similar to or greater than ice thickness i.e. the glacier hydrological system is superimposed upon the karst system to which it becomes adjunct. Hydraulic gradients in the karst are increased. This condition prevailed only for brief periods during glacier advance and, especially, recession in Canada and was normally confined to high-relief terrains. However, when it did prevail erosion rates were much accelerated; individual shafts and galleries were generated in a few decades or centuries.

Geographic relations of karst groundwater flow paths to structure, lithology and topography in glaciated terrains are as varied as they are in extra-glacial karsts although in lowland Canada there is some predominance of short, simple paths (e.g. following single, major joints) due to the youth (post-glacial) of many systems. Paths may trend down-dip, up-dip, to strike or aslant-strike, etc. Valleys may be under-drained, drained along flanks of drained transversely.

Cave systems are composed of six type elements (Ford — this volume) which may be amalgamated into the three familiar types, 'vadose', 'phreatic' and 'watertable' caves. To generalise, the watertable type is comparatively infrequent in glaciated terrains because of the instability of spring positions in the face of frequent glaciation. Springs may be left 'hanging' by glacial entrenchment, favouring vadose development; or raised by glacial aggradation, compelling phreatic development.

Surface karst landforms and their classification with regard to glaciation

Subjected to net glacial erosion, surface karst landforms may be wholly or partly erased. Smaller features (karren, many dolines and residuals such as towers, etc) tend to be wholly erased by long-duration erosion (e.g. main Weichsel). Caves may be truncated, plugged or filled but are rarely collapsed by ice loading, contrary to many opinions. Subjected to net deposition of glacial drift, karst features may be wholly or partly buried. On carbonate rocks the presence of 1.5-2.0m of carbonate-rich till, etc., has sufficed to prevent solution of underlying bedrock during Post-Glacial times unless local hydraulic gradients are excessive. Solution of the more soluble gypsum has not been prohibited even where drift mantles exceed 40m in thickness, (Wigley et al 1973).

From Canadian experience it appears that much previous classification of karst forms in glaciated terrains has been incomplete but overly detailed and thus misleading, because the field experience has been only partial. A simple but complete classification founded upon morphology is as follows:-

1. *Post-glacial karst forms. Forms* are produced entirely by karst and associated processes since the last glaciation of an area, although their *distribution* may be guided by glacial effects. Examples are most karren, suffosion dolines in till etc. N.B. Limestone pavements of Yorkshire, England, and Co. Clare, Eire, are here classified as 'post-glacial', not 'glacio-karstic' as in Williams (1966). Karren dissecting these surfaces are of post-glacial age and owe little or nothing of their individual morphology to glacial action. An essential preliminary requirement is scour of rubble or other residuum; in instances cited above the scouring agents were glaciers but smaller pavements may be seen in extra-glacial areas where scour is by storm waves, a periodic desert flood or even deflation.

2. *Karstiglacial forms* are of glacial origin, adapted and/or modified by karst processes during post-glacial time. Direct glacier scour has created millions of closed depressions of varied shape and size in Canada. If on soluble rocks these may be adapted to karst drainage and modified in form. Type examples are over-deepened cirques drained through the floor. Vagaries of glacial deposition create further abundant closed depressions which may be drained karstically if super-imposed upon soluble rocks.

3. *Glaciokarstic forms* are of karstic origin, subsequently modified by glacier erosion and/or deposition. There may be re-adaptation to a karstic function in post-glacial times. Often there is 'chicken-and-egg' difficulty in distinguishing these from karstiglacial forms. But unequivocal examples of solution dolines modified by Neoglacial ice exist at Mt. Castleguard, Alberta (Ford 1971b) and are the type examples.

4. *Pre-glacial karst forms* predate all known or probable glaciations of an area and have not suffered morphological modification by glacial action. Examples in Canada are limited to relict cave systems. These have been truncated by glacial action but the morphology of surviving portions owes nothing to ice-contact processes.

References

Ek, C. 1966. "Faible aggressivité des eaux de fonte des glaciers", *Ann. Soc. Geol. Belge*, 89(5-10), pp. 177-188.

Ford, D.C. 1971(a), "Characteristics of limestone solution in the southern Rocky Mountains and Selkirk Mountains, Alberta and British Columbia", *Can. J. Earth Sci* 8(6), pp. 585-609.

1971(b), "Alpine karst in the Mt. Castleguard-Columbia Icefield area, Canadian Rocky Mountains", *Arctic & Alpine Res.*, 3(3), pp. 239-252.

Harmon, R.S., White, W.B. Drake, J.J. & Hess J.W. 1975, "Regional hydrochemistry of North American carbonate terrains", *Water Resources Res.* 11(6), pp. 963-967.

Hallet, R. 1967, "Deposits formed by sub-glacial precipitation of $CaCO_3$", *Bull., Geol. Soc. Am.* 87(7), pp. 1003-1016.

Wigley, T.M.L., Drake, J.J. Quinlan J.F. & Ford, D.C. 1973, "Geomorphology and geochemistry of a gypsum karst near Canal Flats, British Columbia", *Can. J. Earth Sci.* 10(2), pp.113-129.

Williams, P.W. 1966, "Limestone pavements with special reference to Western Ireland", *Trans. Inst. Brit. Geogr.* 40 pp. 155-172.

GENETIC CLASSIFICATION OF SOLUTIONAL CAVE SYSTEMS

Derek C. Ford, Department of Geography,
McMaster University, Hamilton, Ontario, Canada

Introduction

Classical theories of cavern genesis (Martel 1921, Davis 1930, Swinnerton 1932 etc.) conflict upon the question of whether solutional caves develop preferentially in the vadose, phreatic or watertable zones. Research by the author (1965, 1968, 1971) and independently by Renault (1967-8) plus published results

of the past 40 years of cave exploration, exemplified by local studies by Waltham (1970,71) and Palmer (1976) indicate that (i) caves originating in all three zones are common (ii) it cannot be shown at present that only one zonal type is in the majority globally (iii) it is not necessary for a unified genetic theory that any one type should be in a majority. This paper presents a simple classification of the principal genetic types. It is recognised that there are many sub-types not discussed here.

Definition of Solutional Caves

Curl's well-known definition (1966) of caves as underground spaces of enterable size is rejected as non-genetic. A karst cave is a conduit or other void possessing dimensions large enough for turbulent flow of ground-water to occur; minimum dimensions vary 5-16 mm diameter (Howard 1964) under the range of all likely hydrologic gradients. Voids that are too small but pass water are in a 'pre-cave' state. Caves are of two fundamental kinds — 1) *Isolated;* the cave conduit or chamber is not continuously connected to any surface input or output by other conduits of the minimum dimensions specified above = "vugs", etc. 2) *Cave systems or integrated caves;* there is continuous connection of ≥ specified dimensions to inputs or outputs or both. Caves attaining explorable dimensions are normally fully integrated between inputs and outputs.

Cave systems may be sub-classified as follows:—

A. *General cases:-*
  1. Phreatic
  2. Watertable
  3. Vadose

B. *Special case:-*
  4. Artesian (Ford 1971)

A complete system may be wholly phreatic or watertable or vadose, etc., or a combination of vadose plus phreatic vadose, plus watertable, etc. Multiphase systems frequently display all three components (active or relict) in differing combinations; this is an expectable consequence of aging.

Differentiation of Phreatic and Watertable Caves: The 'Four-State Model'

Whether a phreatic or watertable cave will develop in a system evolving from the pre-cave condition is a function of the frequency (at the scale of the system) of penetrable, interconnected fissures such as bedding planes, joints and faults — termed 'fissure frequency'. The higher the frequency, the more nearly does an ideal watertable-graded cave develop. In reality, fissure frequency varies as a continuum between low and high frequency conditions. But the continuum may be reduced to just four distinct states producing four different cave geometries — Figure 1.

State 1 is that of minimum frequency, producing a cave that is a single deep loop beneath the piezometric surface = 'bathyphreatic cave': *type examples* — caves of Sierra de El Abra, Mexico (Fish 1973). If fissure frequency is lower (approaching State 0) there can be no cave development in the rock.

State 2 of low frequency produces a cave of multiple phreatic loops, upper apices of which come to define the piezometric surface as the system enlarges. *Type example* — Hölloch, Switzerland.

State 3 of intermediate frequency is a combination of phreatic loops and watertable-graded segments (the latter commonly strike-aligned; Ford 1968). *Type example* — Swildon's Hole, England.

State 4 is of high frequency, permitting development of an ideal watertable cave as in Swinnerton (1932). *Type example* — Domiča Cave, Czechoslovakia. Higher frequencies (State 5+) cannot produce further geometric variation of resultant cave types; as frequency increases, flow is increasingly diffused and cave dimension diminished until a permanent 'pre-cave' state is arrived at, as in many chalk rocks.

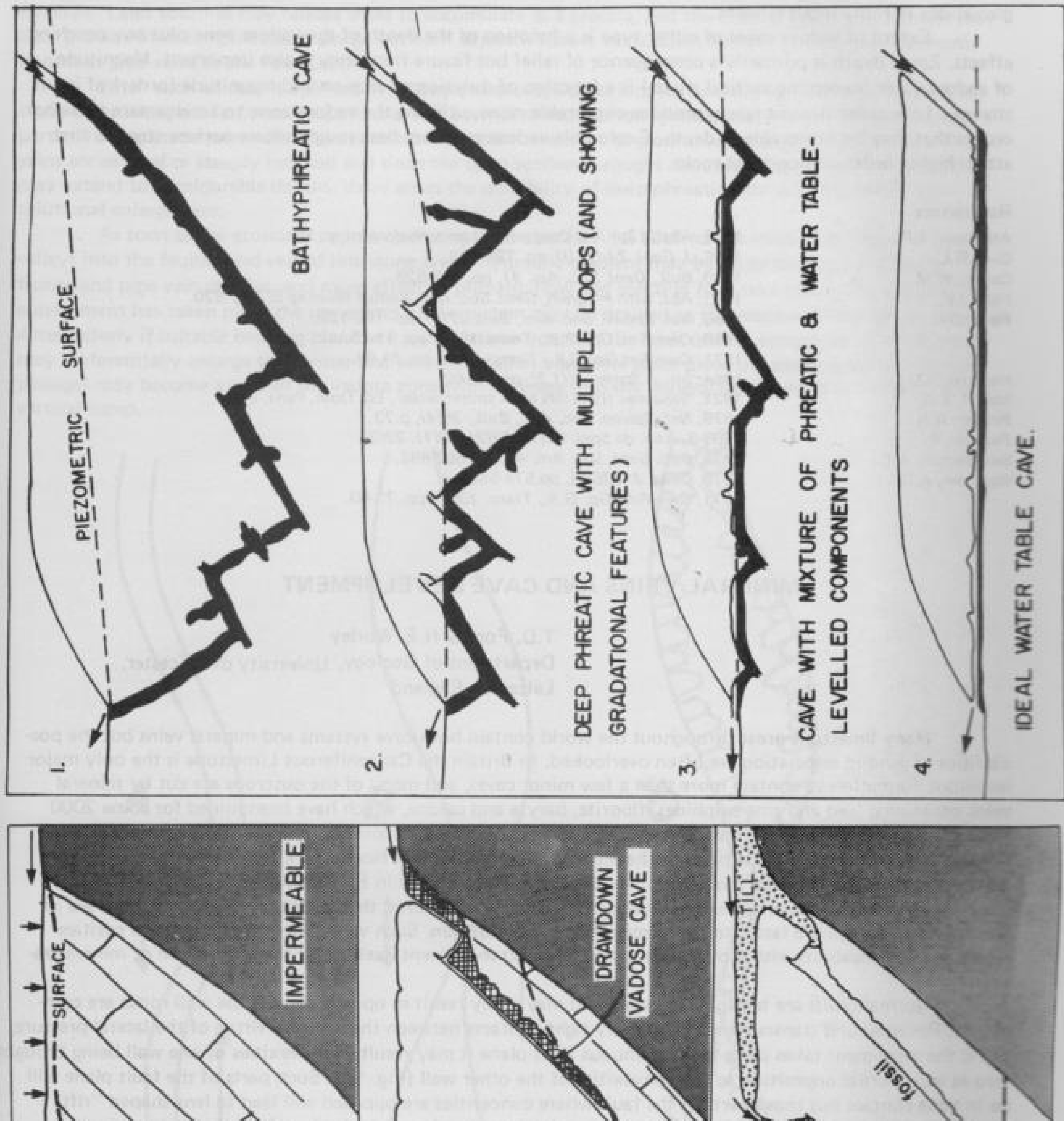
Systems that are combinations of two of these four types exist, indicating intermediate states of fissure frequency. As systems of State 2 or 3 age they may be modified toward higher state by isolated entrenchment or bypassing of loops (Ford 1965, 1968) or paragenesis (Renault 1968). With passage of time after groundwater circulation is established, frequency is increased. Therefore, later caves in a multiphase system tend to higher state.

In well-bedded rocks, varying geologic structure may introduce preferential development of particular types of system. Where flat-lying (stratal dip $< 2\text{-}5^{\circ}$) perching effects frequently favour States 3 or 4. Where dip is steeper, quasi-artesian confinement favours States 1 and 2. Intense folding favours high fissure frequency. Reef rocks are complex because high vug porosity may produce high frequency results although fracture frequency is often particularly low.

Numerical measures of the different states of penetrable fissure frequency are not yet established. In steeply dipping, massive crystalline rocks a link frequency of 10 m may discriminate State 3 from State 4. In such strata in the central Mendip Hills of England it appears that a state intermediate between States 3 and 4 has been attained with aging where, from the work of Atkinson (1975), the modern *effective porosity* of the whole rock mass is only just equal to 1.0% and probably only 1/30th of this constitutes integrated cave passages. This implies great difficulty in distinguishing states by analysis of hydrological output data at springs, rather than by direct exploration.

Differentiation of Vadose Caves

Differentiation is shown in Figure 2. Unless fissure frequency is very high (approaching the non-cave,



diffuse-flow state), initially there is no vadose zone. As the zone is progressively created by draw-down of the piezometric surface consequent upon reservoir enlargement by solution, *Type 1 vadose systems = "Drawdown Vadose Caves"* develop. These largely or entirely follow portions of the initial phreatic cave conduits. *Type example* is G.B. Cave, England, where 90%+ of the volume is attributed to vadose erosion but the initial cave skeleton is phreatic.

Type 2 vadose caves develop where new streams are introduced to karst rock already drained (possessing a vadose zone) as a consequence of earlier Type 1 developments. Such caves are *"Invasion Vadose Caves"*. *Type example* — Spluga della Preta, Italy. This type is common (dominant?) where avulsion events such as

glaciations re-route input streams.

Extent of vadose caves of either type is a function of the depth of the vadose zone plus any perching effects. Zonal depth is primarily a consequence of relief but fissure frequency is also important. Magnitude of vadose caves (excepting vertical shafts) is a function of duration of erosion and magnitude (order) of input streams. Low order streams rarely produce explorable caves, utilising the vadose zone to amalgamate to higher orders that may be explorable at depth. Explorable vadose caves are best sought where surface streams first attain higher order on non-karst rocks.

References

Atkinson, T.C. 1975, *Abs., 12th Int. Cong., Int. Assoc. Hydrogeol.* p. 38.
Curl, R.L. 1966, *J. Geol. 74 (5, II)*, pp. 798-830.
Davies, W.M. 1930, *Bull., Geol. Soc. Am. 41*, pp. 475-628.
Fish, J.E. 1973, *Abs. with Program, Geol. Soc. Am. Annual Meeting 5(7)*, p.620.
Ford, D.C. 1965, *Nat. Speleo. Soc. Am., Bull. 27(4)*, pp. 109-132.
1968, *Cave Res. Gp. G.B., Trans. 10(1)*, pp. 11-25.
1971, *Cave Res.Gp. G.B., Trans. 13(2)*, pp. 81-94.
Howard, A.D. 1964, *Int. J. Speleo. 1(1,2), pp. 47-60.*
Martel, E.A. 1921, 'Nouveau traité des eaux souterraines', Ed. Doin, Paris, 840p.
Palmer, A.N. 1976, *Nat. Speleo. Soc. Am., Bull., 38(4)*, p.73.
Renault, P. 1967-8, *Ann. de Spel. 22(1), 22(2), 23(1), 23(3).*
Swinnerton, A.C. 1932, *Bull. Geol. Soc. Am. 43*, pp. 662-693.
Waltham, A.C. 1970, *Geog. J. 136(4)*, pp.574-585.
1971, *Cave Res. Gp. G.B., Trans. 13(2)*, pp. 73-80.

MINERAL VEINS AND CAVE DEVELOPMENT

T.D. Ford & N.E. Worley
Department of Geology, University of Leicester,
Leicester, England

Many limestone areas throughout the world contain both cave systems and mineral veins but the possibilities of genetic association are often overlooked. In Britain the Carboniferous Limestone is the only major limestone formation to contain more than a few minor caves, and many of the outcrops are cut by mineral veins containing lead and zinc sulphides, fluorite, baryte and calcite, which have been mined for some 2000 years. Several of the larger cave systems of the Peak District were discovered by miners in such veins. Comparable areas in Britain include parts of the Mendip, North Wales and North Yorkshire karst areas. Outside Britain similar associations of caves and mineral veins are widespread in Europe, America and Australia.

The hydrothermal mineral veins mostly occupy fault fissures; the faults may be normal, reversed or transcurrent, though the last category is most common in Britain. Such vein-faults may give rise to cavities resulting in permeability either by the nature of the fault movement itself or by the mechanism of mineralization.

Normal faults are tensional in origin and may easily result in open fissures if the wall rocks are competent. Reversed and transcurrent faults imply tight contacts between the walls by virtue of the lateral pressure, but if the movement takes place along a sinuous fault plane it may result in convexities of one wall being brought into at least partial opposition to the convexities of the other wall (Fig. 1A). Such parts of the fault plane will be in tight contact but those parts of the fault where concavities are opposed will lead to lens-shaped "rift" chambers as shown in Fig. 1B. Such rifts may develop in series along a fault plane in horizontal, vertical or oblique sets. Fracturing of the walls may lead to the cavities being partly filled with a breccia of wall-rock. Thus, faulting may lead to the existence of sets of lens-shaped rift chambers developed in competent rocks and sometimes filled with breccia. If the wall-rocks are calcareous they are thus ready-made for either mineralization or phreatic solution, or possibly both at different times.

If such fault planes have sufficient permeability for mineralizing fluids to penetrate the tight sections, the open sections will then be suitable receptacles for the precipitation of minerals. Normally these crystallize from aqueous solution at moderately high temperatures, precipitating in descending order of crystallization temperature, perhaps somewhat modified by the proportions of solutes. But in most cases the open cavities will not be completely filled as some space must be left for the final demineralized fluid. Also tight sections of veins will tend to become sealed by mineral deposition in the adjoining opens (Fig. 1C). However, in many cases subsequent to mineralization, or between separate phases thereof, further movement takes place and the seals are broken, so that fluid movement can take place along the mineral-lined cavities.

Faulting and mineralization normally takes place at considerable depths, below the usual zone of meteoric water movement, though sometimes the mineral fluid may escape to the surface as hot springs.

The chemistry of mineral fluids is complex and varied, and there is little doubt that in some cases they become acid, so that solution of calcareous wall-rocks will take place as soon as the acid waters enter them. Neutralization will occur of course but may not be completed if there is enough flow of mineral fluid. The result may then be the solution of already deposited calcite in the vein, and of the wall-rock, releasing an insoluble breccia of other minerals to accumulate on the floor of the rift cavities.

Solution of wall-rocks may pick out "favourable" permeable lithologies to the extent of developing pre-mineral-deposition deep phreatic cave systems. These in turn may become lined or filled by hydrothermal

minerals. Later solution may release these to accumulate as a breccia, and the mineral caverns so formed may then provide links for phreatic drainage between adjacent fissure veins. Such mineral caverns are commonly known as pipe-veins in the Peak District.

When such an area is uplifted in subsequent geological periods sufficiently for exposure of the limestone by erosion, the fault cavities, mineral vein cavities or redissolved mineral cavities may provide at least a partially integrated system of conduits suitable for the movement of groundwater. Since most faults or fissure veins are vertical or steeply inclined and since the open sections brought about by opposition of concavities may extend to considerable depths, there arises the possibility of deep phreatic flow with attendant slow solutional enlargement.

As soon as the erosional regime operating on the surface has allowed the incision of one or more valleys into the faulted and veined limestone area a hydraulic gradient may be established via the faults, fissure and pipe vein cavities, and more effective phreatic flow and solution may take place. When enough enlargement has taken place the upper end of the system may be drained so that vadose processes are initiated. Alternatively if suitable bedding plane and joint systems intersect the fault or vein system, phreatic solution may preferentially enlarge the former and when the fall in base-level takes place the bedding plane and joint passages may become a part of the vadose zone with drainage into the mineral vein at what is in effect a deep vertical sump.

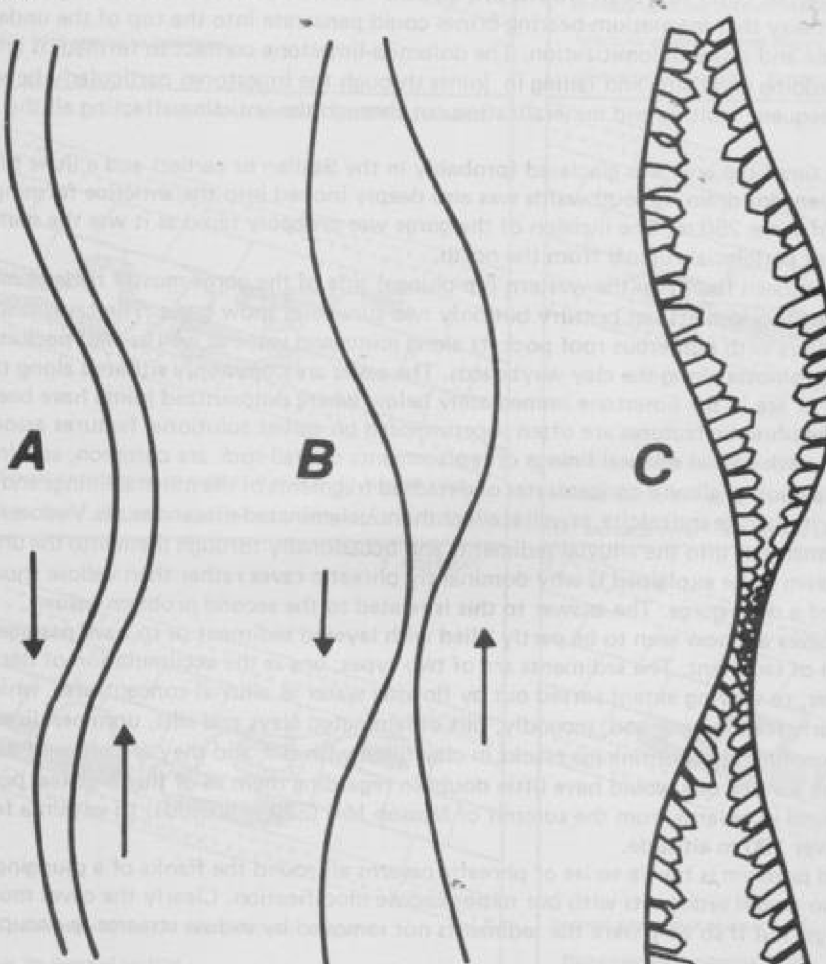


Fig 1 Diagrams of a slightly irregular fault plane. A= before movement. B=after movement has brought bulge against bulge, with lens-shaped voids (rifts) in between. C=after mineralization has lined voids with crystals, and filled in narrow sectors.

Drainage through a whole karst massif may, as in the Peak District, become a system of vadose feeder channels in bedding and joint caves, terminating in canal-like sumps in mineral veins, which feed resurgences also in those veins or in an associated vein network either at surface or in drained effluent caves. Vadose drainage may similarly flow into flooded pipe-vein caverns. Meanwhile some vein caverns may become dry as flow takes new channels; phreatic solution caverns in or along mineral veins may then be left apparently isolated.

The possibility of deep phreatic flow through series of vein and fault cavities not only explains the initiation and early development of many cave systems but also offers an explanation of departures from regularly graded vadose to phreatic and back to vadose systems in suitable circumstances. Partial sealing by mineral deposition can also explain some of the vagaries of profile, while selective solution of wall-rock may help to initiate phreatic cave development outside the vein fractures.

PHREATIC CAVES AND SEDIMENTS AT MATLOCK, DERBYSHIRE

T.D. Ford and N.E. Worley
Geology Department,
Leicester University, England

The caves of the Carboniferous Limestone at Matlock present an unusual combination of features requiring an explanation based on many different aspects of the geological history, as recently reviewed by Ford (1977).

The Matlock area consists of Carboniferous Limestone folded into a broad anticline, plunging eastwards and with minor subsidiary folds on both crest and flanks. The limestone sequence consists of some 500 m of thick-bedded calcarenites, with two basaltic lava horizons, 50 to 100 m thick representing contemporary lava flows. These two flows are some 35 m apart and the intervening limestones are broken by a number of thin clay seams, from 1 cm to 1 m thick, representing volcanic dust showers. The lavas are commonly known locally as toadstones and the clay seams as wayboards. The core of the anticline is partly occupied by a dolerite intrusion, while the flanks are composed of the sandstones and shales of the Millstone Grit Series of Upper Carboniferous age. The folding culminated at the end of Carboniferous times and by Upper Permian times much of the 1000 m or so of Upper Carboniferous cover had been eroded off, and the Permian Zechstein seas transgressed the truncated anticline in such a way that magnesium-bearing brines could penetrate into the top of the underlying Carboniferous Limestone and cause dolomitization. The dolomite-limestone contact so formed, is an irregular plane transecting the bedding and rising and falling in joints through the limestones particularly between the two lava horizons. Subsequent faulting and mineralization cut through the anticline affecting all the strata to varying degrees.

In Pleistocene times the area was glaciated (probably in the Saalian or earlier) and a little till survives in patches. The River Derwent draining southwards was also deeply incised into the anticline forming a gorge with maximum depth of some 250 m. The incision of the gorge was probably rapid as it was the main drain of a large catchment area of periglacial run-off from the north.

Many caves have been found on the western (up-plunge) side of the gorge mostly by lead miners. Several of these were open to tourists last century but only two survive as show caves. The caves display phreatic solutional features with numerous roof pockets along joints and veins as well as wall pockets in the bedding, with local anastomoses along the clay-wayboards. The caves are commonly situated along the dolomite-limestone contact or are in the limestone immediately below where dolomitized joints have been enlarged beyond recognition. The phreatic features are often superimposed on earlier solutional features associated with mineralization, as caves with partial mineral linings or replacements of wall-rock are common, and in some there are (or were before mining) alluvial concentrates of detached fragments of the mineral linings and replacements, commonly galena, fluorite, baryte and calcite, as well as allochthonous laminated silts and muds. Vadose modification is limited to shallow channels cut into the alluvial sediments and occasionally through them into the underlying rock.

The first problem to be explained is why dominantly phreatic caves rather than vadose should be abundant in the walls of a deep gorge. The answer to this is related to the second problem below.

Many of the caves are now seen to be partly filled with layered sediment or to have passages leading off but completely full of sediment. The sediments are of two types; one is the accumulation of detached fragments of mineral matter, to varying extent sorted out by flowing water as alluvial concentrates, which were highly prized by the early lead miners; and, secondly, fills of laminated clays and silts, unmineralized and unconsolidated. These sometimes have shrinkage cracks in clay filled with silt, and they are often of varved appearance. In fact on the surface one would have little doubt in regarding them as of fluvio-glacial pond or lake origin. They can be found in caverns from the summit of Masson Hill (330 m altitude) to within a few metres of river level at little over 100 m altitude.

So the second problem is how a series of phreatic caverns all round the flanks of a plunging anticline can be filled with fluvio-glacial sediments with but minor vadose modification. Clearly the caves must predate the incision of the gorge, but if so why were the sediments not removed by vadose streams re-occupying the choked caves?

The answer to the two problems now proposed may be summarized as a series of events or stages (see diagram)

1. Dolomitization of the Carboniferous Limestone down joints and bedding beneath a former cover of Permian magnesium-rich marine deposits subsequently removed.

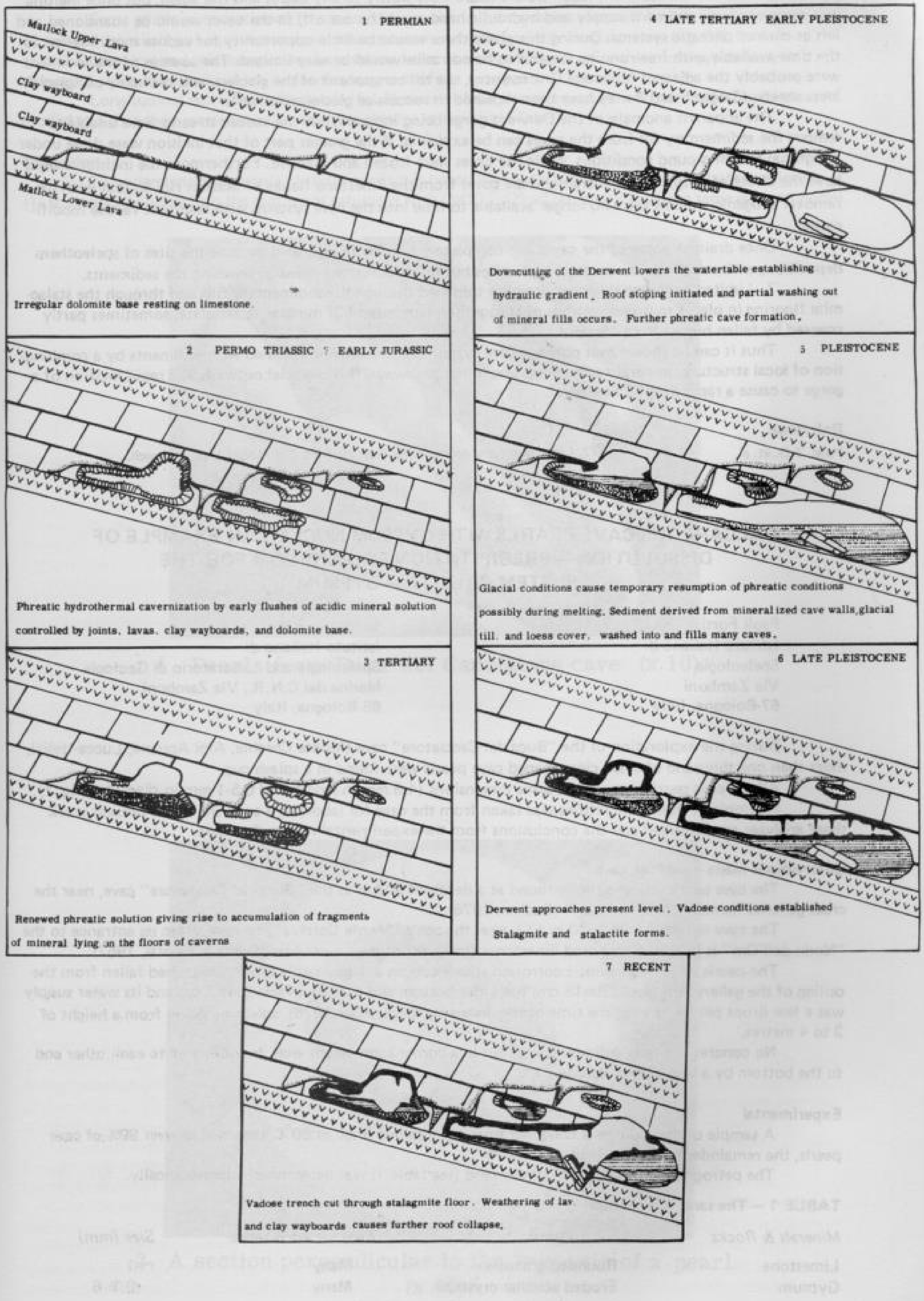
2. Development of early phreatic solution caverns during the hydro-thermal mineralization phases, probably in Permo-Triassic times with filling and lining by hydrothermal minerals.

3. In Tertiary times, with regional uplift starting, gently moving phreatic waters dissolved limestone walls detaching blocks of relatively insoluble minerals which accumulated on the floors.

4. In the late Tertiary and early Pleistocene incision of the modern river system commenced, and phreatic waters began to move under a hydraulic gradient around the flanks of the anticline, within the limestone/dolomite contact zone between the two lavas. Solutional enlargement of mineral cavities permitted further release and accumulation of detached mineral fragments, with limited transport and abrasion. Some downcutting of the Derwent may have allowed drainage of the phreatic caves with ensuing vadose stoping of roof blocks along clay-wayboards.

5. With the onset of glaciation most, if not all, solution ceased, though the effect of ice covering the area may have given a phase of higher water-table and renewed solution under glacio-phreatic conditions. Under waning glacial conditions large quantities of fine-grained outwash sediment and derived loess washed in via

A DIAGRAM ILLUSTRATING THE EVOLUTION OF THE CAVES IN THE MATLOCK AREA



joints to give laminated fills.

6. Glacial retreat and melting released large quantities of water and sediment, and contemporary with the incision of the River Derwent into its gorge, the run off utilized the phreatic cave systems. While under phreatic conditions the sediment-laden waters could flow slowly to any depth and rise again, but once melting was complete both sediment supply and hydraulic head would be cut off, so the caves would be abandoned and left as choked phreatic systems. During this phase there would be little opportunity for vadose modification as the time available with free-running streams to be corrasive would be very limited. The sources of the sediment were probably the adjacent Millstone Grit country, the till component of the glaciers, and probably periglacial loess sheets. (Stages 5 and 6 may have been repeated in successive glacial advances).

The apparent anomaly of the Derwent gorge being incised while the vadose streams were unable to remove the sedimentary fill from the caves can be explained if the greater part of that incision were done under periglacial frozen ground conditions, while the caves were frozen and inactive. Furthermore the incision would have the effect of stripping the marginal shale cover from the limestone flanks of Masson Hill so that with ice removal allogenic streams were no longer available to flow into the cave systems with resultant vadose modification.

Once drained, some of the caves not completely filled with sediment became the sites of speleothem deposition, with relatively few pendant stalactites but much flowstone flooring covering the sediments.

7. Limited post-glacial vadose drainage trenched through the sedimentary fills and through the stalagmite flooring in places to reveal sections of stalagmite/, laminated fill/ mineral accumulate, sometimes partly covered by fallen blocks from the roof.

Thus it can be shown that phreatic cave systems can evolve and be filled with sediments by a combination of local structure, mineralization providing initial pathways, fluvio-glacial outwash and rapid incision of a gorge to cause a rapid drop in base level.

Reference

Ford, T.D. et. al. 1977. *Limestones and caves of the Peak District.* Geo Books Ltd., Norwich.

CALCAREOUS CAVE PEARLS WITH GYPSUM NUCLEI: AN EXAMPLE OF DISSOLUTION – PRECIPITATION EQUILIBRIUM FOR THE SYSTEM CALCITE – GYPSUM

Paoli Forti
Istituto Italiano di
Speleologia
Via Zamboni
67-Bologna, Italy

Giancarlo Pasini
Istituto Italiano di
Speleologia and Laboratorio di Geologia
Marina del C.N.R., Via Zamboni
65-Bologna, Italy

During the exploration of the "Buca del Cacciatore" cave (Monte Corchia, Alpi Apuane, Lucca-Italia), more than one thousand of small cigar-shaped cave pearls were found in a splash cup.

All the cave pearls showed the same dimensions (4.6 mm in length and 0.5-1 mm in diameter (fig. 1).

A sample of these concretions was taken from the cave for laboratory analysis. In the present work these analyses are described and the conclusions from the experimental results discussed.

Observations made inside the cave

The cave pearls analyzed were found at a depth of 300 m in the "Buca del Cacciatore" cave, near the cross galleries named "Nodo dell'Om" (Badino, 1976).

The cave entrance is at 1640 m a.s.l. near the top of Monte Corchia. The cave, from its entrance to the "Nodo dell'Om" is in metamorphosed limestones (marbles) of the Lower Lias (Giglia & Paiotti, 1967).

The pearls were in an elliptic corrosion splash cup, in a large marble block, which had fallen from the ceiling of the gallery; the pool (20x15 cm) has a flat bottom and a depth of less than 2 cm and its water supply was a few drops per minute (at the time of the discovery, September 1976), splashing down from a height of 3 to 4 metres.

No concretions were inside the cup, but in a corner some pearls were found linked to each other and to the bottom by a thin film of calcite.

Experimental

A sample of the sediments collected from the cup and dried at 80°C consisted of over 90% of cave pearls, the remainder being fine sand ($\phi \simeq 1$ mm).

The petrographic composition of the sand (see table 1) was determined microscopically.

TABLE 1 – The sand composition

Minerals & Rocks	*Forms*	*Freq. of occurrence*	*Size (mm)*
Limestone	Rounded granules	Many	~1
Gypsum	Eroded acicular crystals	Many	0.1÷6

Mica	Chips	Rare	~ 1
Quartz	Rounded granules	Few	< 1
Pyrite	Oxided crystals	Few	~ 0.1

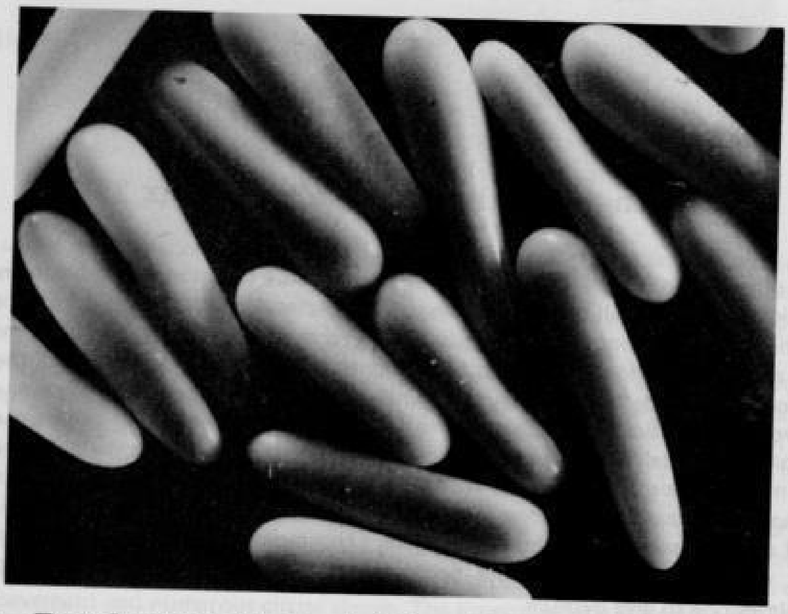
Some pearls were sectioned to expose their nuclei. All the pearls examined ($\simeq 50$) had the same type of nucleus, consisting of equi-dimensional macrocrystals, of gypsum with irregular rims (fig. 3).

Chemical and microscopic analyses showed that the nuclei consist of one or more gypsum crystals elongated along the z axis, which is also the long axis of the cave pearls.

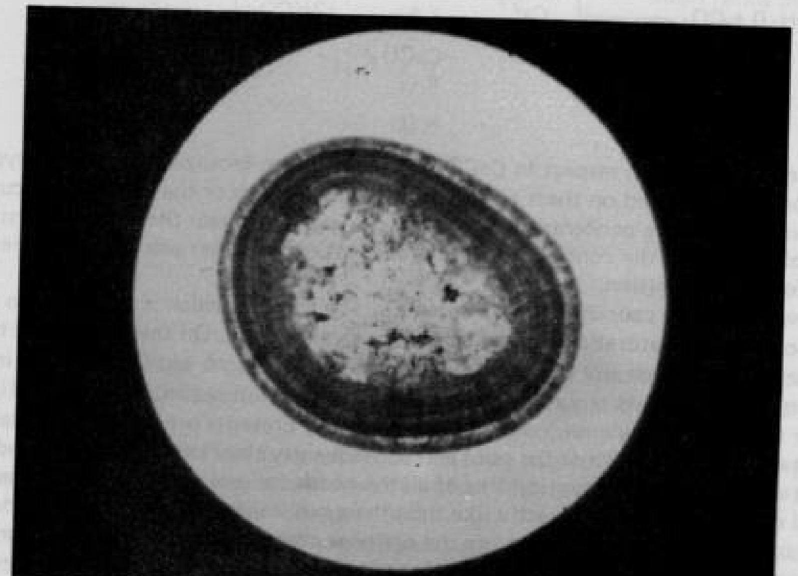
Longitudinal sections of the pearls (fig. 3) clearly show that the gypsum crystals in the nuclei are eroded and that they are very similar to those present in the sand (Tab. 1).

Discussion

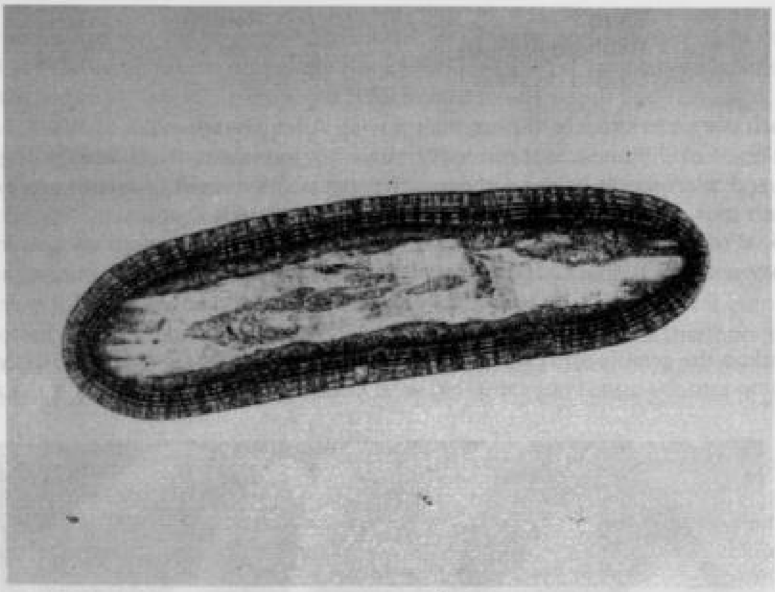
To understand the genesis of those pearls it is necessary to start from two important observations: (1) the water dripping into the cup is not saturated with $CaCO_3$; (2) all the pearls have the same gypsum nuclei.



1. Pearls from Buca del Cacciatore cave (x 10).



2. A section perpendicular to the long axis of a pearl (x 40).



3. Longitudinal section of a pearl (x 25).

The first observation is based on the fact that the pool is a typical corrosion cup and therefore has no calcite deposit inside or in the small drainage channel. The formation of the pearls cannot be ascribed to the usual supersaturation of the system with respect to $CaCO_3$, due to loss of CO_2, but has a more complex origin which the second observation allows us to specify. It cannot be pure coincidence that all the nuclei of the many pearls sectioned consist of eroded gypsum crystals, while there are many potential limestone nuclei present in the sand, which would theoretically be more efficient as precipitation nuclei. The presence of gypsum crystals inside the cup explains why calcium carbonate precipitation takes place only in the observed manner. Gypsum ($CaSO_4.2H_2O$) is much more soluble in water than calcite ($CaCO_3$) and the Ca^{2+} ion is common to both salts. The Mineralogic analysis shows the presence of pyrite (FeS_2) in the sand (see tab. 1); the limestone around this cave is carved contains some of this mineral (pyrite is common in the marbles of the Apuane (Artini, 1945). Percolating water, when in contact with pyrite, becomes rich in SO_4^{2-} ions (the solphur being oxidized), and then reacts with limestone to give gypsum.

It is likely that the gypsum crystals in the cup originate from gypsum flowers growing somewhere on the ceiling of the gallery.

Initially water splashing down carved the cup and caused many small pieces of gypsum crystals to collect inside the pool. The gypsum crystals partially dissolved, increasing the concentration of Ca^{2+} ions and thus depressing the solubility of $CaCO_3$ and causing it to precipitate. The reactions involved can be expressed as:

$$CaSO_4 \longrightarrow Ca^{2+} + SO_4^{2-}$$
$$CaCO_3 + H_2O + CO_2 \longrightarrow Ca^{2+} + 2HCO_3^-$$
$$\downarrow CaCO_3$$

This supersaturation with respect to $CaCO_3$ must have been localized around the gypsum crystals since $CaCO_3$ was only precipitated on these crystals and not on the rim or the floor of the cup. This can be explained if we consider that the concentration of Ca^{2+} ions is greatest near the gypsum crystals; even if there is diffusion of these ions, the continuous supply of unsaturated water would be sufficient to prevent total supersaturation of the solution.

Also the water supply causes a little turbulence inside the cup which is sufficient to disturb the smallest gypsum crystals, so that supersaturation cannot take place around them. On the other hand the same turbulence can only just move the largest acicular gypsum crystals (3÷5 mm in length and 0.3÷0.6 mm in diameter) which, owing to the supersaturation cloud around them, become precipitation nuclei.

Moreover the water turbulence inside the cup evidently prevents precipitation nuclei and growing pearls to remain static on the bottom of the pool and consequently they cannot be cemented to the floor.

The cigar shape and nearly identical size of all the pearls follows directly from those facts.

As stated earlier, some pearls exactly like the others but linked together by a thin dripstone film were found in a corner of the cup, which was far from the drainage channel and only some 2-3 mm deep. This can be explained because the supply of unsaturated water to this corner of the cup would be very small owing to its depth and distance from the point where the water splashes into the cup. For the same reasons the turbulence is less here than in other parts of the cup and therefore only the smallest gypsum crystals can be moved, the rest being still on the floor, and, owing to local conditions, cemented to the stone by calcite precipitation.

Conclusions

From the observation of calcareous cave pearls with gypsum nuclei in a cave and from mineralogical analysis in the laboratory it has been possible to show the existence of a local chemical equilibrium which must be common in gypsum caves but which is difficult to achieve and practically impossible to observe in limestone caves. In the present work only qualitative observations have been made because of the difficulty of making a large number of sophisticated measurements inside the cave.

References

Artini, 1945. *I Minerali*, 596 pp., Hoepli ed., Milano.

Badino, 1976. La prima punta al Fighiera — Grotte, bollettino del Gruppo *Speleologico Piemontese*, n. 59, Torino.

Giglia & Paiotti, 1967. Geologia dell'alta Versilia settentrionale — *Memorie della Soc. Geol. Ital.*, vol. 6, pp. 67-95, Pisa.

PRELIMINARY RESULTS ON THE TEXTURE OF LIMESTONE CLITTER

R. Frank
Department of Geography,
University of Newcastle upon Tyne,
Newcastle upon Tyne, England.

Clitter is a thin accumulation of loose rock fragments whose angle of rest is determined by the underlying material. The distinction between clitter and scree was made by Tinkler (1966) in a study of these materials in a limestone area of North Wales. The terms "shillow" and "shillet" have also been applied to similar accumulations of loose limestone rock fragments on limestone pavements (Sweeting, 1966).

The underlying distinction between clitter and scree has resulted in a lack of investigations on clitter by slope geomorphologists since the form of clitter slopes is not determined by the properties of the rock fragments as is the form of scree slopes. This preliminary report attempts to relate the texture of limestone clitter fragments to the bedrock stratigraphy and structure in the hope that this will help in future investigations of both clitter and scree slopes.

Initial field work has been done on the Whitbarrow fault block in southern Westmoreland. This is one of several easterly dipping blocks of Carboniferous limestone in northwest England most famous for their west-facing-fault scarps and associated scree slopes, but also having exposed limestone on the dip slopes with small areas of limestone pavement and numerous clitter slopes. The limestone strikes northsouth (353°) and dips easterly at 14°. It is well jointed, with thin lenticular bedding and contains stylolites.

On six clitter slopes the length, aspect and slope angle were measured. The three principal axes of 100 rock fragments, equally spaced along the length of maximum slope, were measured to ± 0.5 cm. From four of the slopes, the volume of every second rock fragment was measured to ± 1 cm^3 by water displacement. Table 1 gives data for the slopes and texture of the clitter fragments.

TABLE 1. Data from Whitbarrow clitter slopes. I/L = intermediate/long axes, S/I = short/intermediate axes.

Slope	*Aspect (°)*	*Minimum angle (°)*	*Length of slope (m)*	*Mean volume of 50 fragments (cm^3)*	*Mean ratios of 100 fragments* I/L	S/I
1	18	8	3	32.8	0.61	0.21
2	32	11	5	63.8	0.60	0.27
3	125	6	6	24.4	0.62	0.47
4	32	2	12	–	0.62	0.34
5	348	15	8	73.8	0.62	0.41
6	342	13	11	–	0.53	0.56

The mean volume of clitter fragments from each slope shows a close relationship to slope angle. According to Young (1972) this is also generally true for scree slopes and apparently relates to the size-selectivity of transport processes.

Mean values of the intermediate: long axes ratios (I/L) on each of the six slopes vary little from 0.6. These axes are determined by joint planes and the near constant ratio is probably a result of two major joint sets with an angle of intersection slightly greater than 60°.

The joint geometry was not measured in the field but the rhomboid shape of most of the rock fragments adds support to this suggestion. By contrast, mean values of the short: intermediate axes ratios (S/I) vary considerably and this reflects the lack of interdependency between joint spacing and the spacing of bedding planes, the short axis being determined by the latter. Mean particle shape for all six slopes is bladed according to Zingg's (1935) classification.

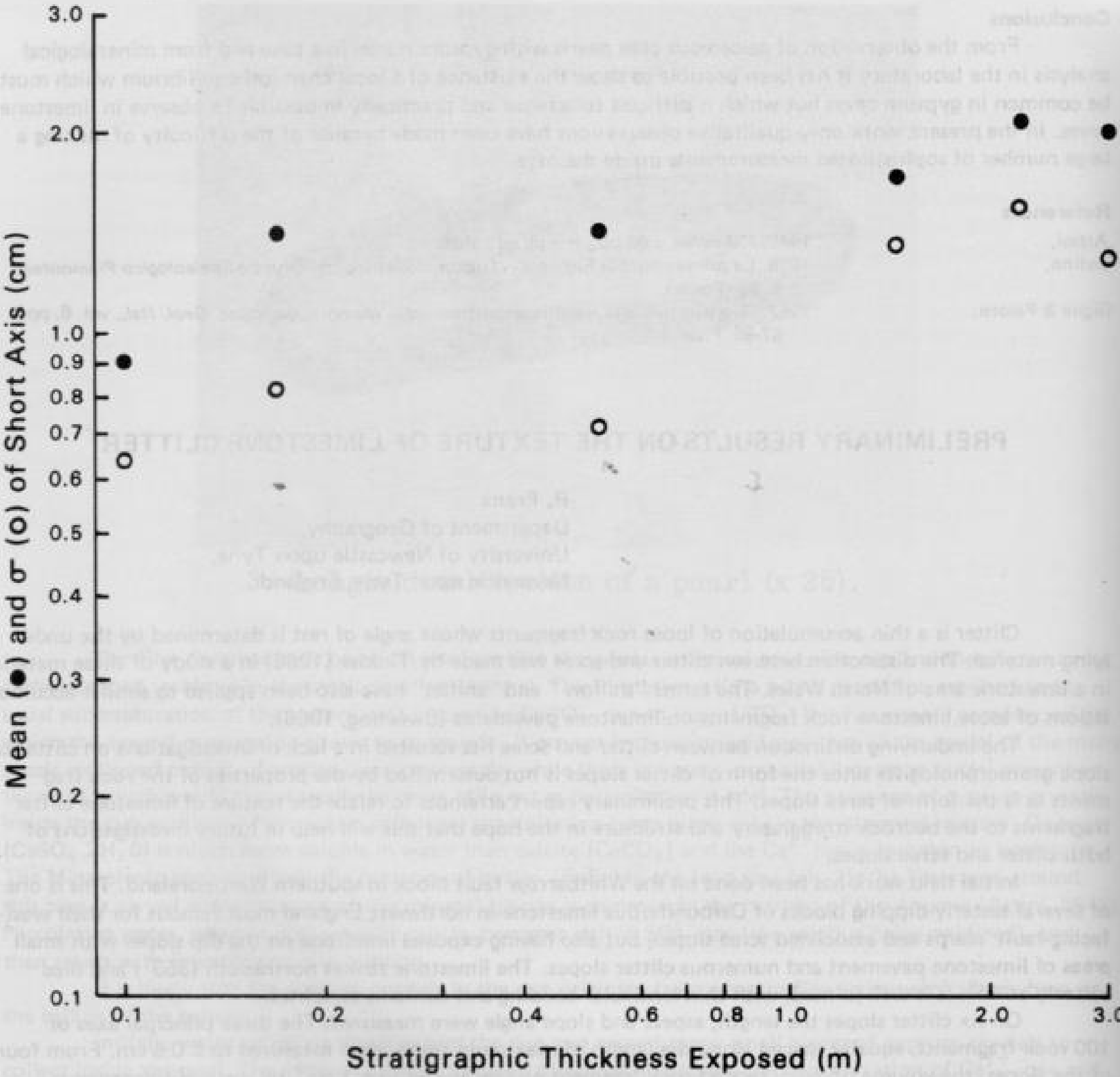


Figure 1

Whitbarrow clitter slopes. Means and standard deviations of 100 clitter fragments <u>vs</u>. stratigraphic thickness of bedrock exposed along the slope. Values for abscissa calculated as follows: Apparent dip of bedrock in direction of slope aspect read from standard alignment diagram for apparent dip. Then, E=L sin(S−A), where E=Stratigraphic exposure, L=Length of slope, S=Slope angle, A=Apparent dip of bedrock.

Mean values and standard deviations of the short axes both increase with stratigraphic thickness of the bedrock that has been exposed along the clitter slope. The log-log plot of this in figure I suggests a power-law relation but because of the small number of samples no regression line has been calculated. This relationship is a result of both bedding-plane control and joint control. As the stratigraphic exposure increases, more beds with different thicknesses are available for clitter fragments — hence the general increase in the standard deviation of the short axis. Also, as the angle between the bedding planes and the slope increases, more fragments will be produced which are two or more beds thick, since joint planes run through several beds — hence the general increase in mean size of the short axis.

References

Sweeting, M.M.	1966. The weathering of limestones, pp. 177-234, in G.H. Dury (ed.) *Essays in Geomorphology.* Heinemann, London.
Tinkler, K.J.	1966. Slope profiles and scree in the Eglwyseg Valley, North Wales. *Geog. Journal* 132: 379 - 385.
Young, A.	1972. *Slopes* Oliver and Boyd, Edinburgh.
Zingg, T.	1935. Beitrag zur Schotteranalyse. *Schweiz. miner. petr. Mitt.* 15: 39-140.

TOWARDS THE TERMINOLOGY OF THE POLJE

I. Gams
Ul. Pohorskega bat. 185
61000 Ljubljana, Yugoslavia

The existent karst geomorphological definitions (Monroe, 1970; Geze, 1973; Slovene karst terminology, 1973; Proposal for Multilingual Lexicon, 1973; Gavrilović, 1964; Roglić, 1974) contain not only the essential characteristics of the basins which are called poljes but also the typical features; however they do not mention the minimal extent of the basin or of the flat bottom and thus do not make it possible to classify large basins into blind valleys, karst valleys, poljes and dolines.

Here is an attempt to propose a more adequate definition of the polje based on an analysis of the 42 most prominent poljes of the Dinaric Karst, whence the name comes. In the Dinaric Karst a polje does not always occupy a very large basin. The polje of Imotski occupies 385 km^2 and the poljes of the R. Lika have 474 km^2 of flat bottom. Below the contour line of 700 m (altitude of the lowest pass Vratnik in Mt. Velebit) the basin of the Lika region occupies over 11 700 km^2. The 42 Dinaric poljes (nearly the same as Gams, 1969) have steep and relatively high slopes, rising sharply from the bottom on two sides on average. For other poljes in the Dinaric Karst the corresponding average is much lower. On the other hand, the sharp transition from polje bottom to the higher surroundings occurs in limestone only.

The only qualifications which uphold a critical analysis are the extensive (closed) basin, karst drainage and the flat bottom built of impermeable, semipermeable or permeable sediments; these are either in rocks or alluviated or covered by fluvisols which favour an intensive agricultural land use. The bottom may be dissected by Quaternary terraces (Gams, 1973a) triggering off special geomorphological processes; erosion and/or corrosion and denudation of impermeable sediments, border corrosion if the alluvium is impermeable and border and/or ground (alluvial) corrosion if alluvium is semipermeable, ground corrosion under the thick colluvial soils at the footslope, denudation on the slopes and caving above the sinks and ponor caves. These processes could be called polje processes and they contribute to the progressive lowering of the karst landscape.

The mere qualitative postulates such as large basin, flat bottom, sinking river, steep slopes rising sharply from bottom are not adequate for a classification of basins into blind valley, karst valley and great doline and even some cenotes in Latin America, since the meaning of "great depression" is subjective and related to other karst forms in the home karst region. Rather the features are typical for a smaller basin which is still called polje in practical work in the Dinaric Karst. Nevertheless, a minimal size of the flat bottom has to be defined; this was realised by the first author attempting to define the polje — Jovan Cvijić (1895, p. 113) according to whom a diameter of 1 km separates the polje from a doline. In the NW Dinaric Karst the width of 400 m of flat bottom (used for field, meadow and pasture) in a distinctive basin is minimal for a polje.

With regard to the practice in our country, the following definition of polje is proposed:

A polje is an extensive (closed) basin with a flat bottom, karstic drainage and steep slope, at least on one side. If the slopes are mostly steep, with a break at the transition to the bottom, and a sinking river, the flat bottom is 400 m wide at least.

The poljes can be classified from different aspects (Gams, 1973b):

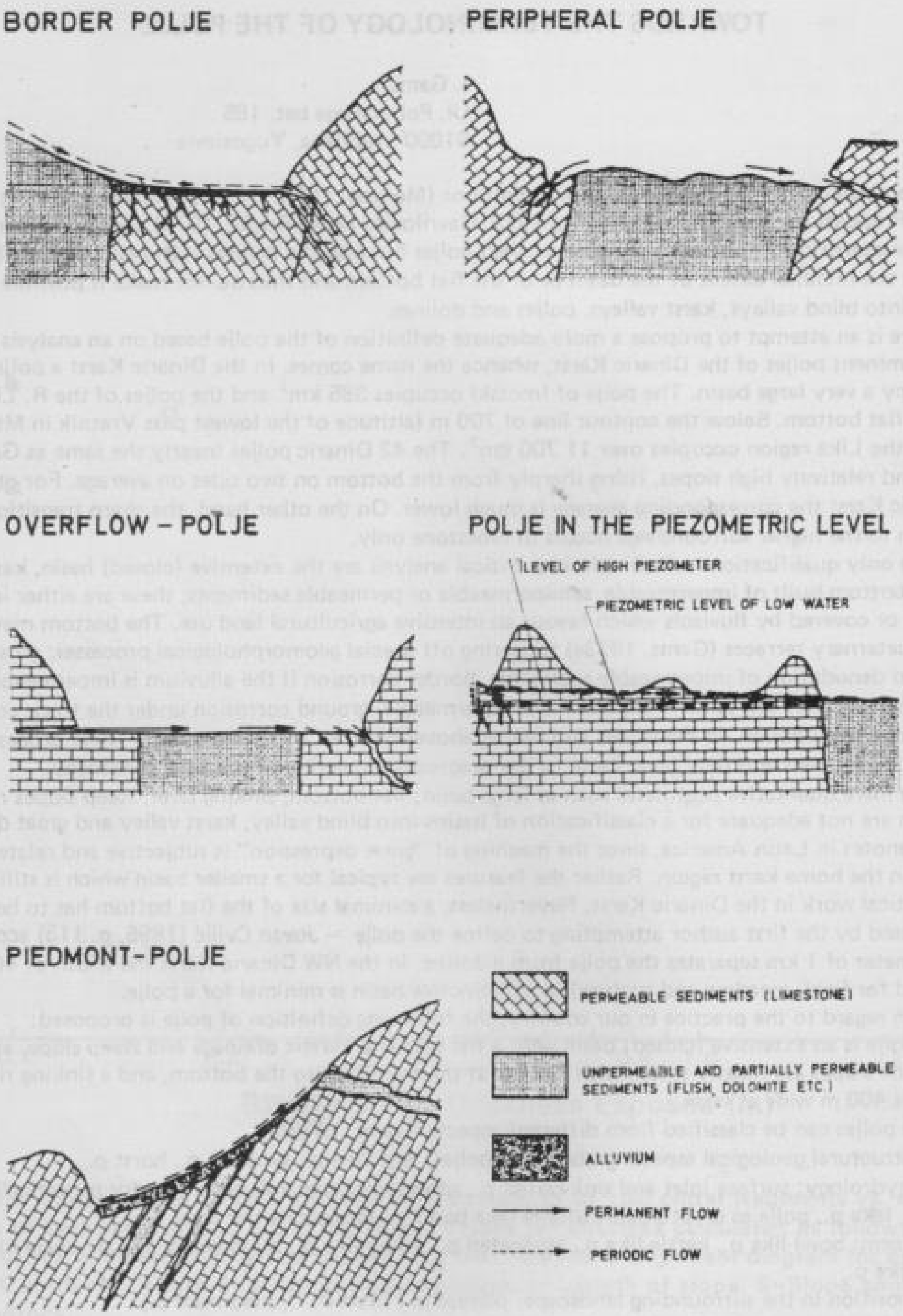
1. structural geological aspect: graben p. (=polje), anticline p., syncline p., horst p.,
2. hydrology: surface inlet and sink-outlet p., spring-inlet and sink-outlet p., dry p., periodically inundated p., lake p., polje as crypto-depressional lake basin, p. in piezometric level,
3. form: bowl-like p., kettle-like p., alongated p., valley-like p., blind valley like p., uvala like p., karst valley like p.,
4. position in the surrounding landscape: plateas p. ("Podi-P."), piedmont p.,
5. origin: tectonic p., tectonically preconditioned p., erosional p., corrosional p., poligenetic p.,
6. climatic viz. chorological aspect: mediterranean p., tropic p., subarctic p.,
7. Quaternary development: glacial p., periglacial p., glacifluvial p.,

The biggest poljes are usually heterogeneous as regards their genesis, hydrology and form in in their different parts.

The factor exercising the greatest influence on the hydrology, genesis and form is the kind, share and position of the impermeable sediments which hold the surface drainage. According to that, the poljes can be classified in the following comprehensive types:

1. Border polje (in sense of Lehmann, 1960). It is formed (or has remained) on the contact of permeable and impermeable rocks which drain off into the polje.
2. Overflow polje has a belt or the whole bottom built of impermeable or semipermeable sediments which act as a barrier for karstic water springing on one side and ponoring at the other side of the bottom.
3. Peripheral polje. Within the polje there is a large area of impermeable sediments which drain off centrifugally towards the bordering limestone and ponors. Rivers form in the impermeable sediments or in limestone blind valleys and plains which can be separated by terraces of hills.
4. Piedmont polje is situated at the footslope of a mountain, from whence eroded debris was deposited in the polje bottom. Impermeable interstrata favour the origin of a basin.
5. Polje in the piezometric level (Vorfluter p.). This is sustained by a river, lake, sea or by impermeable sediments surrounding it in the direction of karst outflow.

These types are represented in figure 1.



References

Cvijić, J. 1895. *Karst.* Geografska monografija, Beograd.

Gams, I. 1969. Some morphological characteristics of the Dinaric Karst. *Geogr. Journal,* Vol. 135, 4.

1973a. Die zweiphasige Quartäzeitliche Flächenbildung in den Poljen und Blindtälern des nordwestlichen Dinarischen Karstes. Neue Ergebnisse der Karstforschung in den Tropen und im Mittelmeerraum. Geographishe Zeitschrift, Blihafte. Wiesbaden.

1973b. The Terminology of the Types of poljes. *Slovenska kraška terminologija (Slovene Karst terminology).* Ljubljana.

Gavrilović, D. 1974. *Srpska kraška terminologija (Die serbische Karst-terminologie).* Beograd.

Geze, B. 1973. Lexique des termes francais de Spéléologie, T.28, 1.

Mehsprachiges Lexicon der Karst-und Höhlenkunde (Spelaologie). Entwurf, Red. A. Fink. Wien-Olomouc 1973, typed.

Lehmann, H. 1960, La terminologie classique de karst sous l'aspect critique de la morphologie climatique moderne. *Rèvue de Géographie de Lyon,* No. 1, XXXV.

Monroe, W. 1970. *A Glossary of Karst Terminology.* Geological Survey-Water Supply Paper 1899-K. Washington.

Roglić, J. 1974. *Prilog hrvatskoj krskoj terminologiji (A Contribution to Chroatian Karst Terminology).* Zagreb.

1973. Slovenska kraška terminologija (Slovene Karst Terminology). Ljubljana.

NEW METHODS IN PASSING KNOTS IN SPELEOLOGICAL ROPES

Mladen Garasic,
Nova Ves 73 a, Yu,
Zagreb, Yugoslavia
(translated by M.K. Lyon).

Recently, speleologists all over the world have been regularly exploring deeper and larger shafts. This means that there is a great need for special speleological equipment. Today, because of their lightness and great strength, ropes of special contraction are usually used in the exploration of shafts in place of the ropes used together with ladders previously. The ropes used:

a) Dynamic ropes, resistant to shock-loading (falls) with breaking loads in the range 1800 – 2500 kg. They are very elastic, with a stretch of 45-50%. Their main use has been for free and artificial climbing in caves and on mountains. The world-known firms producing these ropes are Edelweiss, Edelrid etc.
b) Static ropes are made specifically for caving, having little stretch when loaded, but also having poor resistance to shock-loading (falls). The stretch in these ropes amounts to 3%, the breaking load is from 2000 – 2500kg. World known firms are Bluewater, Mammat, etc.

In the exploration of deeper vertical shafts use of ropes of both constructions is *obligatory*. (The so-called double rope technique). Dynamic rope is used for descending, and static rope for ascending. During such

1. Transferring descender to below the knot; security provided by shunt on static rope.

exploration security is *doubled* by means of the two ropes, so that the possibility of accident is minimised. The length of the ropes is usually standardised (40, 50, 80, 120 and 200 metres), but one can also order specific lengths from the rope makers. However, the rope length available is often insufficient to bottom the shaft to be explored. In that case ropes are knotted together.

The knots themselves create a lot of trouble in descent and ascent, and a special technique is needed to pass them. Yugoslav speleologists (The Speleological Section of the Mountaineering Club of Zagreb University — called "Velebit") have improved this technique during numerous explorations of very deep vertical shafts, and my intention now is to present this technique to you. The deepest vertical system in Yugoslavia (sink-cave Bunovac — depth 445m., with the greatest vertical shaft — *280m.*, has been explored by means of this technique. (By speleologists from "Velebit").

Once this technique has been accepted it will no longer be impractical to explore shafts because the ropes available are individually too short.

In order to make the technique easier to understand the commonest examples are described stage by stage.

A. Passing over knots in descent.

a) Knot in the dynamic rope

1. — Stop the descent before the descender comes to the knot (30 cm min.)
2. — Lock the descender off, attach gibbs via the chest harness, put bloqueur with foot-stirrup on the rope.
3. — Hanging on gibbs, stirrup and shunt, transfer descender to below knot (photo 1).
4. — Lock descender under knot, pull shunt which is braked.

2. Ascending: G = Gibbs; S = Shunt; K = Knot.

5. – Continue descent (shunt serves as safety measure)

b) Knot in the static rope

1. – Stop by means of the descender so that the shunt is a minimum of 20 cm above the knot.
2. – Lock descender, attach gibbs via the chest harness, put bloqueur on the static rope above the knot.
3. – Put shunt under knot, take off gibbs.
4. – Continue descent (shunt serves as safety measure)

B. Passing over knots in ascent.

a) Knot in the dynamic rope

1. – Ascend until the shunt is under the knot.
2. – attach the bloqueur above the knot, via the chest harness.
3. – attach the shunt above the bloqueur.
4. – remove the bloqueur and continue ascending.

b) Knot on the static rope (photo 2)

1. – ascend until the upper gibbs is about 10cm below the knot.
2. – transfer the upper gibbs to above the knot (safety provided by gibbs or shunt).
3. – transfer the second gibbs to above the knot (safety as before).
4. – transfer the last gibbs to above the knot and continue ascending.

Equipment for passing knots in the rope:

a) for descent:	"Petzl" descender "Petzl" bloqueur "Petzl" shunt "Gibbs" ascender-quick release model stirrup (foot-loop) "Troll" body harness.
b) for ascent:	3 "Gibbs" ascenders "Petzl" shunt "Petzl" bloqueur "Troll" body harness.

NB. The exploration of verticals greater than 250m. is not recommended because of the great stretch in the dynamic rope. Knots on the rope can be passed with less equipment, but this removes the double-security needed by the speleologist.

TRACE ELEMENT GEOCHEMISTRY OF SPELEOTHEMS

M. Gascoyne, Department of Geology,
McMaster University, Hamilton, Ontario, Canada

Few detailed analyses of trace element content of speleothems are reported in the literature. Table 1 summarizes much of this previous work. It can be seen that light coloured speleothems are generally low in trace element content but opaque black and yellow-green colorations have been found to be due to large quantities of Mn/Fe and Ni respectively. Differences in crystal texture (i.e. single crystal versus multicrystalline growths) may also lead to colour changes.

The results described below are of a preliminary nature and a number of refinements to analytical techniques have since been made. Future work should therefore improve both precision and accuracy of results. Additional work (not presented here) on the partition of trace elements between calcite and aqueous phases has been undertaken in conjunction with this study, as part of a general project to identify trade elements that may be used as paleotemperature indicators.

Results

Trace element content in calcite has been determined for Mg, Sr, Fe, Mn, Pb, Zn and Cu by Perkin Elmer 303 Atomic Absorption Spectrophotometer. Mixed element standards, buffered by 2,000 ppm NaCL and 2,500 ppm Ca^{2+} were used against calcite samples dissolved in 5N HCL.

Analytical results for 24 speleothem samples are presented in Table 2. Errors quoted are based on re-determinations of some solutions during the course of analysis and on certain interfering effects. In many cases, they are probably overstated.

TABLE I. Previous work on trace element geochemistry of speleothems

Author(s)	*Cave*	*Location*	*Elements Determined*	*Results*
White and Dunn (1962)	Princess Alice Cave (Coffee River Cave)	Jamaica	Mn, Mg, Fe, Al, Ti, Si.	i) white speleothems — low Mn, Fe, (0.01%) ii) black stalactite — 3% Mn, 0.3% Fe. iii) black wall deposit — 10% Mn, $>$30% Fe.
White and van Gundy (1974)	Timpanogos Cave	Utah	Mg, Sr, Ti, Mn, Ni, Fe, Si, Al.	i) calcite crystals and flowstone + calcite/arag. stalactite Mn (5-20ppm) Ni (100-300 ppm) Fe (20-100ppm) Si (400-800ppm) Al (25-200 ppm) ii) yellow calcite flowstone Mn (20-40ppm) Ti (70-100ppm) Fe, Ni (400-600ppm) Si, Al ($>$1000ppm) iii) green aragonite coating Ni (400-600ppm)
Beck (1976)	Natural Bridge Caverns Byers' Cave	Texas Georgia	Fe, Cu, Zn, Co, Pb, Mn.	Two 'fried' egg samples, both yellow in centre, white at edges. No significant T.E. variation seen — colours attributed to crystallographic properties.
Holland et al. (1964)	Luray Caverns	Virginia	Sr.	i) 100% calcite stalactites and pool encrustations $20 < Sr < 55$ppm ii) mixed calcite aragonite stalactites $50 < Sr < 250$ppm iii) 100% aragonite pool crust $340 < Sr < 360$ppm
Harmon (1975)	Cold Water Cave Crystal Cave	Iowa Bermuda	Mg, Fe, Zn, Sr, Mg, Cu.	Zn 2-66ppm Mn 0-12ppm Sr 70-110ppm (I) 200-320ppm (B) Mg 3000-3700ppm (I) 1400-3000ppm (B) Fe 40-280ppm (I) 0.3-4ppm (B) Cu 0.5-1.5ppm (I) Intercorrelations of T.E.'s was seen but no correlation found between any T.E. and 0-18 content.

TABLE 2. Analytical results of trace element determination of coloured speleothem samples from different locations.

Location	*Sample No.*	*Colour*	*Mg*	*Fe*	*Pb*	*Zn*	*Sr*	*Cu*	*Mn*
			in parts per million						
N.W.T. (Canada)	73051	black-brown	2280	7.5	60	36	396	1.7	1.5
	75031	yellow-brown	305	22	77	15	416	2.6	2.7
	73056	white	1664	2.4	34	4670	46	1.0	1.1
	72034	yellow-green	1562	3.9	101	4536	176	1.1	43
Canadian Rockies	69001	black-brown	3733	16	43	76	505	2.5	2.5
	68002	clear, red-brown	3804	5.4	81	38	27	1.5	1.5
	70001	black-brown	4265	11	54	12	71	1.9	2.0
	72025	clear pale brown	496	2.3	70	16	125	1.2	1.0
Vancouver Island	VM1A	white-yellow	203	56	45	16	28	3.4	6.8
	75127	red-brown	1021	5.1	68	12	28	1.8	1.7
	75100	clear + orange	372	4.0	62	10	24	1.3	1.3
	VM1X	white-yellow	213	81	121	13	33	3.7	7.8
	VE2A	white	166	71	125	74	65	6.5	10.2
	VE3A	white	164	61	53	18	46	139	6.7
	VC6A	white	490	12	33	11	38	3.0	3.0
Kentucky	74012	clear brown	6243	13	62	132	936	1.6	1.7

TABLE 2 cont'd

Location	*Sample No.*	*Colour*	*Mg*	*Fe*	*Pb*	*Zn*	*Sr*	*Cu*	*Mn*
					in parts per million				
Bermuda	73021	brown	990	27	42	6.9	548	3.6	3.1
	BDA1	clear yellow	2637	5.8	65	10	55	1.8	1.6
Jamaica	J11A	pale orange	1799	14	37	14	9.2	3.2	3.1
	J10A	white	3683	9.8	103	8.8	21	2.0	2.1
	J9	white	8275	16	73	11	54	14	3.5
	J8B	white	163	7.5	72	12	543	7.7	N.D.
	J12B	white	913	14	47	11	37	4.4	3.6
	J3A	white	1057	24	77	22	22	12	4.5
Estimated Analytical Error			± 10%	20%	20%	20%	20%	10%	10%

Discussion

Mean annual temperature of each location approximately increases with descending order in Table 1. There appears to be no significant correlation of temperature with any of the trace elements. Of note are:

(i) two samples from N.W.T. containing very high Zn levels

(ii) high Sr levels for some calcites from N.W.T. and the Canadian Rockies (these are unlikely to be aragonitic samples since their Mg content is high). Sr and Mg content appear to be largely a function of local geology.

(iii) sample J8B was found to be aragonite by X-ray diffraction analysis and this is reflected in the high Sr and low Mg concentrations.

(iv) apparently anomalous results such as high Cu in VE3A and high Mn of 72034 cannot be readily explained. Genuine local variations may exist or contamination may be the cause.

(v) there is no obvious relation between colour and trace element content. Frequently the white samples of Vancouver Island have Fe and Mn levels equal to or in excess of those of dark speleothems from the Rockies or N.W.T.

The cause of the deep coloration of these latter samples is probably the presence of organics (humic and fulvic acids) trapped in the calcite lattice. Evidence for this was seen during the dissolution of these samples in hydrochloric acid; an extremely thick froth was formed by the effervescence.

The froth was very similar in appearance to that seen on peaty, moorland streambeds after a flood, or associated with sumps in caves. How the organics become incorporated in the speleothem is not easy to answer since at first sight there is little chemical compatibility between inorganic species in solution (HCO_3, Ca^{2+}) and largely unionized, high molecular weight organic molecules. One explanation may be that they are moderately soluble if complex with Ca^{2+} ions (humic acid is quite soluble in weakly alkaline solutions). An alternative explanation may rest in the nature of many of these caves; very slow drip-rates and good ventilation cause the speleothem to form largely by evaporation. Incorporation of organics would then be inevitable. Humate layers have been observed in parts of Mammoth Cave, Kentucky, where they coat small areas of cave ceiling (Quinlan 1967). Previous analysis of sample 69001 by Optical Emission Spectrographic Analysis has been reported as showing the presence of Fe, Mn etc. and the brown coloration has been attributed to these elements (Harmon 1973). The results from the present study negate this work, and are more comparable to those of Beck (1976), who also could not attribute differences in coloration to trace element content.

A high error margin has been quoted in the analytical results owing to the somewhat variable Ca^{2+} concentration of the samples relative to the standards, thus causing variable interference with certain elements (e.g. Sr, Zn). Broad molecular absorption bands of $Ca(OH)_2$ at these wavelengths are dependent on Ca concentration in solution and so affect each sample differently. These results should therefore be considered as preliminary and somewhat qualitative in nature. Accurate standardization of all Ca- containing solutions will be done in all future work.

Conclusions

No direct correlation has been found between speleothem colour and trace element content; instead it is felt that organics and possibly optical properties of the calcite may often control speleothem colour.

References

Beck, B.F. 1976. "The Cause of Colour Differentiation in "Fried" egg Stalagmites", *N.S.S. Convention* (Morgantown W.Va) Abstracts.

Harmon, R.S. 1973. Chemical composition of cave calcites, *N.S.S. Convention*, (Bloomington Ind.) Abstracts.

Harmon, R.S. 1975. Late Pleistocene Paleoclimates in North America as inferred from Isotopic Variations in Speleothems. Unpub. Ph.D. thesis, Department of Geology, McMaster University, Hamilton, Ontario.
Holland, H.D. et.al. 1964. On some Aspects of the Chemical Evolution of Cave Waters, *Jnl. Geology, 72,* 36-67.
Quinlan, J.F. Traverse, A. 1967. Humic acid and humate deposits in Salts Cave and Mammoth Cave, Kentucky, *N.S.S. Bull. Abstracts 29* (3).

DOES THE PRESENCE OF STALAGMITES REALLY INDICATE WARM PERIODS? NEW EVIDENCE FROM YORKSHIRE AND CANADIAN CAVES

M. Gascoyne. Department of Geology,
McMaster University, Hamilton, Ontario.

Two opposing arguments have been cited by previous workers to relate the presence of stalagmite deposits to past climatic conditions. One view is that most speleothem deposition took place during cold periods when erosional activity by streams and sediments was at a minimum (Waltham, 1974). Alternatively, stalagmite deposition should occur most rapidly during interglacial maxima, as evidenced by abundant modern growths. Two reasons to support the latter can be cited (Thompson et. al., 1974):

i) glacial or periglacial conditions would either reduce or stop groundwater movement due to plugging of inputs by debris or freezing of water.
ii) a certain amount of biological activity in the soil zone is required to produce CO_2 to propagate the $CaCO_3$ solution-deposition cycle in forming speleothem.

Until the advent of radiometric dating of cave deposits and additional paleotemperature data gained by stable isotope analysis of these deposits, it has been difficult to resolve the problems.

Stable isotope measurements can be used in two ways to give paleoclimatic data. Firstly, oxygen isotope changes in speleothem calcite can be used as a general indicator of climate change since ^{18}O content in the calcium carbonate is inversely related to temperature. However, since the calcite is precipitated from water then the ^{18}O content is ultimately moderated by that of the water itself, so that any change in the water composition may mask the temperature effect. Secondly if both ^{18}O of the calcite and water are determined then the fractionation of ^{18}O is related directly to the temperature of deposition. For fossil speleothems however, only the water trapped in micro-inclusions in the calcite is still present, and these must be extracted and analysed before the ^{18}O fractionation can be determined (Schwarcz et. al., 1976).

Speleothem results herein are from two glaciated regions: Yorkshire (England) and Vancouver Island (Canada).

Results

a) Vancouver Island

Speleothem has been successfully dated from two caves on the Island; other samples collected suffer from extremely low concentrations of uranium. The date is shown in Table 1(a). All samples have been dated by the $^{230}Th/^{234}U$ method (Thompson, 1973). The caves themselves appear to be fairly recent in age as they are often small and in most cases active. A complex sediment infill sequence in one cave (Euclataws) suggests that this cave was fully-formed prior to the last ice age.

b) Yorkshire

A number of stalagmites and flowstones (usually already broken) were collected from important caves in the Craven area of Yorkshire during the summer of 1976. At the time of writing, only a few results have been obtained but high uranium concentrations (Table 1(b)) make the samples studied, eminently suitable for age dating and many more results should be available soon. Cross-checking of ages by the $^{231}Ps/^{230}Th$ dating method (Thompson, 1973) is feasible for the samples especially high in uranium. Although of a preliminary nature the dates obtained lie within known warm events, especially the ages 100-120,000 years B.P. (the Last Interglacial, or Ipswichian stage).

TABLE 1 (a) Summary of radiometric ages obtained for speleothems from the caves in Vancouver Island, Canada.

Sample No.	*Cave*	*Height above base (cms).*	*Uranium conc. (ppm)*	*Th/U age ($x10^3$ yrs).*	*Description*
76002-1	Euclataws	0	0.01	42 ± 10	Piece of flowstone on fallen block, not in growth position.
75123-1	Cascade	0-0.5	0.15	55.5 ± 3	Base layer of fallen stalagmite
75123-2A	"	6-9	0.09	47.0 ± 4	Top " " "
75125-3	"	3-5	0.25	33.8 ± 3	Top of in situ stalagmite/flowstone
75125-4	"	1-3	0.39	44.1 ± 10	Middle " " "
75125-6	"	0-1	0.15	50.3 ± 5	Base " " "
75125-7	"	1-2	0.14	42.4 ± 2	Lower middle " "

TABLE 1(a) cont'd

Sample No.	*Cave*	*Height above base (cms)*	*Uranium conc. (ppm)*	*Th/U age ($x10^3$ yrs)*	*Description*
75125-8	Cascade	3-5	0.20	32.8 ± 2	Top of in situ stalagmite/flowstone
76013C-1	"	—	0.11	53.2 ± 6	Sub-base layer " " " (separated from 75125 by 10cms sediment)
75126-1	"	0-3	0.09	11.3 ± 1	Base of fallen stalagmite.
75126-2	"	15-20	0.07	12.5 ± 2	Top " " "
75127-1	"	0-2	0.11	15.5 ± 3	Base of small modern stalagmite
75127-2	"	2-4	0.09	16.9 ± 3	Lower middle " "
76008-1	"	?	0.08	57.9 ± 4	One end of fallen flowstone (orientation uncertain)
76010-2	"	?	0.07	59.0 ± 5	Other end (?) of similar fallen flowstone slab to 76008.
76011-1	"	0-1	0.08	57.7 ± 5	Base of a brown flowstone block

TABLE 1(b) Summary of radiometric ages obtained for speleothems from caves in the Craven district, Yorkshire, England.

76208-1	Gaping Gill	—	0.42	1.9 ± 0.2	Top layer of flowstone base of broken (presumably once-active) stalagmite from Stalactite Chamber, Sand Cavern
76121-1	Lancaster Hole	19-22	2.40	117*	Top of loose stalagmite from Bill Taylors Passage.
76121-2	"	0-4	1.50	120*	Base of same.
76125-1	"	0-0.5	1.98	37*	Base of short stalagmite from Bill Taylors Passage

* These results are preliminary hand-calculated ages (likely error ± 5%).

Discussion

Most speleothem ages quoted in this paper correspond to warm periods occurring during the last 120,000 years, themselves determined from deep-sea core, polar ice core and pollen data etc. The position of the last interglacial maximum however, has not been exactly determined by these methods and two schools of thought exist at present. The age of a temperature maximum at 95,000 years B.P., proposed by Emiliani (1971) has been offset to 120-125,000 years B.P. by Bröecker and Ku (1969). Speleothem results from North America have placed this maximum at 105,000 years B.P. (Harmon, 1975). It is hoped that new data from English samples will help to resolve this problem. In spite of these differences it nevertheless seems that speleothem grows most intensely during warm events, being largely a function of biological activity in the soil zone and unrestricted groundwater percolation. Increased temperatures also greatly increase the kinetics of reaction, and hence rate of deposition.

In contrast to these theories is the observation that speleothem is actively growing in Castleguard Cave, Alberta, under a thick, permanent ice sheet. Temperature within the cave is +3.6°C (maximum) and growth seems to occur all year round. Geothermal heat and the insulating effect of the ice cover have been cited as reasons for the high temperatures(Ford et. al., 1976). Until now, no satisfactory explanation of the source of CO_2 has been given since the area is devoid of organic matter. The explanation voiced here is that CO_2 solubility in ice is substantially greater than N_2 and 0_2 of air due to formation of a CO_2 — ice clathrate ('cage') compound. The gas is subsequently released when the ice melts and $CaCO_3$ dissolved as water (rich in CO_2 relative to the atmosphere) enters the limestone.

One aspect of these observations is that the temperature reflected by $^{18}0$ measurements on speleothem calcite and its fluid inclusions is not equal to the mean annual surface temperature (originally a prerequisite to all speleothem paleotemperature work — Duplessy et al., 1970, Harmon, 1975). Hence the argument of speleothem growth during glacial events becomes important, especially when the cave is overlain by sufficient depth of bedrock.

Conclusions

In general, stalagmite deposits are indicators of warm events in the paleoclimate record. However, present-day growth of speleothem in caves in a glacial environment serves as a warning that paleotemperature data may not directly reflect the true surface conditions.

References

Broecker, W.S., Ku. T.L. 1969, Caribbean cores P6304-8 and P6304-9; new analysis of absolute chronology. *Science, 166,* 404-6.

Duplessy, J.C. et. al. 1970, Continental climatic variations between 130,000 and 90,000 years *B.P. Nature 226,* 631-2.

Emiliani, C. 1971, The last interglacial, paleotemperatures and chronology. *Science 171,* 571-3.

Ford, D.C. et. al. 1976, Geohydrologic and thermometric observations in the vicinity of the Columbia Icefield, Alberta and B.C., Canada. *Jnl. of Glaciology 16,* (74) 219-230.

Harmon, R.S. 1975, Late Pleistocene paleotemperatures in North America as inferred from isotopic variations in speleothems. Unpub. Ph.D. thesis, Department of Geology, McMaster University, Hamilton, Ont.

Schwarcz, H.P. et. al. 1976, Stable isotope studies of fluid inclusions in speleothems and their paleoclimatic significance, *Geochim Cosmochim Acta 40*, 657-665.

Thompson, P. 1973, Speleochronology and Late Pleistocene climates. Unpub. Ph.D. Thesis, Department of Geology, McMaster University, Hamilton, Ontario.

et. al 1974, Continental Pleistocene climatic variations from speleothem age and isotopic data. *Science 184*, 893-5.

Waltham, A.C. 1974, "Limestones and Caves of North-West England", ed. Waltham, pub. David and Charles Newton Abbot., 477pp.

PALEOCLIMATIC SIGNIFICANCE OF SUBMERGED SPELEOTHEMS

M. Gascoyne, Department of Geology, McMaster University, Hamilton, Ontario, Canada.

G.J. Benjamin, Benjamin Film Laboratories, 247 Richmond St. E., Toronto, Ontario, Canada.

The classic 'Blue Holes' of Caribbean Islands have been known for many centuries, the ones off the north coast of Jamaica, British Honduras, Florida and the Bahamas being among the best known. More recently with the advent of theories of glaciation, Blue Holes became recognised as presently-flooded cave and pothole systems exactly similar to those found on dry land. They had been formed by normal sub-aerial weathering processes when sea-level fell due to ice accumulation on the continents. Recently a Blue Hole at least 140m deep has been found about 40 km off the Florida coast and dye-dispersion tests have shown there to be a slight inflow of seawater to the hole, possibly representing a point of seawater intrusion in to the Floridan aquifer (Kohout et. al., 1975).

It was not until 1970 however, that conclusive proof was obtained of the sub-aerial nature of these systems. A team of divers led by one of us, Benjamin, explored a horizontal passage leading off from the bottom of a 60m deep shaft near Andros Island and after about 400 m of rift passageway a large chamber was found, festooned with stalagmites and stalactites (Benjamin, 1970, McKenney, 1972). Since this time many other systems containing speleothem have been found and unfortunately damage to the caves by frequent visitors has occurred. Recently parts of some broken columns were retrieved for radiometric dating. Human bones and artifacts dated from 7,200 to 10,300 years B.P. have been found in submerged caves off Florida at 6 to 12 m below present sea level (Kohout et. al., 1972).

Previous work on sea-level fluctuations during the Late Pleistocene have concentrated on dating warm events when sea-level has been at a maximum. Fossil reef terraces, at present above sea-level, have been exhumed from their growth position by tectonic uplift. Dating by uranium disequilibrium methods ($^{234}U/^{238}U$, $^{230}Th/^{234}U$ and $^{231}Pa/^{235}U$) has determined periods of high sea-stand and given a measure of change in sea-level between climatic events. Studies of this type on reef terraces in Barbados (Mesolella et. al., 1969) and New Guinea (Bloom et. al., 1974) have shown that sea-level may change more than 120 m between a full glacial and interglacial event. The Bahamas are less suited to these studies since tectonic movement is known to be slight (about 0.3 m subsidence per 10,000 years).

Little work has ever been done on low sea-stands since most of the evidence is at present submerged. However, a single stalagmite recovered from a depth of about 12 m from a submerged cave has been dated at 21,900 ± 600 years B.P. (by ^{14}C) and 22,000 ± 350 years B.P. (by Th/U), (Spalding and Mathews, 1972). This age agrees well with other evidence indicating a glacial maximum (Late Wisconsin) between 15,000 and 20,000 years B.P. Six stalagmites submerged to depths of up to 11.5 m have been dated by Harmon (1975) and show growth periods of 195-160,000; 130-100,000 and 37-17,000 years B.P.

In this paper are presented results of dating a speleothem recovered from depths substantially greater than in previous work and a further three other samples are presently being analysed.

Results

The sample described here and two of the other samples under investigation came from 'Cave No. 4' of the Andros Island Blue Holes, recorded and mapped by one of us (Benjamin). It was recovered from a depth of approximately 45 m. The speleothem, 0.3 m long, was heavily encrusted by algal secretions and tests of boring organisms and of the average diameter of 10 cm, only 1 to 3 cms of the original pure calcite remained in the centre.

Two portions of this sample were dated at 130,200 ± 8,300 and 159,500 ± 16,800 years B.P. Uranium concentrations were 0.4 and 0.3 ppm and $^{234}U/^{238}U$ ratios were 0.998 and 0.960 respectively – significantly different to marine carbonates (between 1,000 and 1,150). Unless the speleothem is a stalactite (which is unlikely) the ages are inverted for normal stratigraphic layering of a stalagmite. This may be due to incorporation of some of the outer 'crust' when attempting to chip out the calcite. Results of dating the other samples will be available shortly and given orally.

Discussion

The ages obtained above are in good agreement with data from deep-sea cores, continental speleothems and reef terraces and place a minimum age for the development of the Blue Holes around the Illinoian (Riss) glaciation. The presence of speleothem at over 50m depth indicates a sea-level lowering of at least this amount to give vadose conditions in the caves. Future work on the speleothem will include a stable isotope profile of

the calcite, although the purity and clarity of the calcite is an indication of the absence of sufficient fluid inclusions for determination of absolute temperatures of deposition.

Conclusions

Previous work and evidence from this study have shown the importance of presently-submerged speleothem in defining periods of low sea-stand due to ice accumulation on the continents during glacial events. Results presented here verify data from Pleistocene reef terraces suggesting large-scale change in sea-level from glacial to interglacial maxima. One of the goals of future exploration will be to try and find speleothem from greater depths, to determine whether the Blue Holes were ever completely vadose.

References

Benjamin, G.J. 1970 Diving into the Blue Holes of the Bahamas, *National Geographic, 138*, 347-363.

Bloom, A.L. et al. 1974. Quaternary sea-level fluctuations on a tectonic coast: New 230Th/234U dates from the Huon Peninsula, New Guinea, *Quat. Res. 4*, 185-205.

Harmon, R.S. 1975. Late Pleistocene paleoclimates in North America as inferred from isotopic variations in speleothems. Unpub. Ph.D. thesis, Geology Dept., McMaster University, Hamilton, Ontario.

Kohout, F.A. et. al. 1972, Ocean-groundwater interface: sinkholes, Blue Holes and submarine springs — geologic windows in the Florida-Bahama platform. *Geol. Soc. of America*, Abs. of Ann. Meetings, Minneapolis.

1975, Red Snapper sink and groundwater flow, offshore northeastern Florida, *Abs. from 12th Int. Congress of the International Assoc. of Hydrogeologists*, Huntsville, Alabama.

McKenney, J. 1972, Diving in the World's largest underwater cave, *Skin Diver 21*, 42-49.

Mesolella, K.J. et. al. 1969, The astronomical theory of climate change: *Barbados data. Jnl. of Geology 77*, 250-274.

Spalding, R.F., Mathews, T.D. 1972, Stalagmites from caves in the Bahamas; Indicators of low sea-level stand. *Quat. Res. 2*, 470-472.

GENETIC TYPES OF CAVES IN THE SAHARA

Dusan Gavrilovic
Belgrade Sv. Markovica 28
Yugoslavia

In the Sahara, one of the most arid regions on the Earth, there have been registered all karst forms — from karren and sinkholes to poljas. However, little is known about the karst and the caves, which is understandable considering the size of this desert region and difficult conditions of work there. Pure limestone rocks have small extent and karst forms occur most frequently in Tertiary sandy and argillaceous limestones and in carbonate sandstones and marls. The caves are met with both in carbonate and in non-carbonate rocks. The caves are most numerous in silicate and carbonate sandstones but they occur also in different kinds of magmatic rocks. It is obvious that the processes of speleogenesis do not have the same characters everywhere.

In dependence upon the lithologic composition of terrains and upon the prevailing geomorphological processes there have been distinguished three fundamental types of caves: in carbonate rocks, in silicate sandstones and the magmatic rocks. The caves in carbonate rocks have been created by mechanical erosion and corrosion of subterranean streams during the young Quaternary pluvial periods. The caves in silicate sandstones have been created by salt disintegration of rocks and by mechanical erosion of water at the end of the Tertiary and in the beginning of the Quaternary. The caves in magmatic rocks are conditioned by special structural-lithological circumstances which make possible further action of individual geomorphological agents. Except for primary caves, most of them were formed during the last pluvial periods of Quaternary.

CAVE DEPOSITS AT KOZI GRZBIET (HOLY CROSS MTS, CENTRAL POLAND) WITH VERTEBRATE AND SNAIL FAUNAS OF THE MINDELIAN I/MINDELIAN II INTERGLACIAL AND THEIR STRATIGRAPHIC CORRELATIONS

Jerzy Glazek & Leszek Lindner
Institute of Geology,
Warsaw University
Al. Zwirki i Wigury 93
02-089 Warszawa, Poland

Kazimierz Kowalski, Marian Mlynarski & Ewa Stworzewicz, Institute of Systematic and Experimental Zoology, Polish Academy of Sciences, Ul. Slawkowska 17,
31-016 Krakow, Poland.

Piotr Tucholka
Institute of Geophysics
Polish Academy of Sciences
Ul. Zielna 37,
00-108 Warszawa, Poland

Tadeusz Wysoczanski-Minkowicz
Institute of Geology,
Polish Academy of Sciences
Al. Zwirki i Wigury 93
02-089 Warszawa, Poland.

A very rich fauna in karst deposits was discovered in 1970 at Kozi Grzbiet Hill (20°22'13" long.E, 50°51'16" lat. N) in the south-western part of the Holy Cross Mts (Fig. 1). The first results of the investigations there were reported by Glazek et al. (1976) and supplemented by Rzebik-Kowalska (1976) and Mlynarski (1977).

Geological setting

The Holy Cross Mts, as a distinct geological unit, are the result of post-Cretaceous movements. Since the Laramian rise of the Holy Cross Anticlinorium denudational processes have removed c. 3 km thick Mesozoic cover, consequently Palaeozoic deposits come to the surface in their axial part. The Laramian rising was largely compensated by profound weathering and erosion, thus this region has never been a high mountain chain (Kutek & Glazek 1972).

The existing variability of karst forms here have been controlled by repeated periods of erosion and burial of valleys during the Late Cenozoic due to vertical movements and climatic changes. These valleys were maximally overdeepened and then buried under 30-40 m thickness of Early Pleistocene deposits before the Cracovian (Mindelian, Elsterian) Glaciation. The Mindelian sequence of the area consists of the three tills, the first of which reached only the northern slopes of the Holy Cross Mts, while the both younger covered almost the whole area, and were divided only by interstadial sands (Lindner 1977). During these stadials, the marked hills stopped the ice-sheet (Fig. 4), and in effect the nunatacks formed, one of which was concave in the axial part of the Checiny Anticline and was sheltered by hills along the anticline limbs. Such an "oasis" was devoid of tills, but filled up to 320 m a.s.l. with silts and sands. The maximal stadial of the Riss (Saalian) Glaciation caused accumulation of outwash sands up to 255 m a.s.l., whereas less extended glacial events resulted in periglacial and river deposits.

The Kozi Grzbiet Hill (280 m a.s.l.) is situated in the northern limb of the Checiny Anticline, the core of which is built up of Lower Cambrian shales. The limbs embrace Devonian carbonates and Buntsandstein siltstones, the Givetian (?) thick-bedded biosparites, being more resistant to denudation and forming elevations.

Sequence of karst deposits

The sequence of karst deposits, exposed at Kozi Grzbiet Hill, are subdivided into lithological units, some of them containing secondary layers (Fig. 2). The Uppermost *Unit 1* consists of yellow glacifluvial sands with limestone blocks and flowstone debris. The sands contain admixture of feldspars and a very diversified heavy mineral association. *Unit 2* represents brown, sandy cave loams with bones, snail shells, smoothed debris of limestones and flowstones. The heavy mineral association is similar as in Unit 1. The mineralogical investigation revealed, besides quartz and calcite, some smectite, kaolinite, illite hydrated iron oxides and feldspars. The *Layer 2b* is marked for its dark-brown colour, while *Layer 2c* by presence of large limestone blocks and slices of fine crystalline flowstone crusts, as well as only sporadic occurrence of snail shells. *Unit 3* consists of crumbled laminated cherry-red clays composed of kaolinite, hematite and vermiculite. These clays represent the altered top part of underlying deposits. *Unit 4* consists of a set of layers of cherry-red fine grained clayey sands and sandy clays, with smoothed limestone and flowstone debris as well as flakes of underlying sediments. Kaolinite, quartz and hematite are the main mineral components of this unit. The mineral composition of these layers resemble Buntsandstein deposits of the area. *Unit 5* consists of brownish-yellow clays filling lower part of the karst form, the niche on the wall and formed slices within overlying unit. Mineral composition of these clays is very close to that of the residuum of the neighbouring Devonian limestones.

Limestone walls of the cave are partly covered with reddish coarse-crystalline flowstone, which also supplied much debris in Units 1-4. It is evident that coarse-crystalline flowstones had covered the cave before or during the sedimentation of Unit 4. After the deposition of Unit 3, fine-crystalline white flowstones were formed, as their fragments were encountered only in Units 1 and 2, 2 and 3 as well as 4 and 5.

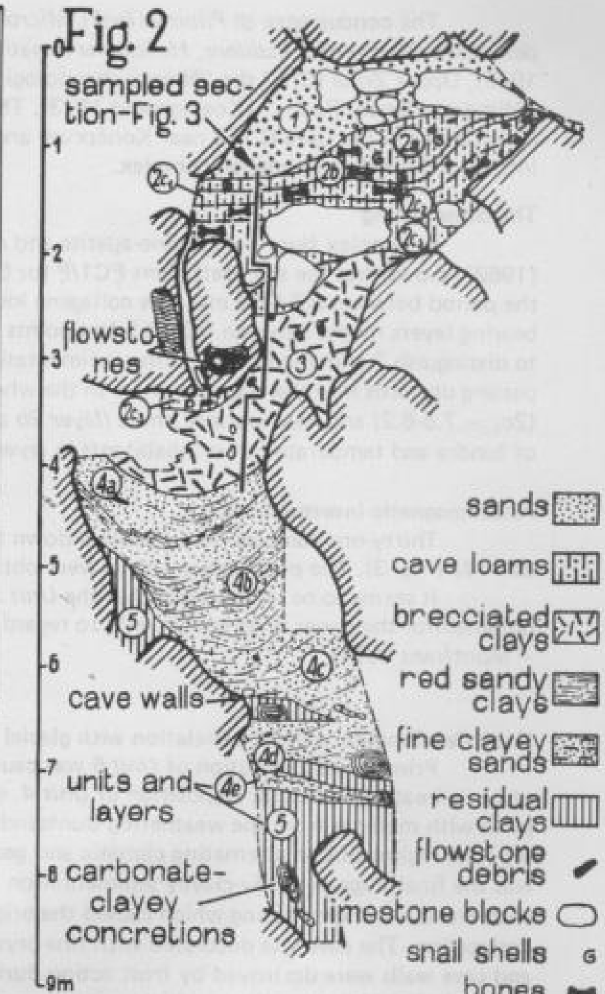
Fauna

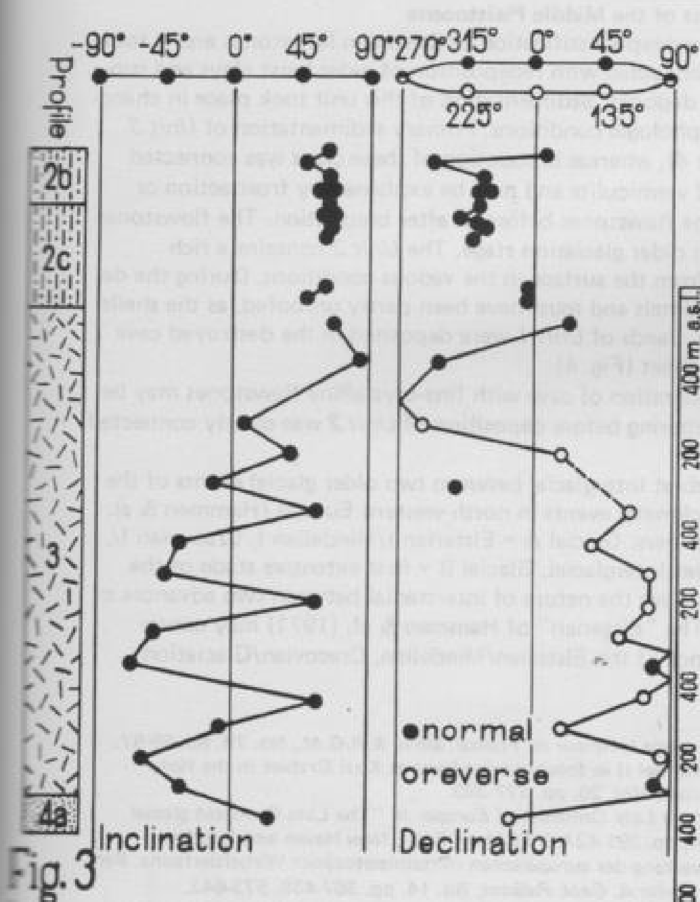
Cave loams (*Unit 2*) contain very rich snail, amphibian, reptilian and mammalian remnants. The snail fauna consisting of: *Bradybaena fruticum, Helicigona banatica, H. lapicida,* cf. *Soosia diodonta, Isognomostoma personatum, Zenobiella vicina, Cochlodina laminata, C. cerata, C. orthostoma, Laciniaria cana, Ruthenica filograna, Clausilia dubia, C. cruciata, Iphigena tumida, I. latestriata, Acanthinula aculeata, Discus rotundatus, Perpolita radiatula, Vertigo angustior, Carychium minimum* and *Vallonia pulchella* belongs to hygrophile association of the culminating interglacial period (*Banatica* fauna, cf. Ložek 1961).

The herpetofauna is represented by: *Triturus* cf. *cristatus, Bombina* cf. *bombina, Pelobates* cf. *fuscus, Bufo* cf. *viridis, Rana* cf. *temporaria, Pliobatrachus langhae, Anguis* cf. *fragilis, Natrix* cf. *natrix, Coronella* cf. *austriaca, Elaphe* cf. *longissima* and *Vipera* cf. *berus,* among which *Natrix* and *Triturus* predominate indicating a deciduous and wet forest environment; less frequent are thermophilic forms, *(Pliobatrachus, Elaphe)*, and steppe inhabitants are rare (*Pelobates*).

The mammalian fauna includes: *Ursus deningeri, Sus* cf. *scrofa, Alces* sp., *Beremendia fissidens. Citellus polonicus, Dicrostonyx simplicior, Lemmus lemmus, Microtus* ex gr. *arvalis, M.* ex. gr. *oeconomus, Pliomys lenki, P. episcopalis, Castor fiber, Glis* sp., *Mimomys savini, Clethrionomys* cf. *glareolus, Pitymys gregaloides* and *P. arvaloides,* among which *Castor, Clethrionomys, Sus* and *Alces* are indicative of a wet forest environment, while less frequent are inhabitants of cold steppe (*Lemmus, Dicrostonyx*).

The frequence analysis of stated taxa in differentiated layers shows that the forest forms are frequent in all layers, while in the *layer 2c* the cold steppe as well as warmer continental inhabitants are more frequent, whereas layers *2a* and *2b* contain more inhabitants of wet environments.





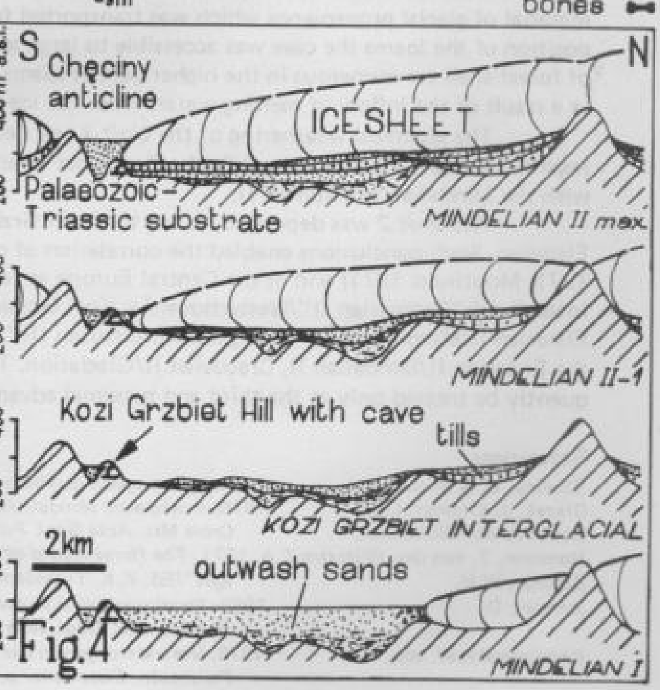


Fig. 1. Relationship of the Kozi Grzbiet Cave during the Mindelian glaciation.

Fig. 2. Cross section of the cave sediments.

Fig. 3. Results of palaeomagnetic measurements.

Fig. 4. Hypothetic evolution of the area studied during the Mindelian.

The concurrence of *Pliomys lenki, Microtus, Pitymys, Mimomys savini, Dicrostonyx simplicior, Ursus deningeri, Beremendia fissidens, Helicigona banatica, Pliobatrachus langhae* indicates the Tarko Phase (Jánossy 1969), Upper Zone (C) of the "Niveau chronologique des Valerots" (Chaline & Michaux 1974) and Younger "Mimomys Savini Fauna" (Koenigswald 1973). The localities of most similar age are Voigtstedt, Süssenborn, lower layers in the Cave C 718 near Koněprusy and in the Tarko rock (shalter, all of them belonging to the interglacial dividing Mindelian complex.

The Bone dating

A complex fluorine-chlorine-apatite and collagene method, elaborated by Wysoczański-Minkowicz (1969), shows that the age coefficient FC1/P for 6 samples of bones ranges between 1.01-1.28, and points to the period between 0.7-0.55 my. The collagene loss coefficient for 26 bone samples distributed in all the bone-bearing layers ranges between 5.0-10.5 and points to interglacial climatic conditions. This coefficient allows us to distinguish 3 climatic phases during sedimentation of *layer 2c:* cold at the bottom ($2c_3$ – coll. coef. 5.8), passing upwards into the warmest phase in the whole section ($2c_2$ – 7.7-10.5), followed by a cool phase ($2c_1$ – 7.5-8.2) and next warmer phase (*layer 2b* and *2c* – 7.8-9.4). These results explain well the coexistence of tundra and temperate forest inhabitants in *layer 2c.*

Palaeomagnetic investigations

Thirty-one samples were obtained down the prepared vertical face of exposure representing *layers 2b – 4a* (Fig. 3). The preliminary results were obtained after 200 Oe a.c. demagnetization.

It seems to be unequivocal that the *Unit 2* belongs to Brunhes normal magnetic epoch, whereas data obtained for the lower units enable only to regard them as older than the Brunes/Matuyama boundary (0.7 my – Montfrans 1971).

Karst development and its correlation with glacial events of the Middle Pleistocene

Primary sedimentation of *Unit 5* was caused by deep karstification of Devonian limestones and it took place in freatic conditions. Deposition of *Unit 4* was connected with redeposition of older karst clays and supplied with material from the weathering Buntsandstein deposits. Sedimentation of this unit took place in changing flow regime due to alternating climatic and geomorphologic conditions. Primary sedimentation of *Unit 3* was the final stage of sandy-clayey sedimentation (*Unit 4*), whereas brecciation of these clays was connected with erosion and weathering which caused the origin of vermiculite and may be explained by frost action or desiccation. The cave was decorated with fine-crystalline flowstones before or after brecciation. The flowstones and cave walls were destroyed by frost action during an older glaciation stage. The *Unit 2* contains a rich material of glacial provenience which was transported from the surface in the vadous conditions. During the deposition of the loams the cave was accessible to large animals and must have been partly unroofed, as the shells of forest snail are numerous in the higher part of loams. Sands of *Unit 1* were deposited in the destroyed cave as a result of the inflow of melting waters from the ice-sheet (Fig. 4).

The chemical weathering of the *Unit 3* and decoration of cave with fine-crystalline flowstones may be regarded as Early Pleistocene, while the final frost weathering before deposition of *Unit 2* was clearly connected with the Mindelian I (Elsterian I).

The *Unit 2* was deposited during the Kozi Grzbiet Interglacial between two older glacial events of the Elsterian. Such conclusions enabled the correlation of climatic events in north-western Europe (Hammen & al. 1971, Montfrans 1971) and in the Central Europe as follows: Glacial A = Elsterian I/Mindelian I, Cracovian I/, Interglacial "Cromerian II"/Westerhoven/ = Kozi Grzbiet Interglacial, Glacial B = first extensive stade of the Elsterian II/Mindelian II/, "Interglacial Cromerian III", have the nature of interstadial between two advances of the Elsterian II/Mindelian II, Cracovian II/Glaciation. The "Elsterian" of Hammen & al. (1971) may consequently be treated only as the third and maximal advance of the Elsterian/Mindelian, Cracovian/Glaciation.

References

Chaline, U. & Michaux, J. 1974. Les rongeurs du Pléistocène Inférieur de France. *Mém. B.R.G.M.*, No. 78, pp. 89-97.

Glazek, J. Lindner, L. & Wysoczanski-Minkowicz, T. 1976. Interglacial Mindel/I/Mindel II in fossil-bearing karst at Kozi Grzbiet in the Holy Cross Mts. *Acta Geol. Polon.*, Vol. 26, pp. 377-393.

Hammen, T. van der, Wijmstra, T.A. Zagwijn, W.H. 1971. *The floral record of the Late Cenozoic of Europe. In* "The Late Cenozoic glacial ages"/Ed. K.K. Turekian/, pp. 391-424. Yale Univ. Press, New Haven and London.

Janossy, D. 1969. Stratigraphische Auswertung der europäischen mittelpleistozänen Wirbeltierfauna. *Ber deutsch. Ges. Geol. Wiss Reihe A. Geol. Paläont*, Bd. 14, pp. 367-438, 573-643.

Koenigswald, W. von. 1973. Veranderungen in der Kleinsaugerfauna von Mitteleuropa zwischen Cromer und Eem Pleistozän. *Eiszeitalter u. Gegenwart.*, Bd. 23/24, pp. 159-167.

Kutek, J. & Glazek, J. 1972. The Holy Cross area, Central Poland, in the Alpine cycle. *Acta Geol. Polon.*, Vol. 22 pp. 603-653.

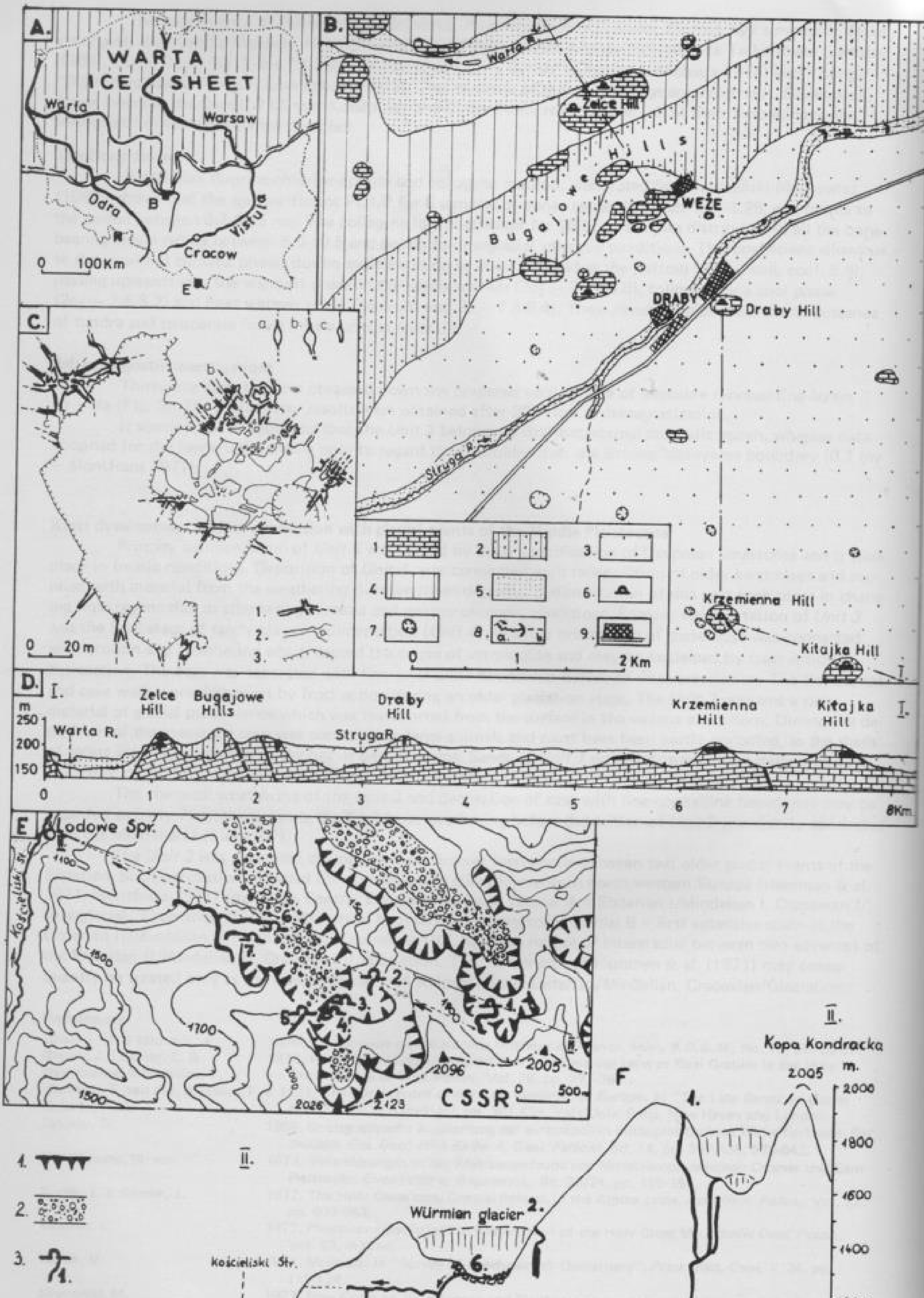
Lindner, L. 1977. Pleistocene glaciations in western part of the Holy Cross Mts. *Studia Geol. Polon.*, Vol. 53, in press.

Lozek, V. 1961. Mollusca. *In* "Survey of Czechoslovak Quaternary". *Prace Inst. Geol.* T. 34, pp. 119-124.

Mlynarski, M. 1977. New Notes on the Pliocene and Pleistocene herpetofauna of Poland. *Acta Zool. Cracoviensia*, T. 22 in press.

Montfrans H.M. van. 1971. Palaeomagnetic Dating in the North Sea Basin. *Earth Planet, Sci. Letters*, Vol. 11, pp. 226-235.

Rzebik-Kowalska, B. 1976. The Neogene and Pleistocene Insectivores/Mammalia/of Poland. III. Soricidae: *Beremendia and Blarinoides. Acta Zool. Cracoviensia*, T. 21, pp. 359-385.


A.
WARTA ICE SHEET
Warta
Warsaw
Odra
Vistula
Cracow
B
E
0 100Km
B.
Warta R.
Zelce Hill
Bugajowe Hills
WĘŻE
DRABY
Draby Hill
Struga R.
Krzemienna Hill
Kitajka Hill
C.
0 2 Km
C.
a b c
0 20m
D.
I.
Zelce Hill
Bugajowe Hills
Draby Hill
Krzemienna Hill
Kitajka Hill
Warta R.
Struga R.
m
250
200
150
0 1 2 3 4 5 6 7 8Km
E
Lodowe Spr.
Kościeliski St.
1100
1300
1500
1700
2005
2096
2123
2026
CSSR
0 500m
II.
Kopa Kondracka
2005
F
m.
2000
1800
1600
1400
1200
1000
Würmian glacier
Kościeliski Str.
Lodowe Spr.
0 1000 2000 3000 4000 5000m
1.
2.
3.
4.
5.
2005

Proglacial caves in Poland

(A) — Area Map; (B) — Geological sketch of the vicinity of Chessboard Cave; 1. Oxfordian to: limestones; 2 Warta Glaciation: end moraines; 3 — outwash sands; 4 — tills; Late Quaternary: 5 — terraces; 6 — caves, 7 — sinkholes, 8 — ponors, 9 — roads and villages); (C) — Sketch map of the Chessboard Cave (1 — natural passages, 2 — passages enlarged by limestone exploitation, 3 — quarry escarpments, a, b and c — passage vertical sections); (D) — Geological section (caves black, other symbols as in B); (E) — Sketch-map of the Czerwone Wierchy Massif (1 — glacial cirques and trim-lines, 2 — tills, 3 — caves named in the text, 4 — stated underground water flows, 5 — State boundary along the mountain summits); (F) — Hypothetical section during the Würm symbols as in E).

Some other examples

Similar, but smaller caves, (e.g. the one in Kitajka Hill is shown in Figs. B and D) than the Chessboard Cave, occur in other limestone hills elevated above outwash sands of the Warta Glaciation.

Very similar to the Szachownica Cave is the network of the Na Spicaku Cave in Czechoslovakia (N in Fig. A), in the marginal zone of the Riss Glaciation; this cave probably developed due to corrosive action of Riss proglacial waters. Jennings and Sweeting (1959) suggested this kind of origin for the Honeycomb Caves at Mole Creek, Tasmania. Many Alpine caves probably originated in a similar manner to that postulated here for the Tatra caves.

Conclusions

Among the numerous caves existing in glaciated areas during the Pleistocene, some can be genetically linked with the corrosive action of proglacial waters circulating along networks of fissures. This corrosive action may be restricted to the rapid first type of dissolution, that is to ionisation of calcium carbonate and the reactions between ions (Bögli 1960). Bulk inflow of meltwaters connected with this rapid solution may be sufficient for the development of a network of narrow cave passages or shafts. Such caves may be termed *proglacial caves.* These caves occur in lowlands and uplands in the form of young horizontal passages connected with the surfaces of glacial outwash accumulations. They are therefore higher than older caves due to elevation of the glacial water table. In the high mountains, proglacial caves may begin as gouffres with phreatic terminations. These phreatic portions may later develop into horizontal exsurgence type caves during the interglacials and/or the Holocene. Thus, the older horizontal passages may originate during the older glaciations as proglacial caves. During following glaciations they may be flooded, and subsequently abandoned by water due to the development of younger exsurgence systems (e.g. present flow to Lodowe exsurgence, present Castelguard Cave II).

The proglacial caves are to be correlated with higher water tables during the glaciations. They exhibit no clear correlation with river valleys pattern.

Acknowledgements

Dr. J. Grodzicki, Institute of Geology, Polish Academy of Sciences, supplied data on the Tatra Caves. Dr. A. Wierzbowski, Warsaw University, contributed to the geological setting of the Chessboard Cave. Professor J.N. Jennings, Australian National University, discussed the here presented concept in the field, and contributed on the Honeycomb example. Finally, Dr. K. Peterson, University of Liverpool, carefully improved the English text.

References

Bögli, A. 1960. Kalklösung und Karrenbildung. *Z.f. Geomorph., Supplementbd.* 2, pp. 4-21.

Burchart, J. 1972. Fission-track age determinations of accessory apatite from the Tatra Mts., Poland. *Earth Planet Sci. Letters,* Vol. 15, pp. 418-422.

Ciry, R. 1959. Une catégorie spéciale de cavités souterraines: les grottes cutanées. *Ann. Speleol.,* T.14, pp. 23-30.

Dabrowski, T. 1967. Karst hydrogeology of the Polish Tatra Mts. obtained by colouring methods. *Steir. Beitr. Hydrogeol.,* Jg. 1966/67, pp. 219-226.

Ford, D. 1975. Castelguard Cave an Alpine cave in the Canadian Rockies. *Stud. Spel.,* Vol. 2, pp. 299-310.

Ford, D.C., Harmon, R.S. Schwarcz, H.P., Thompson, P., & Wigley, T.M.L. 1976. Geo-hydrologic and thermometric observations in the vicinity of the Columbia Icefield, Albert and British Columbia, Canada. *J. Glaciology,* Vol. 16, No. 74, pp. 219-230.

Gèze, B. 1965. Les conditions hydrogéologiques des roches calcaires. *Chron. Hydrogeol.,* No. 7, pp. 9-39.

Glazek, J., Bednarek, J., Szynkiewicz, A. & Wierzbowski, A. 1978. Origin of the Szachownica Cave — the greatest cave system in the Cracow-Wieluń Jura Upland. *Kras i Speleologia,* T. 11 /inpress/.

Grodzicki, J. 1970. Le role de la tectonique dans la genèse des cavernes karstiques du massif Czerwone Wierchy/Les Tatras Occidentales/. *Speleologia,* T.5, pp. 33-48.

Grodzicki, J. 1975. Gouffre "Wielka Sniezna"/Reseau Grande Sniezna/, -783 m. Résultats de l'exploration du Siphon "Terminal". *Speleologia,* T. 8, pp. 119-126.

Jennings, J.N. & Sweeting, M.M. 1959. Underground breach of a divide at Mole Creek, Tasmania. *Aust. J. Sci.,* Vol. 21, No. 8, pp. 261-262.

Korzhuev, S.S. 1965. Karst of Yakutia. *Trans. Moscow Soc. Natur.,* Vol. 15, pp. 67-72.

Rudnicki, J. 1967. Origin and age of the Western Tatra caverns. *Acta Geol. Polon.,* Vol. 17, pp. 521-591.

Wagner, G.A. & Reimer, G.M. 1972. Fission track tectonics: the tectonic interpretation of fission track apatite ages. *Earth Planet Sci. Letters,* Vol. 14, pp. 263-268.

SIMULATION OF RILLENKARREN

John R. Glew, Department of Geography,
McMaster University, Hamilton, Ontario, Canada.

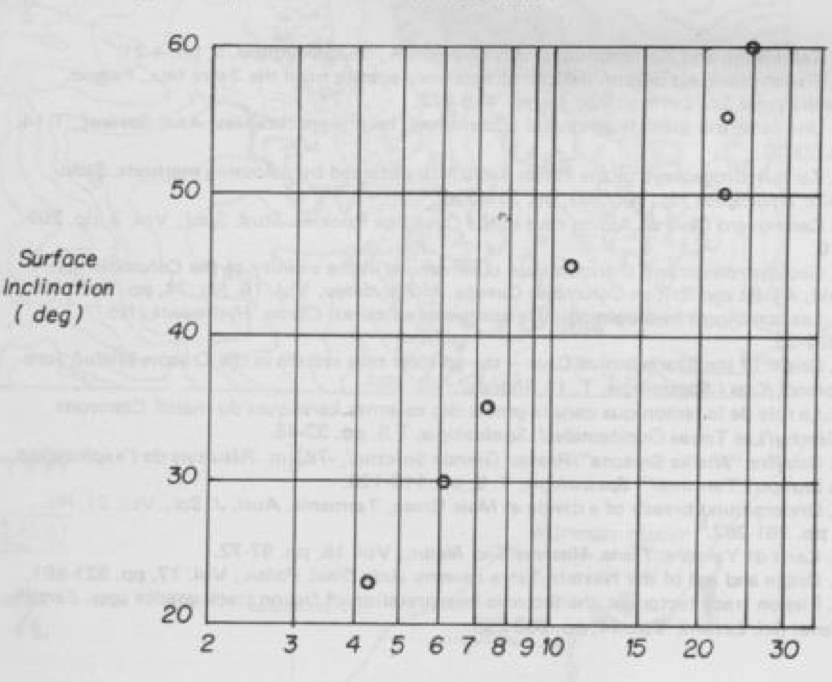
Rillenkarren or Lapies are small scale features attributed to the solutional weathering of such readily soluble rocks as Carbonates, sulphates and halides. Although Rillenkarren surfaces are distinctive and have been described in many different locations throughout the world, their development remains unexplained. A variety of theories have been advanced regarding the rate of development and their significance in terms of solutional rock weathering, but no attempt to substantiate these has been made in the past (Cvijic 1924, Miotke 1968, Sweeting 1972).

The Rillenkarren surface is dominated by parallel grooving of a very uniform width. Grooves are always aligned down the steepest incline and develop in sets that produce a completely fluted surface. Sharp-crested ridges separate grooves. The grooving or rilling appears to be propagated from the highest part of the slope and in many examples washes-out at some distance below the crest.

A series of experiments were designed to provide basic data on Rillenkarren and the major processes involved in their development. Rainfall appeared by field observation to be the dominant process, which suggested that hardware simulation could be used to study the surfaces under laboratory conditions. This method proved to be economical in terms of both time and equipment. A rainfall simulator was designed to provide controlled rainfall similar to that prevailing on natural rock surfaces. Particular attention was paid to the replication of droplet size, droplet size distribution, and droplet velocity; this ensured that the kinetic energy developed at the intercepting surface was close to that generated by a natural rainstorm. For the experiments substitute soluble surfaces of either plaster of paris or salt were selected. Model surfaces were set fixed inclinations and subjected to uniform rainfall intensity. At regular intervals throughout each experiment the eroding surface was measured and photographed to provide information on surface form. 16 experiments were conducted using rainfall intensities from 20 to 40 mm/hour and surfaces set at angles from 22½ to 60 degrees from the horizontal. Individual experiments ranged from 500 to 800 hours duration for plaster surfaces, and from 6 to 24 hours for salt surfaces.

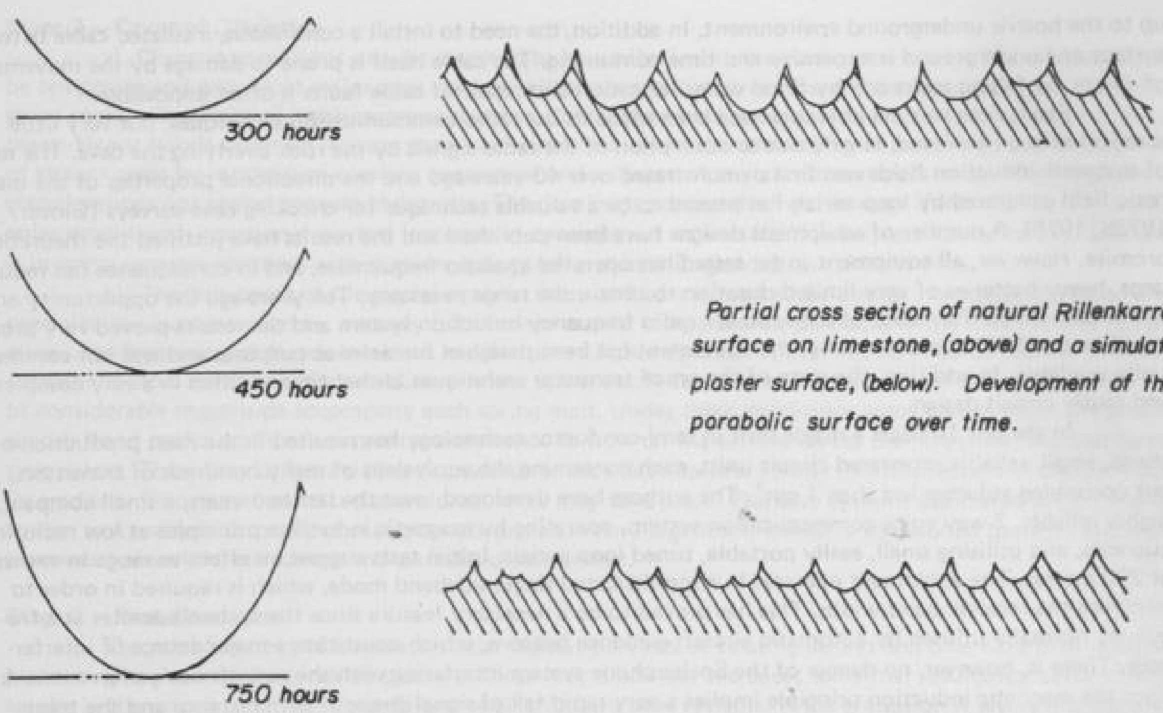
Collectively, the data from the experiments support the theory that rainfall is the process responsible for the development of Rillenkarren. In all experimental cases rill development was propagated from the uppermost edges of the inclined surfaces. The development of the rilled surface, the cross-sectional profiles and the size of the rills appeared closely comparable to natural rillenkarren. For the experiments carried out on plaster surfaces a direct relationship between the length of rill and the slope angle of the model surface was determined (Fig. 1). Examination of rill cross-section development indicated that the deepening rill approached a final parabolic form (Fig. 2); the parabola is the optimum form for efficient interception, of raindrops in this instance. Rill width is a function of the material eroded. Compared to widths from natural limestone occurrences, plaster rills were smaller and salt rills (artificial salt) larger; rills on natural salt were also larger than those on limestone.

Rills terminate in the down-slop direction where the thickness of flowing water film attains a critical value, which was measured. This implies that rillenkarren are an "edge effect", created at crest and edge zones able to support very thin or no stable water film.



Inclination	Mean length
60	25·0
55	23·4
50	23·3
45	11·2
35	7·4
30	6·1
22½	4·1

Plot of rill length vs. slope angle. **Fig. 1**



Partial cross section of natural Rillenkarren surface on limestone, (above) and a simulated plaster surface, (below). Development of the parabolic surface over time.

Fig 2

Other measurements made during the experiments indicate that original slope angles do not change significantly during the development of rilling. Development on model and natural surfaces of an upper rilled zone that washes-out into a smooth lower zone is one of adjustment to the rainfall process, and slope. Such a surface once developed undergoes commensurate surface reduction in both the smooth and rilled portions.

Some of the problems associated with the formation of the Rillenkarren surface have been resolved. The rills themselves are not micro drainage features, although they are very efficient forms for directing surface flow; they represent a form developed by impacting droplets of water striking an inclined surface. Such a surface is an adjustment to this process and will be reduced by solution without further change in overall configuration once it is established. Viewed as an erosional surface, therefore, Rillenkarren are mature and stable, a product of lengthy exposure to a single dominant process. This is contrary to some earlier opinions that explained the Rillenkarren surface as an initial one, a transitional feature that developed quickly and gave way in time to larger-scale solutional karren features.

References

Cvijic, J.	1924, *Geog. J.* 141, pp. 26-29.
Miotke, F.D.	1968, *Jahrb. Geogr. Ges., Hannover, Sd. 4*, 161.
Sweeting, M.M.	1972, *'Karst Landforms'*, Macmillan, London.

THE SPELEOPHONE – A RADIOFREQUENCY CAVE COMMUNICATION SYSTEM

R.R. Glover & R.O. Mackin
West Penwith, Over Kellot,
Carnforth, Lancashire, U.K.

Throughout the history of caving use has been made of a restricted range of communication techniques which have evolved partially as a result of advances in communication technology and partially as a result of the increase in severity of the types of caves explored (Glover 1973a). The most common use of a cave communication system has been, and still is, coordination between cavers ascending or descending vertical shafts and the man supervising the lifeline at the top. A secondary, but not less valuable requirement has risen as a result of the exploration of very long and/or deep cave systems, which has necessitated the establishment of underground camps. Communication between groups of cavers, the camps and the surface becomes necessary to coordinate the activity of various groups within the system. Warning of sudden weather changes is required in some of these caves and in the case of underground accidents fast and efficient communication with the surface has proved, literally, vital in organising speedy rescue and treatment.

Over the years, a number of communication systems and equipment types have been used for these purposes, with the telephone in one form or another remaining the principal method. In many cases these have given a great deal of trouble, since the equipment used is basically designed for surface operation, and fails to stand

up to the hostile underground environment. In addition, the need to install a continuous, insulated cable between surface and underground is expensive and time-consuming. The cable itself is prone to damage by the movement of cavers, by falling rocks and by flood water. Location and repair of cable faults is often impossible.

From time to time attempts have been made to use radio communication techniques, but very little success has been achieved, largely due to absorption of the radio signals by the rock overlying the cave. The use of magnetic induction fields was first demonstrated over 40 years ago and the directional properties of the magnetic field generated by loop aerials has proved to be a valuable technique for checking cave surveys (Glover, 1973b, 1976). A number of equipment designs have been published and the results have justified the theoretical promise. However, all equipment so far tested has operated at audio frequencies, and in consequence has required large, heavy batteries of very limited duration to obtain the range necessary. Ten years ago the opportunity arose to evaluate the performance of a low power radio frequency induction system and the results proved very promising (Glover, 1967). Unfortunately, the equipment has been designed for defence purposes and was not commercially available. In addition, the state of the art of transistor techniques at that time resulted in a very complex and costly circuit design.

In the last 10 years a major shift in semi-conductor technology has resulted in the mass production of cheap, small, reliable integrated circuit units, each containing the equivalent of many hundreds of transistors, but occupying volumes less than 1 cm^3. The authors have developed, over the last two years, a small compact, highly reliable, 2-way voice communication system, operating by magnetic induction principles at low radio frequencies, and utilising small, easily portable, tuned loop aerials. Initial tests suggest an effective range in excess of 200 metres. The equipment operates in a sophisticated single sideband mode, which is required in order to minimise the receiver band width. This has proved to be a necessary feature since the system operates at a frequency normally utilised by automatic aircraft guidance beacons, which constitute a major source of interference. There is, however, no danger of the Speleophone system interfering with the aircraft navigation network, since the magnetic induction principle implies a very rapid fall of signal strength with distance and the transmitted power falls below ambient noise threshold at distances in excess of 300 metres. Nevertheless, a special licence is required for operating this type of equipment in Britain. This is obtainable from the Radio Research and Development Unit of the Home Office.

Current trials of the equipment have been carried out in the Gaping Gill system with a view to establish the accuracy of existing surveys. The facilities for establishing both surface plan position, and the depth below the surface, of the underground transmitter, which are inherent features of the magnetic induction system, are proving invaluable in this respect.

References

Glover, R.R. 1973a. Communication Underground — a review of Available Techniques — In *Technical Aids — Caving supplement to CRG Newsletter*, No. 133.

Glover, R.R. 1973b. Cave Depth Determination by Magnetic Induction. In *Journal Lancaster University Speleological Society*, Volume 1 no. 3, pp. 66-72.

Glover, R.R. 1976. In Ellis, B.M. — *Surveying Caves*. Chapter 9 in Cave Surveying by Magnetic Induction pp. 42-58, published by BCRA.

Glover, R.R. 1967. The 1967 Ingleborough Field Meet Report, *CRG Newsletter*, no. 107, pp. 4-6.

A CONCEPTUAL MODEL OF CAVE DEVELOPMENT IN A GLACIATED REGION

R.R. Glover
West Penwith, Over Kellet,
Carnforth, Lancashire, England.

Many of the major limestone areas in the northern hemisphere have suffered multiple glaciations during the Pleistocene. The advance and retreat of an icesheet over an area of limestone containing caves has greatly modified the nature, pattern and type of cave development in these areas. In order to interpret many of the features found in such caves it is helpful to have an overall model of the conditions, processes and events which may be expected to occur during a cycle of glaciation. The following conceptual model is deliberately structured in the simplest possible outline and does not purport to encompass the full range of phenomena actually occurring. Many of these, however, may be inferred by simple modification of the model.

It is proposed to divide the cycle of glaciation into four stages, (1) full interglacial, (2) onset of glaciation, (3) peak glaciation, (4) glacial retreat.

Stage (1): Full Interglacial

At the height of a major interglacial the overall climate is warm and dry, and resembles that presently occurring in the Mediterranean. The treeline may rise as high as 600 meters or more above sealevel in Britain. A considerable thickness of soil may cover most outcrops of limestone. Percolation water moving through the soil acquires high concentrations of carbon dioxide and rapid solution takes place at the top surface of the limestone. All drainage is organised vertically and percolation water entering existing caves contains large quantities of calcium carbonate in solution. The cave air temperatures are high and humidity low and massive development of stalagmite deposits take place in the caves. The most important process occurring in existing open caves during this period is therefore one of infill by calcite deposition.

Stage 2 – Onset of Glaciation

a). Climatic conditions may be assumed to be similar in Northwest Europe today. The climate would be temperate and wet. Most major cave systems will contain active streams and those originating on non-limestone rocks will consist of highly aggressive water. Both vadose and phreatic development by solution will take place. Heavy floods occur on average once every decade or so, and these result in a major phase of enlargement of stream caves by mechanical erosion, excavation and collapse of any clastic materials remaining from previous glacial periods not sealed beneath stalagmite. The dominant process during this stage is therefore one of steady enlargement with occasional marked increases in development as a result of infrequent heavy floods. This stage is in many respects identical with that prevailing in Northwest England at the present time.

b). The true onset of the glacial cycle in these latitudes is marked by a slow increase in the mean annual precipitation, accompanied by a steady fall in mean annual temperatures, particularly the mean winter temperature. The frequency of floods increases and the pace of cave development increases in consequence. Eventually permanent snow fields become established in the upper catchment areas of active stream caves and annual floods of considerable magnitude accompany each spring melt. Under these conditions some cave systems are unable to absorb flood peaks, and surface streams commence to flow on the surface across the limestone, beyond former sink points. These may utilise existing dry valleys or may develop new valleys in the direction of highest hydraulic gradient. Re-occupation of old abandoned sinks may take place. The cave systems associated with the original stream sinks return to totally phreatic conditions and many high level, formerly abandoned passages undergo a renewed phase of both vadose and phreatic development.

Stage 3 – Peak Glaciation

The establishment of icesheets on the highest portions of existing valleys and over extensive upland plateaux give rise initially to valley glaciers. These may block the entrances to former resurgence caves which results in the return to phreatic conditions of all tributary cave systems. If the glaciation is severe enough and/or lasts long enough, the valley glaciers will grow, eventually spreading across the surface of the limestone areas between valleys. This is accompanied by major erosion of valley floors and sides, and glacial stripping of much loose superficial material, as well as younger, thin bedded rocks overlying the limestone. Little, if any, surface water enters the caves, which may slowly drain. Truncation of both resurgence and sink caves may take place, and the weight of ice may promote collapse in those cave passages lying at shallow depth. Cave development ceases and little, if any, calcite deposition takes place in the dry, abandoned passages below the ice.

Stage 4 – Glacial retreat

The end of the glacial peak is marked by a steady rise in mean annual temperature accompanied by an increase in the amount of warm, moist air entering the high pressure zone covering the ice sheet. Spring and summer melts become rapid and prolonged as the shrinking icesheet releases vast quantities of meltwater, heavily laden with sediments, whose particle size ranges from the finest rockflour to large boulders weighing many hundreds of tons. Many rock fragments are still angular as a result of mechanical erosion by the ice. Initially, meltwater streams develop on the surface of the limestone, incising deep gorges, particularly where the direction of flow coincides with lines of weakness, such as joints and faults. Eventually, such meltwater streams re-enter existing cave systems via old entrances or new ones, exposed by mechanical erosion. Open caves on the upper surfaces of the limestone may take annual meltwater streams of considerable size, carrying into the caves huge quantities of clastic sediments. Resurgence caves may still be blocked by valley glaciers and many cave systems therefore undergo a massive phase of infill. As the climate, returns to the warm, dry conditions of an interglacial, the barren wastes of fluvio-glacial material, deposited by outwash streams or by in situ melting of stagnant ice, become colonised by vegetation. Large areas of bare limestone surface, exposed by glacial erosion and which were washed clean of the products of this erosion by meltwater streams, being to develop classic pavement features. Eventually conditions return to those described in Stage 1.

Many of the features observed in the major cave systems of Northwest Europe and America and in particular those occurring in nearby horizontal bedded limestones may be explained in terms of this model.

MORPHOLOGY OF GYPSUM KARST

Gorbunova K.A.
Perm State University
U.S.S.R.

The most widely-spread surface forms of gypsum karst are dolines. The dolines are depressions of simple crater-, dish-, cone- or cauldron-shape being up to 50 m in diameter and 10 m in depth. In five districts of the Perm region, amounting to 700 km^2 some 22510 (1,3,5) dolines were found, while in three districts of Bashkir republic on a total surface of 1152 km^2, 11567 dolines were discovered. [2].

On the basis of statistical processing of 2800 doline size data the following classification of their diameters (in metres) has been suggested: small $\leqslant 5$, usual (i.e. most widely spread); 5-25; large, 25-50; very large $>$ 50 to 100; in depth (in metres): small $<$ 1, usual 1-5, deep 5-10, very deep $>$ 10-15 (to 25). In karst districts of Perm region the dolines of 5-25 m in diameter constitute 50-70 per cent and less than 5m deep, 60-90 per cent of the total quantity. The morphometric indices of the dolines show the influence of various

factors: depth of gypsum and anhydrite cover, composition and thickness of overlying deposits, hydrodynamic conditions, stages of karst development. Isolated groups of dolines form so-called fields. The quantity of the dolines in the field counted per 1 km^2 is the density (D). Maximum densities (up to 1000 d/km^2) are found in crowns of folds, at the contact of the gypsum, with terrigenous or calcareous rocks, in zones of rock fractures, over areas of concentrated subsurface drainage, close to ravines, on slopes and (in slope places) on interfluves.

The relation of the total area of dolines to the area of the field expressed as a percentage the area karstification ratio – R_a [4,6].

The relation of the total volume of dolines to the field area in mm, cm or sometimes in m constitutes the karst denudation ratio Rd [3] or the conditional average decrease of earth surface at the expense of the dolines [6].

In areas of gypsum karst there are all genetic types of dolines [4], but the collapse dolines are the most characteristic. Some researchers [4,6] use the stability degree of karstified areas by using the two indices: 1) N – the number of collapses originating during a year on 1 km^2; 2) T – number of years within which one collapse originates on 1 km^2.

For one of the karstified areas of the Perm region, where the number of dolines is 143, these indices are: D = 381d/km^2, Ra = 22%, Rd = 1.46 m, N = 2.25 collapses/per year per 1 km^2. This area is rated as very unstable. The karst dolines are a very important index of the degree of karstification and stability of karst districts.

References

Butirina, K.G. 1975. Karstified districts and sections of central part of Perm region. Problems of Ural Physiography. Issue 2, Perm.

Verzakov, M.S. Kostarev, V.P. 1968. Karst of sulphate deposits of the Ryazano-Okhlyabinsky swell. Karst of the Urals and Priuralye. Perm.

Gorbunova, K.A. 1965. Specific features of gypsum karst. Perm.

Maximovich, G.A. 1963. Principles of karst science. V.I. Perm.

Pechorkin, I.A., Murdasov M.D. 1974. Karstologic zonation of Polazna peninsula. Geology and petrography of West Urals, issue 6, Perm.

Savarensky, I.A. 1963. Probable origin of karst collapses of different diameters in the district of Dzerdjinsk town. News of karst science and speleology, No. 3, M.

[All references published in Russian]

EXOGENETIC GYPSUM TECTONICS

K.A. Gorbunova,
Perm State University
U.S.S.R.

When speaking about exogenetic gypsum tectonics we mean deformations occurring in gypsum/anhydrite and the overlying non-karstic rocks under the influence of epigenesis and karst-formation processes. Depending on the basic cause the exogenous deformations are divided into two types: I – epigenesis or hydration, II – karst or solution.

Deformation by epigenesis is caused by the hydration of anhydrite, recrystallisation of gypsum and by the dissolution of sulphates in karst waters.

In the opinion of some researchers calcium sulphate deposits in ancient water basins were laid down as gypsum. After burial the gypsum was converted to anhydrite. When uplifted, the anhydrites come into a zone of weathering and reconversion to gypsum occurs [10,12,14]. Depth of hydration is usually 150-300 m with considerable variations [4,9,10].

The hydration varies depending upon local conditions. In some cases it occurs without an increase in volume; when this happens a part of the calcium sulphate dissolves and is carried away by water [8]. In many cases the hydration is accompanied by an increase in volume of initial rock from 30 to 67 per cent [4,9,10]. The increase in volume creates additional pressure. With depths up to 150-200m this pressure can exceed the outer pressure of overlying rocks and become the cause of deformation.

During the hydration process there takes place some increase in thickness (swells) of gypsum/anhydrite beds, the formation of dome-shaped structures, gypsum bulges, puckering and little folds in stratified gypsum. This affects the rocks contact with them, causing tension joints, minor faults, brecciation of overlying rocks or rocks interbedded with the gypsum [4,3,9].

Bulging of anhydrite in the process of hydration can be a cause of damage to the bottom of artificial tunnels [13]. There are cases described of deformation accompanied by sudden uplifts and breaking of rock that lie over the gypsum [12].

The karstic deformations is the consequence of subsidence or downfall of overlying rocks into karst cavities [2,3,5,6]. The solution of gypsum and anhydrites interbedded with carbonaceous or terrigenous rocks leads to a decrease of rock thickness. When the gypsum dissolves in the roof through joints, the overlying deposits are downwarped in the shape of minor synclines. Major synclines up to 30 m in height and extending up to hundreds of metres along the strike form over areas of concentrated subsurface drainage. Above zones of intensive solution the overlying deposits subside in the form of gently sloping depressions [11].

Joints, minor individual and step faults, graben-shaped subsidences in both solid and Quaternary deposits appear in the roof of chambers, walls of sinks, on the slopes of blind valleys and karst valleys.

When the gypsum and anhydrites dissolve, non-karstic carbonaceous and terrigenous rocks collapse into karst cavities, breaking and brecciating. Thick karst breccias of solution and of downfall are found on the eastern and western flanks of the Ufimsky swell in Perm region [1,7].

The processes of hydration and karstification which can proceed simultaneously are accompanied by dislocation by folding as well as by dislocation by faulting in gypsum/anhydrite rock masses (see table 1).

Table 1. Exogenetic dislocations in gypsum/anhydrite rocks and rocks in contact with them.

Types	*Epigenesis (hydration)*	*Karst (solution)*
Folded structures	Swellings of beds	Decrease in the thickness
	Increase of dip angle in roof of monoclinal beds	Minor synclines
	Puckering (corrugation)	Major synclines over areas of concentrated subsurface drainage
	Disharmonic folds	Gently sloping depressions above zones of intensive solution
	Dome-shaped folds	
	Gypsum bulges	
Fractures	Tension joints	Gravitational joints
	Minor faults	Microfaults
	Breccias	individual
	mechanical [5]	step
	of crystallisation [5]	Micrograbens
	of uplifts	collapse breccias

Literature Cited (mostly in Russian)

1. Gorbunova, K.A. — Formation of karst breccias of the eastern flank of the Ufimsky swell in the light of hydrogeological data. Pr. of higher educ. inst., Geology and exploration, No. 10, 1960.
2. Gorbunova, K.A. — 1965. Specific features of gypsum karst. Perm book publ.
3. Gorbunova, K.A. Maximovich, E.G. — 1975. Epigenetic deformations in gypso-anhydrite rock masses. Hydrogeology and karst science, issue 7, Perm.
4. Kosygin, J.A. — 1940. The salt and gypsum tectonics of Aktiubinsk region. Pr. of Academy of Sciences, USSR, ser. geologic, issue I,
5. Lukin, V.S. — 1960. Karst tectonic of Kungur district of Perm region. Coll. Geomorphology and neotectonics of the Volgo-Ural region and South Urals. Ufa.
6. Maximovich, G.A. & Gorbunova, K.A. — 1958. Karst of the Perm region. Perm.
7. Nalivkin, V.D. — 1949. Stratigraphy and tectonics of the Ufimsky plateau and Yuruzano-Silvinsky basin. Gostoptechizdat.
8. Parfenov, S.I. — 1967. Specific features of anhydrites gypsumization. Lithology and useful minerals, No. 3.
9. Pisarchik, Y.K. — 1958. Gypsum and anhydrites. Ref. guidance on the petrography of sedimentary rocks, II, Gostoptechizdat.
10. Strakhov, N.M. — 1962. Principles of lithogenesis theory, V, 3, Publ. of Sciences Academy, USSR, M.,
11. Khodkov, A.E. — 1955. Processes of subsurface solution of saliferous and gypso-anhydrite rocks in the Slavyanovsky deposit field and their exposure on the surface. Sci. works of All-Union galurgy res. inst., i. XXX.
12. Brune, G. — 1964. Anhydrite and gypsum problems in engineering geology, California.
13. Durchfuhrung eines felsmechanischen grossversuches in der Nordrohre des Wagenburgtunnels in Stuttgart. "Strassenbau und Strassenverkehrstechn", N. 184.
14. Murray, R.G. — 1964. Origin and diagenesis of gypsum and anhydrite. J. of Sedimentary Petrology, v. 34, N 3.

THE COLLAPSE OF SPELEOTHEMS IN THE POSTOJNA CAVE SYSTEM

Dr. Rado Gospodaric
Institute for Karst Research, SAZU, Postojna,
Yugoslavia

The underground cave systems, including water and dry channels, are mostly due to complicated speleogenesis. Specially difficult to explain are several occurrences of dry galleries, filled by deposition of allochthonous and autochthonous sediments. As in these galleries the speleogenetic history is reflected, such study is important, for comprehension of cave system origin and development indone karst region.

Up to now known perceptions about the age of caves on classical karst show that the principal speleogenetic processes were in the Quaternary. The principal cave systems among the karst poljes were developed in the Lower and destroyed in the Upper Quaternary. The dating of these processes could be either relative, using stratigraphic, sedimentologic, paleolithic or palynologic analyses, or absolute, using C14 and U/Th speleothem analyses. The speleogenesis of the Postojna Cave System is the best studied (Gospodarič, 1976). In the upper Quaternary the following processes were going on in the dry galleries of this system:

— deposition of allochthonous sediments — middle Quaternary, (Riss)

- autochthonous sedimentation (travertine)
- partial deposition of allochthonous and parautochthonous sediments
- autochthonous sedimentation (travertine)
- partial deposition of allochthonous clays and partial erosion in channels,
- autochtonous sedimentation (rubble, breakdown rocks and stalactites)
- autochtonous sedimentation (travertine) floor subsidence, collapse of speleothems – Postglacial – Holocene.

The deposition of fluvial material, (travertine), deposits and gradual channel degradation are the indicators of destruction processes. The underground Pivka river formed and simultaneously destroyed the channels in their horizontal extension, while percolating water formed vertical ones. Mechanical and chemical activity of either waters caused complete or partial filling up and destruction of underground channels. In later geological periods the climatic and geomorphologic conditions were changed, therefore they were differently efficaceous in the destruction processes. The infilled gallery could be again accessible through vertical pits and collapse-dolines and passable because of continous erosion and because of floor subsidence.

Flowstone formations are the most expressive indicators for climatic changes and destruction processes. Their importance, regarding the speleogenesis increases because of either relative or absolute dating possibilities.

In the Postojna cave system we find interglacial, interstadial, postglacial, and holocene speleothem.

Interglacial speleothems are preserved in erosional terraces on the walls and under and above the fills. Their age is relatively and partly absolutely dated. This homegeneous, reddish and yellowish flowstone had grown only 1 mm/100 years, therefore its deposition was possible from the pre-Würm interglacial up to the second Würm interstadial. In water channels of the Planina cave the underground river interrupted this deposition in the lower Würm, while the growth in dry galleries did not cease until Würm 3. In upper galleries of Postojna cave numerous ample stalagmites have grown, but their growth also has been interrupted by the inundation and by deposit of allochthonous clays before the culmination of the last Würm stadial. In the last Würm stadial seepage water through the ceiling was halted, low average annual temperatures obtained in the galleries causing general destruction of the galleries and of their contents.

In the postglacial period new water channels were formed. In dry galleries percolating water has gathered into rills, displacing the clay sediments from upper into lower parts. On deformed floors and above interglacial flowstone new speleothems have been deposed mostly between 12,000 – 14, 000 B.P. as have shown by the C^{14} date. Holocene travertine is present in independent slim stalagmites and stalactites and columns. It surrounds older speleothems fills and breakdown blocks on the floor, on the walls and on the roof. In many cases its features depend on pre-Holocene shapes. Still today percolating water deposits travertine, while where it corrodes too, and everywhere washes off the clay into deeper karst below river level. The destruction processes are going on before our eyes.

The most obvious destruction processes are seen in collasped speleothems. This decomposition process is known and several times described in speleological literature, its occurrences in Postojna cave system have been partly described by R. Gospodaric (1968) in detail. This contribution has inspired the interest of W. Franke and M. Geyh (1971) and they have helped in absolute dating of this collapse, and of B. Schillat (1969) who has commented on the collapse from the earth-quake point of view.

The different views about the collapse causes have excited further study. Here we give the additional information about the speleothems collapses in Postojna cave system to get better knowledge and perception of this destruction process:

In the Postojna cave system the following appearances of collapsed travertive occur:

- broken and subsided travertine floors
- collapsed stalagmites and columns rotated around the horizontal axis for 180°,
- columns, displaced from ceiling or from floor for 1 m,
- formations, turned around their horizontal axis showing their slow and continuous movement on breakouts and on loam floor,
- fractured formations on the gallery walls,
- broken off ceiling stalactites and rocks, lying with any order on the secondary gallery floor,
- several collapsed stalagmites of all generations without regular space orientation.

We think that these phenomena had been caused by subsidence and by washing off of rubble and clay from secondary passage floors. This process was going on in dry, old galleries, which are after their level the most distant to the level of sunk cave river. Therefore in old galleries, as are Pisani rov, Carobni vrt, Tartarus and Lepe jame and Velika gora are the majority of collapsed speleothems. In lower lying channels near the underground river these phenomena are less common but here also there are a lot of different old speleothems and allochthonous sediments.

A look into a gallery with collapsed speleothems gives the impression of great devastation. But the impression of sudden catastrophe looses its sense considering the facts that

- large stalagmites, 3 m thick and up to 5 m high, of interstadial age are horizontally fractured,
- among the collapsed stalactites blocks from the ceiling and walls are rare, although at a supposed catastrophe (earth-quake) they would surely fall off the unstable roof amidst collapsed speleothems,
- we have seen cases of continuous movement of stalagmites and of their fracturing,
- collapses in different galleries or in groups of nearby galleries is very different, depending on geology, morphology and content.

But it is worth mentioning that in two cases the collapse of interstadial (interglacial?) stalagmites has been absolutely dated to about 10000 B.P. As we know of several similar situations we can conclude, that at this period several great stalagmites collapsed. These syndronous falls could be of earth-quake origin. Most probably such jerks have influenced mostly stalagmites and columns, which were already fractured and separated from the ceiling or walls because of a subsidenced floor. Also weaker earth-quakes could easily influence them, while the stable, non-fractured stalagmites could not be fractured even by great earth-quakes. We can enumerate examples of stalagmites which are fractured in the lower third part and are still standing and even stalagmites of equally old travertine which are not fractured at all. At occurrence of general sudden destruction we would expect that all the old formations would collapse and not only some of them. The similar conclusion can be made for younger speleothems.

We can conclude that the speleogenetic development and destruction processes in galleries or cave systems respectively are *primary*, and earth-quakes the *secondary* reason for speleothem collapses. In favourable conditions, i.e. in the postglacial period, when the subsidence was the most intensive, both reasons could be duplicated and could simultaneously and several times accelerate the collapse. Obviously this example also appeared in the Postojna cave system. In other places, e.g. in Langenfelder Höhle, (Schillat, 1969) only the secondary, earth-quake collapse reasons present a better explanation.

References

Franke, H.W. und Geyh, M.A. 1971: 14 C Datierungen von Kalksinter aus slowenischen Höhlen. *Der Aufschluss*, 22/7-8, 235-237.

Gospodaric, R. 1968: Podrti kapniki v Postojnski jami (Les stalactites et stalagmites renversées dans la Grotte de Postojna). *Nase jame*, 9 (1967), 15-31, Ljubljana.

Gospodaric, R. 1976: Razvoj jam med Pivski kotlino in Planinskim poljem v kvartarju (The Quaternary Caves Development between the Pivka Basin and Polje of Planina). *Acta carsologica*, 7, 8-135, Ljubljana.

Schillat, B. 1969: Erscheinungsformen von gebrochenen Sinter. *5 Int. Kongr. Speläologie Stuttgart*, Abh. 2., 33 (1-12), München.

A MODEL OF THE DRAINAGE SYSTEM OF A POLYGONAL KARST DEPRESSION IN THE WAITOMO AREA, NORTH ISLAND, NEW ZEALAND

J. Gunn,
Department of Geography, University of Auckland,
New Zealand

Limestones outcrop over several hundred square kilometres in the south-west of Auckland Province, North Island, New Zealand. The karst landscape is dominated by closed depressions which, when delimited on the basis of their topographic divides, form a cellular network known as polygonal karst (Williams, 1972). Polygonal karst networks in tropical areas have been described by a number of authors (see Sweeting, 1972) and research on their hydrology has been undertaken by Williams (1972) and Day (1976). Both of these authors noted that individual depressions appear to exhibit characteristics of small drainage basins; similar conclusions were reached by Pringle (1973) in New Zealand. In order to understand how these centripetal drainage basins function, research has been undertaken in an area of polygonal karst near Waitomo (Fig. 1). The results and a model of the drainage system of these depressions are presented in this paper.

NATURAL ENVIRONMENT

Climate and Vegetation

The study area has a warm temperate maritime climate, rainfall being distributed throughout the year but with a marked winter maximum. Annual rainfall in the study area is approximately 2500 mm and Coulter (1973) estimates mean potential evapotranspiration to be some 750 mm. Thus the annual water surplus is of the order of 1750 mm.

The natural vegetation of the district is evergreen broadleaf podocarp forest, but this has been cleared over part of the area and replaced by improved pasture.

Geology and Soils

The geology of the district has been discussed by Marwick (1946), Barrett (1962), Nelson (1973) and Kermode (1975). Figure 2a shows an idealised stratigraphic column and 2b illustrates the relationship of the three main lithological units in the study area. The limestones, which total approximately 100 m in thickness, are of Oligocene Age. They are characteristically strongly jointed, flaggy and well bedded, the interval between bedding planes being frequently less than 40 cm. The Waitomo Sandstone is calcareous and glauconitic and being much less permeable than the limestone is of considerable hydrological importance. It occurs as tongues of varying thickness within the Orahiri Limestone (Fig. 2b). Dips in the study area are usually less than 10°.

During the Plio-Pleistocene the Waitomo area was blanketed with volcanic debris, the most recent being the Mairoa ash shower. This adnesitic tephra has a fine granular structure and weathers to a brown sandy loam. The ash cover is variable in thickness from 0-2 m.

FIG:1

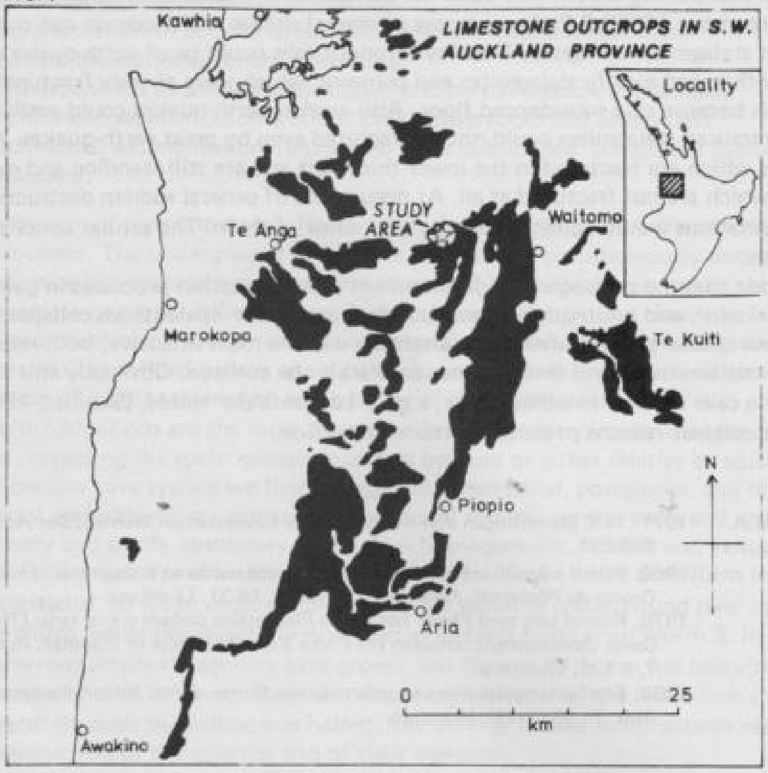


FIG:2a

GENERAL MORPHOLOGICAL-LITHOLOGICAL RELATIONSHIP IN AN IDEALISED STRATIGRAPHIC COLUMN FOR THE STUDY AREA (AFTER NELSON)

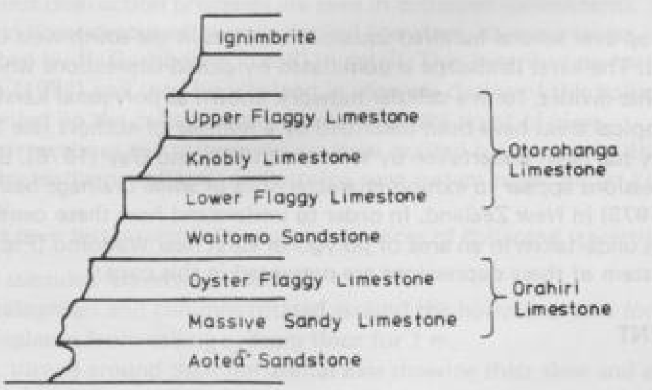
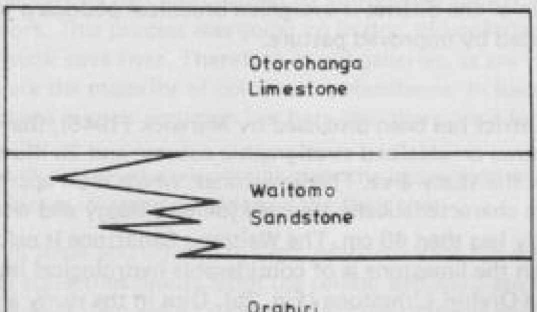


FIG:2b

RELATIONSHIP BETWEEN THE 3 MAJOR UNITS IN THE STUDY AREA



DEPRESSION HYDROLOGY

Working Model

As a first stage in the investigation of depression hydrology a working model was established based on previous research. For conditions in New Guinea polygonal karst Williams (1972) proposed that water moves to the central depression outlet by three main paths: (i) as a thin diffuse film of overland flow; (ii) as flow through organic litter and soil, named subsurface storm flow by Whipkey (1965) and throughflow by Weyman (1970); and (iii) subcutaneous flow that has passed through the upper, most weathered layers of bedrock (Birot, 1966). These three paths form the "near surface lateral flow" components in the initial working model. Pitty (1966) and Drew (1968) emphasised the importance of water percolating directly to subterranean conduits and Gunn (1974) suggested that this percolation water could be divided into two basic types, slow flow and fast flow, with different physical and chemical characteristics. These two types form the "vertical flow" components in the working model.

Sampling Programme

The working model forms the basis of a water sampling programme which was designed to test the proposition that the various flow components may be chemically distinguished as follows:

1. soil water is collected in permanently located tubes designed to intercept water moving in the upper 30 cm of soil (Atkinson, 1971);
2. throughflow water is collected from seepages at the break of slope at the head of vertical open shafts (tomos) at the base of depressions;
3. pipe flow from the sub-cutaneous zone is also collected at the head of tomos;
4. slow percolation (arbitrarily defined as a mean flow less than one litre/week) is collected in containers underneath stalactites in caves underlying depressions, and
5. fast percolation (a mean flow greater than one litre/week) is collected from drip points in caves.

Results

Results for the first 40 weeks of a 60 week sampling period are presented in Table 1. Analysis for Ca^{2+} is by atomic absorption spectrophotometry. It can be seen from the table that waters from sites 1, 2, 3 and 4 are chemically distinct, but that waters from sites 3 and 5 are chemically indistinguishable. The differences may be explained as follows:

Type 1 samples (soil water tubes) represent water which has infiltrated a short distance into the soil. Hardness values are low (less than 10 mg/1 Ca^{2+}), but fluctuate according to the availability of limestone fragments for solution in the soil.

Type 2 samples (seepage outflow) represent water which has moved laterally up to 40 m downslope through the soil and has thus had more time and opportunity to dissolve limestone particles.

Type 3 samples (pipe flow) characterise water which has infiltrated into and moved through the upper layers of limestone. This water frequently emerges along the top of the Waitomo Sandstone, suggesting that this is an important control on the near surface hydrology.

Type 4 samples (slow percolation water in caves) have lower hardness values than either pipe flow or the fast percolation sites. This may be partly due to calcium being precipitated on stalactites before being collected, although this is probably not the whole explanation as water collected from hollow stalactites using a system designed to prevent contact with cave air (Fig. 3) also showed low hardness values. A more likely explanation seems to be that the slower percolation is moving through small, water-filled cavities and thus attains 'closed system' equilibrium (Garrels and Christ, 1965) which is lower than the 'open system' equilibrium attained where there is free (soil) air circulation.

Type 5 samples (fast percolation in caves) cannot be distinguished from pipe flow. This is to be expected as pipe flow water has moved laterally through the limestone in conditions allowing free air circulation and fast percolation water has moved vertically through widened fractures and joints, again with free air circulation. Variation in the Ca^{2+} values may be ascribed to the speed with which the water has moved through the limestone, faster flows not attaining equilibrium and thus having lower hardness values.

Waters of types 1, 2, 3 and 4 can thus be differentiated on the basis of their calcium hardness values, the variation in which may be ascribed to different flow paths that provide unequal opportunities for limestone solution. Detailed geological observations have necessitated modification to the working model as the Waitomo Sandstone forms a layer of low permeability. The sub-cutaneous flow route of Williams (1972) may thus be modified to include water which has percolated vertically through limestone and then moved laterally along the top of a sandstone tongue. Slow percolation may be thought of as having percolated slowly through the sandstone, whilst fast percolation water has moved swiftly through along joints and fractures. The modified model of the hydrologic system of an individual depression is shown in Fig. 4.

The flow routes described above all lead to subterranean streams the solute load of which and discharge hydrograph should thus reflect the relative contribution of each route. The results of 41 water analyses from the Mangapohue Stream are shown in Table 1. The mean hardness is in the same range as pipe flow sites and slightly higher than the two fast percolation sites. This suggests, firstly, that pipe flow and fast percolation are the major contributors to the discharge of the stream and, secondly, that waters arriving in the cave stream may still be slightly aggressive. The stream discharge hydrographs are also being examined to try to isolate the flow components described above.

FIG. 3 Sampling device for slow percolation water to prevent CO_2 loss. (After Picknett and Hendy, pers. comms.)

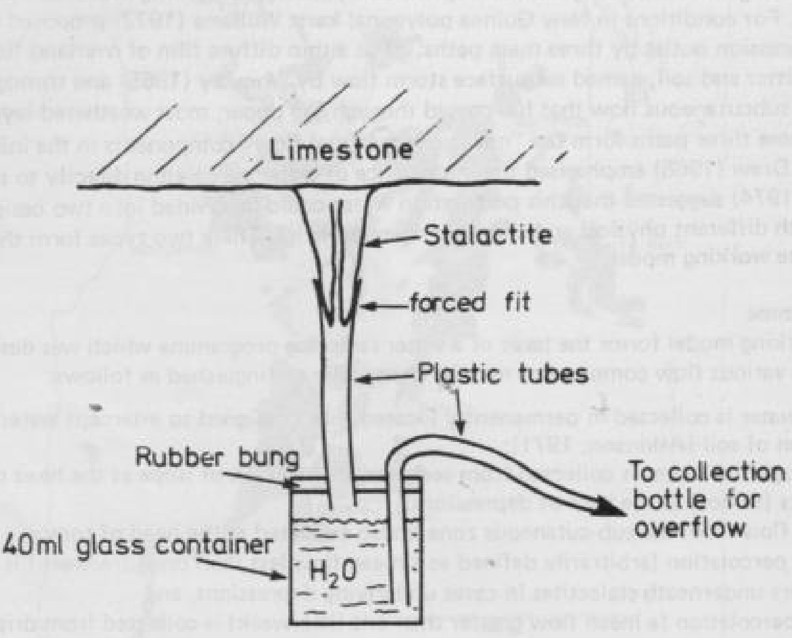
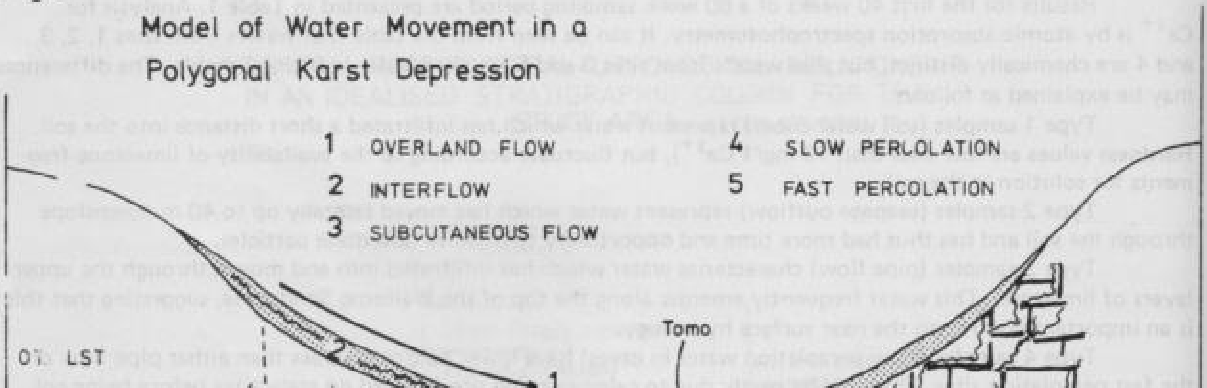


Fig. 4



Conclusion

An area of polygonal karst near Waitomo has been described and similarities with tropical areas pointed out. Results of a water sampling programme indicate that the hydrologic system of individual depressions may be interpreted by means of a five route flow model. Further research is being undertaken to determine the quantitative contribution of each route to the discharge of water and solute load by the cave stream.

Acknowledgements

The work for this paper was undertaken as part of the author's doctoral research at the University of Auckland. It was funded by a Commonwealth Scholarship and supervised by Professor P.W. Williams who provided much helpful advice on the compilation of the draft.

TABLE 1 Ca^{2+} Hardness Values (mg/1)

Water Type	*No. of Samples*	*Mean*	*Standard Deviation*
Rainwater	5	0.97	0.77
Type 1 Samples (soil water tubes)	33	6.1	2.57

TABLE 1 cont'd

Water Type		*No. of Samples*	*Mean*	*Standard Deviation*
Type 2 Samples	site a	40	14.0	3.92
(seepage outflow)	site b	34	24.4	6.75
Type 3 Samples	site a	39	41.3	3.42
(pipe flow)	site b	21	51.0	4.59
	site c	35	49.0	4.56
Type 4 Samples	site a	26	35.7	3.23
(slow percolation)	site b	37	35.0	3.87
	site c	39	38.2	6.60
	site d	39	32.0	5.68
Type 5 Samples	site a	40	40.1	3.42
(fast percolation)	site b	38	46.7	4.68
Cave Stream Water		41	48.9	5.06

References

Atkinson, T.C. 1971. *Hydrology and Erosion in Limestone Terrain.* Unpubl. Ph.D. Thesis, Bristol.

Birot, P. 1966. Étude d'usure d'un versant calcaire sous un climat tropical humids, in *Macar, P. ed., l'Evolution des Versants: Colloque Internat. Univ. Liege,* p.69-74.

Barrett, P.J. 1962. *The Te Kuiti Group in the Waitomo-Te Anga Area.* Unpubl. M.Sc. Thesis, University of Auckland.

Coulter, J.D. 1973. A water balance assessment of New Zealand rainfall. *J. Hydrol. (N.Z.)* 12, 2, 1973.

Day, M. 1976. The Morphology and Hydrology of Some Jamaican Karst Depressions. *Earth Surface Processes* 1, 2, 111-129.

Drew, D.P. 1968. Tracing percolation waters in karst areas. *Trans. Brit. Cave Res. Grp.* 10, 2, 107-14.

Garrels, R.M. & Christ, C.L. 1965. *Solutions, Minerals and Équilibria.* Harper and Row, New York.

Gunn, J. 1974. A model of the percolation system of Waterfall Swallet, Derbyshire. *Trans. B.C.R.A.* 1, 3, 156-164.

Kermode, L. 1975. Geological setting of the Glowworm Cave, Waitomo. *N.Z. Speleo. Bull.* 5, 92, 361-9.

Marwick, J. 1946. *The Geology of the Te Kuiti Subdivision,* N.Z. Geol. Survey Bull. No. 41.

Nelson, C.S. 1973. *Stratigraphy and Sedimentology of the Te Kuiti Group, Waitomo County,* Unpubl. Ph.D. Thesis, University of Auckland.

Pitty, A.F. 1966. An approach to the study of Karst Water. *Univ. of Hull. Occ. Papers in Geog.* No. 5.

Pringle, J.M. 1973. *Morphometric analysis of surface depressions in the Mangapu Karst.* Unpubl. M.A. Thesis, University of Auckland.

Sweeting, M.M. 1972. *Karst Landforms.* MacMillan, London, 362pp.

Weyman, D.R. 1970. Throughflow on hillslopes and its relation to the stream hydrograph, *B.I.A.S.H.,* 15, 2, 25-33.

Whipkey, R.Z. 1965. Subsurface storm flow from forested slopes, *B.I.A.S.H.*, 10, 74-85.

Williams, P.W. 1972. Morphometric analysis of Polygonal Karst in New Guinea. *B.G.S.A.*, 83, 761-796.

THE HYDROLOGY OF POLYGONAL KARST IN THE WAITOMO AREA, NORTH ISLAND, NEW ZEALAND

John Gunn,
Department of Geography,
University of Auckland,
New Zealand

Oligocene limestones outcrop over several hundred square kilometres in the south-west portion of Auckland Province, North Island, New Zealand. Well developed interlocking depressions occur over much of the limestone area forming a cellular network known as polygonal karst (Williams, 1972). Within the polygonal karst areas there is little perennial surface drainage and flow is concentrated in conduits in the shallow ground-water zone. Many of these conduits are accessible to man and have been explored and surveyed by members of the New Zealand Speleological Society. Polygonal karst has been described in many tropical limestone areas (see refs in Sweeting, 1972) and some authors have suggested that a tropical climate is essential for its development. However, Pringle (1973) has shown that the Mangapu karst in the North Island of New Zealand is morphometrically similar to areas of polygonal karst described by Williams in New Guinea. In this paper, the hydrology of an area of polygonal karst near Waitomo is described and similarities to Jamaican polygonal karst are noted.

THE WAITOMO POLYGONAL KARST

Climate and Vegetation

The study area is located about ten kilometres west of Waitomo Caves at an elevation of 300-350 m (Fig. 1). Two years of records give an annual precipitation of 2500 mm. Coulter (1973) estimates mean potential evapotranspiration for the area as 750 mm, leaving an annual water surplus of 1750 mm.

The natural vegetation of the district is broadleaf podocarp forest, but this has been cleared over much of the area and replaced by improved pasture. Research is at present underway to determine the hydrological effects of this clearance.

Geology and Soils

An idealised stratigraphic column for the district is shown in Fig. 2a. Within the study area only three units are present: the Otorohanga Limestone, the Waitomo Sandstone, and the Orahiri Limestone. The limestones are biocalcarenites of Oligocene age and are characteristically strongly jointed, flaggy, and well bedded (Nelson, 1973). The glauconitic, calcareous Waitomo Sandstone occurs as tongues within the Orahiri Limestone (Fig. 2b). These form important less-permeable bands.

During the Plio-Pleistocene the Waitomo area was blanketed with volcanic debris, the most recent being the Mairoa ash shower. This andesitic tephra has a fine granular structure and weathers to a brown sandy loam.

Landforms

As part of a larger study of the hydrologic and solutional processes in polygonal karst two small areas of about 500 m^2, one under forest and one under improved pasture, were chosen for detailed study and comparison. The following discussion refers only to the area under forest, most of which has been mapped by compass traverse (Fig. 3). The positions of all stream sinks, risings, cave entrances, and vertical shafts are also shown on Figure 3, as are the surveyed traces of all accessible cave passages. The enclosed depressions are of a variety of shapes and sizes, though the majority are roughly polygonal, 40-75 m in diameter, and 10-30 m in depth. Two types of depression may be recognised: those which have some form of vertical shaft (tomo) situated at their lowest point (Type 1), and those with no obvious outlet (Type 2). In all cases so far examined the lip of the shaft in the Type 1 depressions corresponds to an outcrop of the Waitomo Sandstone, while Type 2 depressions frequently have shallow ponds at their base, suggesting that the sandstone has not yet been breached. The shafts vary in depth from 5 to 35 m and the majority are blocked at depth or lead to tight rift caves which can only be followed for short distances.

The Type 1 depressions are often asymmetric in plan, their long axis being orientated in the direction of the major fault/joint traces in the area. These depressions are also frequently asymmetric in their long axis cross section, the shorter slopes being considerably steeper than the longer slopes. Bare rock frequently outcrops on the steeper slopes, showing well developed karren and solutional enlargement along joints. Smith et al (1972) and Day (1976) describe areas of Cockpit Karst in Jamaica which would appear to be remarkably similar to the Waitomo polygonal karst.

Hydrology

The study area is drained by the Mangapohue Stream and four of its tributaries (Fig. 3). Research is in progress to determine the precise catchment area of each of these streams and the relationship between surface and subsurface features.

Water Tracing

At the time of writing 17 successful traces have been carried out and more are planned. (Fig. 3). In all cases fluorescein dye was introduced into water sinking at the base of Type 1 depressions; detection was by charcoal bags and fluorometer. Detector bags were usually removed one week after dye introduction; thus precise flow through times are not available for most of the traces. In the case of the traces from depressions 27, 28 and 35, however, it was possible to observe the dye in the Max's Cave Stream. The calculated straight line flow velocities are 275, 325 and 125 m/hr respectively. Surface streams sink in depressions 27 and 28 so that the two high flow velocities probably represent the speed of travel in the conduit system, whereas the water from depression 35 probably percolated vertically at a relatively slow rate before reaching an open conduit.

depression 35 probably percolated vertically at a relatively slow rate before reaching an open conduit.

All the depression outlets so far traced drain to only one of the four streams which suggests that each cave stream has a discrete catchment. This is in agreement with conclusions drawn by Day (1976) and Smith et al (1972) in Jamaica.

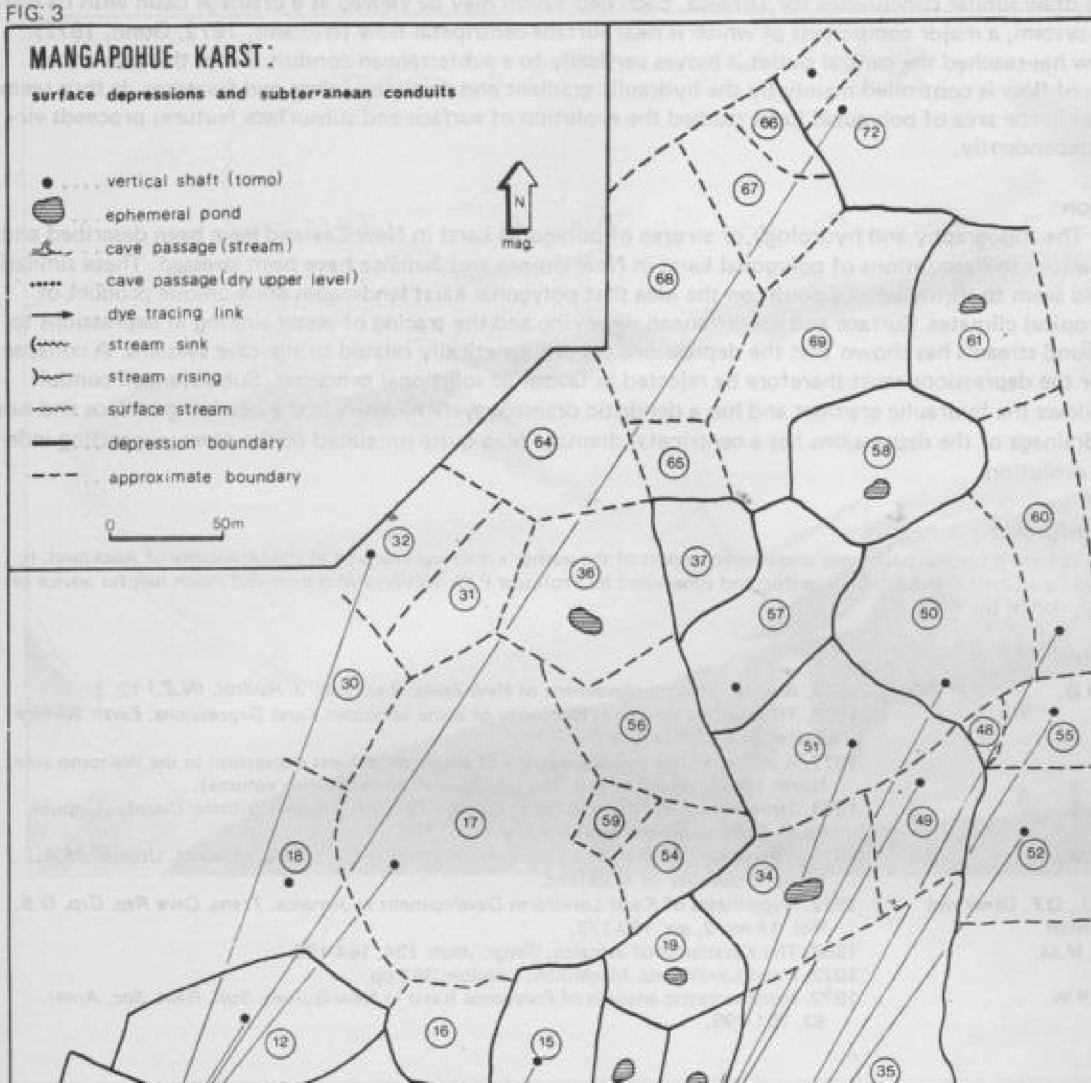
While the techniques described above have proved adequate for Type 1 depressions with open shafts, considerable difficulty has been experienced in tracing water from Type 2 depressions with no obvious outlets. Initial attempts using Pyranine Conc scattered around the base of the depression were unsuccessful as were attempts to wash the dye into a joint.

The presence of a sandstone of low permeability beneath the floor of these depressions often results in ponding following heavy rainfall and it seems likely that water from these depressions percolates slowly through the sandstone or moves laterally down – dip into another depression. Sweeting (1958) ascribed similar ponding in the Cockpit Country of Jamaica to the impermeable nature of a residual clay in the bottoms of affected cockpits.

Surface and Subsurface Features

The cave surveys and dye tracing links (Fig. 3) indicate that the underground drainage system is dendritic and bears little relationship to the surface topography. Since caves may underlie any part of a depression, collapse is unlikely to play any part in the evolution of depressions and they must be viewed as solutional features. The vertical shafts in Type 1 depressions are, however, almost certainly partly collapse features. Smith et

FIG: 3


MANGAPOHUE KARST:
surface depressions and subterranean conduits
vertical shaft (tomo)
ephemeral pond
cave passage (stream)
cave passage (dry upper level)
dye tracing link
stream sink
stream rising
surface stream
depression boundary
approximate boundary
0
50m
N
mag.
J P Cave
Cymru Passage
Mangapohue Cave
Max's Cave

al (1972) draw similar conclusions for Jamaica. Each depression may be viewed as a drainage basin with its own drainage system, a major component of which is near surface centripetal flow (Williams, 1972; Gunn, 1977). Once flow has reached the central outlet it moves vertically to a subterranean conduit. From this point the direction of flow is controlled mainly by the hydraulic gradient and partly by joints and fractures. It thus seems likely that in the area of polygonal karst studied the evolution of surface and subsurface features proceeds virtually independently.

Conclusion

The topography and hydrology of an area of polygonal karst in New Zealand have been described and the similarities to descriptions of polygonal karst in New Guinea and Jamaica have been stressed. These similarities would seem to throw serious doubt on the idea that polygonal karst landscapes are a unique product of humid tropical climates. Surface and subterranean surveying and the tracing of water sinking in depressions to underground streams has shown that the depressions are not genetically related to the cave systems. A collapse origin for the depressions must therefore be rejected in favour of solutional processes. Subterranean conduit water follows the hydraulic gradient and has a dendritic drainage system, whereas the overlying surface and near surface drainage of the depressions has a centripetal drainage plan quite unrelated to the caves, suggesting independent evolution.

Acknowledgements

The work for this paper was undertaken as part of the author's doctoral research at the University of Auckland. It was funded by a Commonwealth Scholarship and supervised by Professor P.W. Williams who provided much helpful advice on the compilation of the draft.

References

Coulter, J.D. 1973. A water balance assessment of New Zealand rainfall. *J. Hydrol. (N.Z.)* 12, 2.

Day, M. 1976. The Morphology and Hydrology of some Jamaican Karst Depressions. *Earth Surface Processes* 1, 2, 111-129.

Gunn, J. 1977. A model of the drainage system of a polygonal karst depression in the Waitomo area, North Island, New Zealand. 7th Int. Speleo. Congress (this volume).

Nelson, C.S. 1973. *Stratigraphy and Sedimentology of the Te Kuiti Group, Waitomo County.* Unpubl. Ph.D. Thesis, University of Auckland.

Pringle, J.M. 1973. *Morphometric analysis of surface depressions in the Mangapu karst.* Unpubl. M.A. thesis, University of Auckland.

Smith, D.I., D.P. Drew and T.C. Aktinson 1972. Hypotheses of Karst Landform Development in Jamaica. *Trans. Cave Res. Grp. G.B.* Vol. 14 no. 2, pp. 159-173.

Sweeting, M.M. 1958. The Karstlands of Jamaica. *Geogr. Jour.* 124, 184-199.
1972. *Karst Landforms.* MacMillan, London, 362 pp.

Williams, P.W. 1972. Morphometric analysis of Polygonal Karst in New Guinea. *Bull. Geol. Soc. Amer.* 83, 761-796.

AIR CONDITIONING SURFACE BUILDINGS WITH CAVE AIR

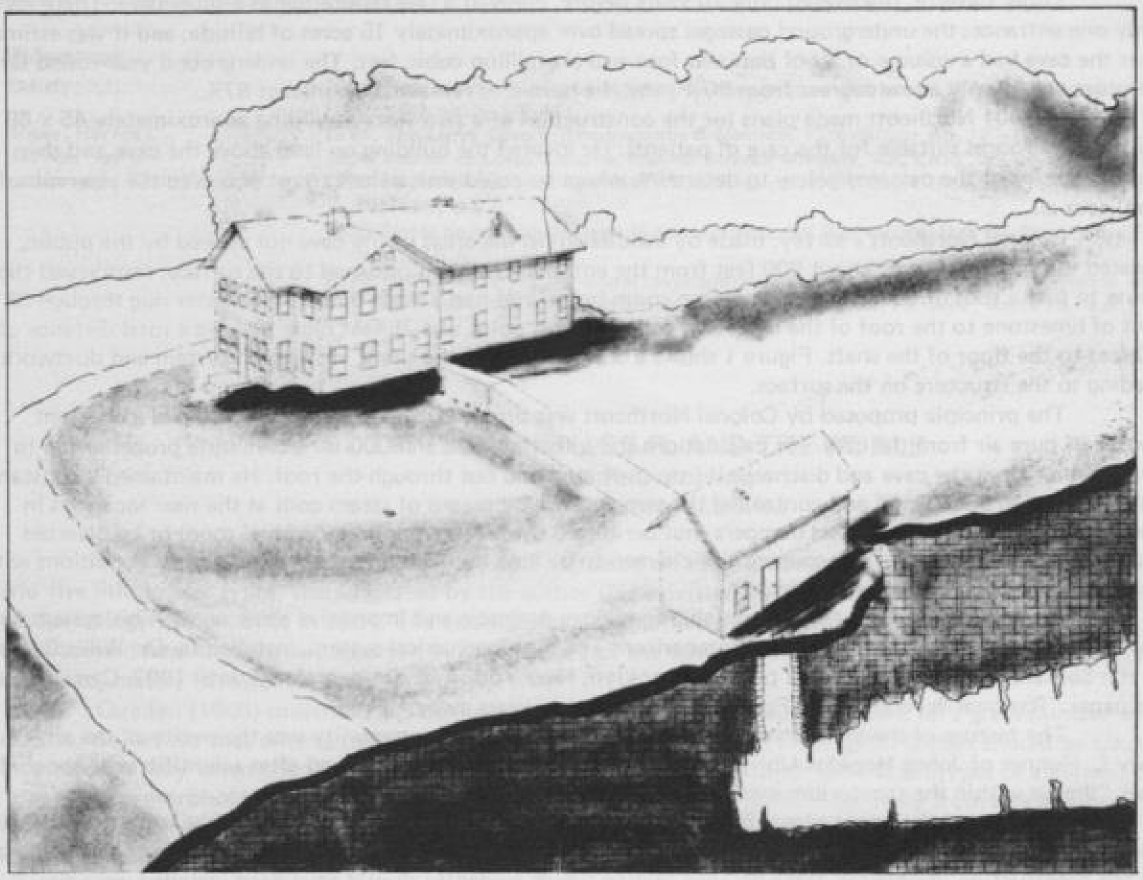
Russell H. Gurnee
231 Irving Avenue, Closter, New Jersey 07624
U.S.A.

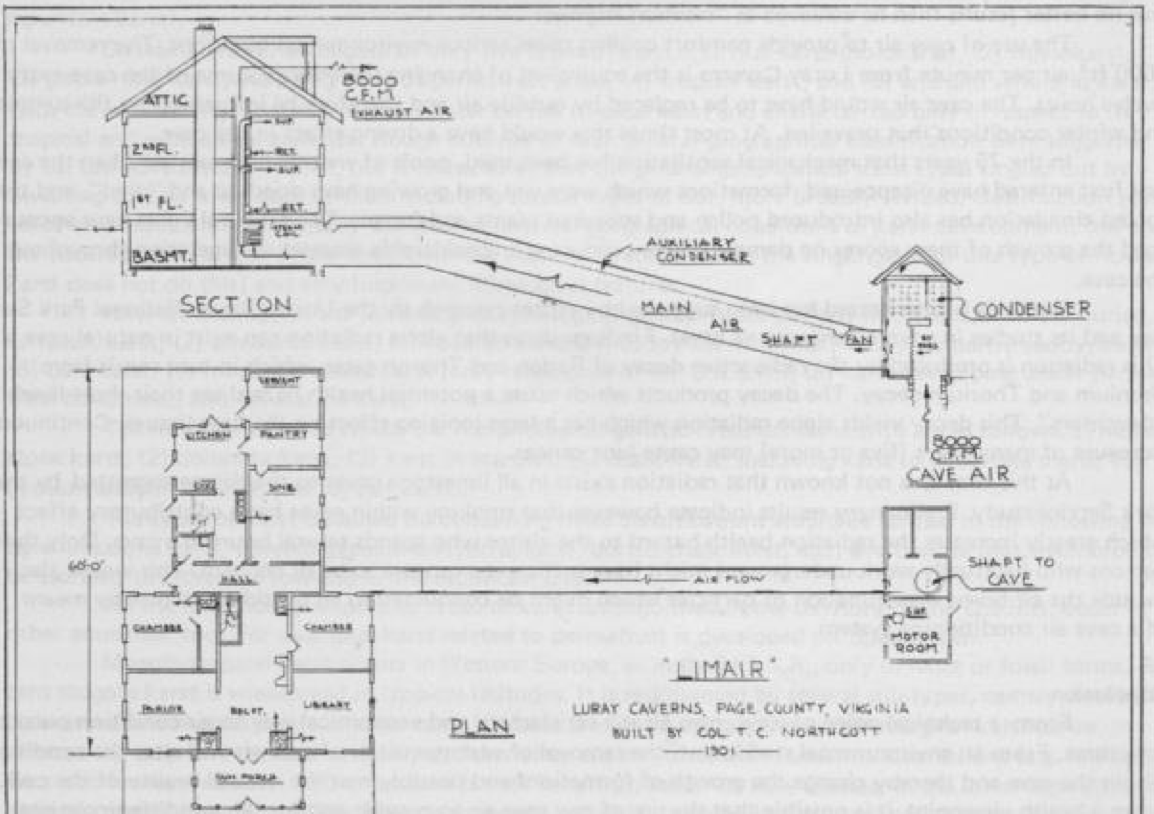
Air conditioning as defined today is the control of the atmosphere within an enclosed space. This includes control of temperature, humidity, air movement and filtration. As a science this is a relatively new concept. Until the 18th Century air was considered by the scientific community as an element. It was only 200 years ago that it was defined as a mixture of individual elements.

Perhaps the earliest example of a controlled environment occurred naturally in caves. These chambers of uniform temperature, humidity, air movement and filtration were the homes of primitive man, and they become enduring test chambers that preserved evidences of his work, art and earthly remains. It was inevitable that the natural environment within caves would be exploited, first by primitive man as shelter, then as storage, later an an important step in the aging and curing of wines, beer and cheeses. In recent times artificial cellars have been dug and used as storage for vegetables and fruits, simulating the conditions which occur in nature in limestone caverns located in temperate zones.

The development of mechanical refrigeration in 1875 permitted the manufacture of ice, leading to a revolution in the food-processing industry and in turn affecting the diet and general health of the entire world. It had profound social impact in industrial nations, as it permitted greater concentrations of people in urban areas and affected developing nations, as they could export their perishable foods.

In 1900 Colonel T.C. Northcott, a retired heating and ventilating engineer, purchased Luray Caverns in Virginia, U.S.A. He had visited the cave in 1899, became intrigued with the possibility of using the cave air (which appeared to be extremely healthful) as a means of heating, cooling and ventilating an outside structure. The health aspects of cave air had been the subject of several experiments by medical doctors for nearly a hundred years. None of the experiments had been successful, when the patients had been located within a cave, and Colonel Northcott believed that the problem was in the method of housing, not in the attributes of the cave air. He approached the problem with a thorough background of engineering as it was known at that time.





8000 C.F.M. EXHAUST AIR
ATTIC
2ND FL.
1ST FL.
BASMT.
SUP
RET
AUXILIARY CONDENSER
SECTION
MAIN AIR SHAFT
FAN
CONDENSER
8000 C.F.M. CAVE AIR
KITCHEN
PANTRY
HALL
CHAMBER
PARLOR
LIBRARY
60'-0"
45'-0"
AIR FLOW
SHAFT TO CAVE
MOTOR ROOM
"LIMAIR"
PLAN
LURAY CAVERNS, PAGE COUNTY, VIRGINIA
BUILT BY COL. T. C. NORTHCOTT
1901

Luray Caverns, discovered only 20 years before, enjoyed a fine reputation as a show cave. There was only one entrance; the underground passages spread over approximately 15 acres of hillside; and it was estimated that the cave had a volume of air of between four and six million cubic feet. The underground year-round temperature varied only a few degrees from 56°F, and the humidity remained a constant 87%.

In 1901 Northcott made plans for the construction of a two-storey building approximately 45 x 60 ft. with twelve rooms suitable for the care of patients. He located the building on land above the cave and then made a survey of the passages below to determine where he could sink a shaft to get access to the reservoir of cool cave air.

Colonel Northcott's survey, made by candlelight in the areas of the cave not viewed by the public, located the proposed shaft about 800 feet from the entrance. He then returned to the surface, resurveyed the route to find a spot directly above the chosen room below and had a shaft 5 feet in diameter dug through 35 feet of limestone to the roof of the cave. The ceiling at this point was 25 feet high, making a total distance of 60 feet to the floor of the shaft. Figure 1 shows a cross section of the shaft, ventilation system and ductwork leading to the structure on the surface.

The principle proposed by Colonel Northcott was simple but imaginative. He assumed a constant source of pure air from the cave. His calculations show that he used an 8000 ft^3-per-minute propeller fan to draw the air from the cave and discharge it into the house and out through the roof. He maintained a constant volume flowing at all times and controlled the temperature by means of steam coils at the riser locations in the house and by manual by-pass dampers that permitted the air to enter an individual room or be diverted out the roof at the will of the occupant. He claimed to be able to maintain summer and winter conditions within the house of 70°F, 70% relative humidity.

There is no question that he was able to make a dramatic and impressive showing with his system. At the time there was no other system for comparison. The first mechanical system, installed by Dr. Willis Carrier in the Sackett-Wilhelms Lithograph plant in Brooklyn, New York, was not completed until 1902. Carrier's classic paper "Rational Psychrometric Formulae" was a dozen years away.

The feature of the installation that impressed the scientific community was the purity of the air. Dr. Guy L. Hunner of Johns Hopkins University Medical School visited the cave and after scientific tests concluded that "the air within the sanatorium was practically free of bacteria."

A survey of the house plans (Fig. 2) shows that Colonel Northcott was remarkably accurate in his heat gain and heat loss calculations. Unfortunately the building was destroyed by fire in 1940, making investigation of the construction impossible. (One obvious feature which evidently should have been installed were fire dampers in the vertical flues).

The designer today would probably use partially recirculated air, filter all of the supply air, introduce outside air to pressurize the building, and exhaust sufficient air to give freshness to the rooms. However he would arrive at a system which would do no more than the original system and use much more energy. The greatest advance would be in the area of controls, motorized dampers, thermostats, humidistats and timing devices that would provide a total environment at the flick of a switch. It would delight Colonel Northcott, but probably give no better results than he achieved as "resident engineer".

The use of cave air to provide comfort cooling raises serious environmental questions. The removal of 8000 ft^3 air per minute from Luray Caverns is the equivalent of changing the entire volume of the cave every twelve hours. The cave air would have to be replaced by outside air and therefore be influenced by the summer and winter conditions that prevailed. At most times this would have a drying effect in the cave.

In the 75 years that mechanical ventilation has been used, pools of water which existed when the cave was first entered have disappeared, formations which were wet and growing have dried up and "died", and the forced circulation has also introduced pollen and spores of plants and fungus. The artificial lights have encouraged the growth of these spores on damp surfaces producing a considerable amount of vegetation throughout the cave.

A serious health hazard has been suggested by recent research by the United States National Park Service and its studies in government-owned caves. Findings show that alpha radiation can exist in natural cave air. This radiation is produced by the radioactive decay of Radon and Thoron gases, which in turn result from Uranium and Thorium decay. The decay products which cause a potential health hazard are their short-lived "daughters". This decay yields alpha radiation which has a large ionizing effect on the lung tissues. Continuous exposure of many years (five or more) may cause lung cancer.

At this time it is not known that radiation exists in all limestone caves to the degree suggested by the Park Service study. Preliminary results indicate however that smoking within caves has a contributory effect which greatly increases the radiation health hazard to the visitor who spends several hours in a cave. Only those persons who habitually work underground might have sufficient exposure to be of concern. This would also include the air-borne dissemination of particles which might be conducted to an outside structure by means of a cave air conditioning system.

Conclusion

From a technical point of view, cave air is a satisfactory and economical way to air condition outside structures. From an environmental standpoint, the removal of vast quantities of cave air will alter the conditions within the cave and thereby change the growth of formations and possibly mar the natural beauty of the cave. From a health viewpoint, it is possible that the use of raw cave air to provide comfort air conditioning might provide exposure to radiation contributory to causing illness. In weighing the advantages of the inexpensive cooling and filtration obtained from the cave air against the disadvantages, it does not appear that the use of

cave air for air conditioning is advisable.

References

Claudy, C.H. 1908. How cave air is used to regulate the temperature of a house. *Scientific American*, Vol. 98, pp. 353-354.

Hovey, Horace C. 1924. The Luray Cavern. *Encyclopedia Britannica*, 13th edition, pp. 127-128.

Hunner, Guy L. 1904. The air of Luray Caverns. *Popular Science Monthly*, vol. LXIV, no. 36, pp. 557-564.

Yarborough, Keith A., et. al. 1976. Radiation monitoring in Nat. Pk. Service caves. SW Reg. Office. Nat. Pk. Serv., Santa Fe, N.M., U.S.A.

1976. Notes on natural air flows in cave systems. SW Reg. Office, Nat. Pk. Serv. Santa Fe, N.M., U.S.A.

1976. Radiation survey of natural caves administered by the Nat. Pk. Serv. for Radon and Thoron radioactive decay products. SW Reg. Office, Nat. Pk. Serv., Santa Fe. N.M., U.S.A.

KARST TYPES IN THE U.S.S.R. AND THE WORLD

N.A. Gvozdetsky
(Moscow, U.S.S.R.)

A classification of karstlands of the U.S.S.R., based on the combination of six morphological-genetic and five lithological types, was suggested by the author (Gvozdetsky, 1965) at the International Conference on Speleology held at Brno in 1964. The classification is amplified in this paper, and also some karst types are discussed here that are not observed in the territory of the Soviet Union but are known to occur in other countries, mostly in lower (tropical) latitudes.

Quinlan (1966) presented a classification approximating ours, but it is based on a great number of criteria. We believe that criteria following the morphological-genetic and lithological factors should be taken into account only when dividing the types into smaller classificational units, such as subtypes or varieties, etc.

The morphological-genetic types distinguished by the author differ essentially from one another morphologically and genetically in that they comprise diverse superficial (and occasionally subterranean) karst forms and their combinations. The reason for taking due account of the lithological differences even when singling out the types is that the non-uniform solubility of rocks, the rate of solution and the rapidity of saturation of the solvent, differences in the processes of solution of carbonate and non-carbonate rocks and their non-uniform changes due to temperature (and hence climatic) conditions — all these affect the specific features of development of karst, its morphology and practical (particularly engineering-geological) evaluation.

The types of karst obtained from combining the morphological-genetic and the lithological classifications are grouped into two classes of lowland and mountain karst (with subclasses of low-, mid- and high-mountain karst).

Sweeting (1972) distinguishes only five types of karst: (1) true karst (holokarst), (2) fluviokarst, (3) glacio-nival karst, including karst of permafrost areas, (4) tropical karst, and (5) arid and semi-arid karst, with the latter being discussed in the chapter on the tropical karst and characterized only in respect to its tropical and subtropical varieties. Rough outlines of such general-geographical classification were suggested by us, too (Gvozdetsky, 1954), but it seems to us that the general-geographical karst types singled out by Sweeting are too wide, each of them including several types of our, more broadly divided, classification which takes into consideration not only the general physical-geographical conditions of karst development, but also the nature and thickness of the cover over the karstifying rocks (while the singling out of one type of fluviokarst does not do this) and very important lithological features.

Now we distinguish the following morphological-genetic types of karst in the U.S.S.R.: (1) buried, or fossil, karst; (2) armoured karst; (3) covered karst; (4) soddy karst; (5) half-soddy, or partly soddy, karst; (6) bare karst; (7) mogote tropical karst (only relict ones in the U.S.S.R.); (8) karst developing under permafrost conditions; and (9) marine karst.

The lithological types which the morphological-genetic types combine with are as follows: (1) limestone karst; (2) dolomite karst; (3) karst in marbles; (4) chalk karst, including karst in chalk-like marls; (5) gypsum-anhydrite karst; and (6) salt karst.

The types of karst obtained by combining these classifications would be termed in the following way: bare limestone karst, covered gypsum-anhydrite karst, buried chalk karst, etc., and besides that, each type can be ascribed to either the lowland or the mountain class.

All the morphological-genetic types of karst distinguished in the territory of the U.S.S.R. occur in other countries, too. For example, karst related to permafrost is developed on Spitzbergen.

Mogote tropical karst occurs in Western Europe, as in the U.S.S.R., only in relict or fossil forms. Recent mogote karst is widespread in tropical latitudes. It is represented by several sub-types, namely, tower, cone and dome-shaped karst. In some cases mogotes are found upstanding within marginal karst plains, in others they may be unrelated to these, and then they are conjunct with numerous depressions (e.g. in Puerto Rico and locally in Cuba). Rather unusual is the "labyrinth karst" in New Guinea, in the lower high-altitude zone of tropical karst in the Star Mountains, where pyramid-shaped hills are combined with rounded dolines (Verstappen, 1964).

A transitional type between bare and mogote tropical karsts is that of the tropical karst with gigantic

sharp karren edges, described in Indo-China (Cuisinier, 1929). Probably similar to it is also the famous "Stone forest" on the Yünnan Plateau in China, which is regarded also as a surface with karren (Gellert, 1966).

Rather unusual morphological types of tropical karst are those of karstified surfaces with continuous distribution of deep steep-sided cavities (locally in Cuba and Jamaica) and the karst of low maritime plains with waterlogged tunnels and gaps in the surface (Yucatan and Florida).

Also in tropical and equatorial latitudes there are found to occur such morphological-genetic types as have their analogues in the karst of temperate regions. For example, in Cuba we happened to observe almost bare mountains, karst in combination with mogote karst, the lowland partly soddy afforested karst, or with solutional dolines and pans, and lowland covered karst. Though all these morphological-genetic types of karst are similar to the corresponding karst types of the temperate latitudes, they should be regarded as specific types of tropical karst (Gvozdetsky, 1972). The karst of coral reefs rising above the level of oceanic breakers should also be considered as a separate morphological-genetic type of the tropical karst.

A particular variety of bare karst is found to occur in the sub-boreal zone in glacial drift areas, a bare character of the limestone surface being associated with the drift here. Such bare karst with moss-covered karren and limestone protuberances in the form of small residual outcrops is observed on Gotland Island in the Baltic. (Gvozdetsky, 1970).

Bare marine karst is widespread over the Dalmatian coast of the Adriatic Sea in Yugoslavia, which owes its origin to the solvent action of sea water both above and below high-tide mark (Zenkovich and Kaplin, 1965). It occurs rarely in the U.S.S.R., e.g. on the Caspian coast (Mangyshlak Peninsula).

The main types of karst on Earth are distinguished, like those in the U.S.S.R., by combining the morphological-genetic and the lithological classifications. Certain types can be represented only by one lithological variety (e.g. karst of coral reefs and probably mogote tropical karst can be only one limestone type). Many types are common for both the U.S.S.R. and other countries. The grouping of types into classes of lowland and mountain karst also maintains its importance, as does the distinguishing of sub-classes of karst on the bases of altitudinal zonality. A number of types, e.g., marine karst, coral-reef karst, and the tropical karst of maritime plains, are not found to occur in the mountains at all.

References

Cuisinier, L. 1929. Régions calcaires de l'Indochine. *Annales de Géographie*, N213, 38 année, 15 Mai.
Gellert, I.F. 1966. Tropicheskiy bashennyi i konicheskiy karst. *Vestn. Mosk. un-ta, ser. geogr.*, No. 5.
Gvozdetsky, N.A. 1954. *Karst*, Izd. 2-e, Moskva.
1965. Types of karst in the U.S.S.R. "Problems of the Speleological Research", Prague.
1970. *Po zarubezhnoi Evrope.* Moskva.
1972. Karstovye landshafty i tipy karsta. *Vestn. Mosk. un-ta, ser. geogr.*, No. 5.
Quinian, J.F. 1966. Classification of karst and pseudokarst types: a review and synthesis emphasizing the North American literature, 1941-1966. Paper, 123rd Meeting of Amer. Assoc. Adv. Sci. Symposium on 25 Years of American Speleology.
Sweeting, M.M. 1972. *Karst landforms.* London and Basingstoke.
Verstappen, H.Th. 1964. Karst morphology of the Star Mountains (Central New Guinea) and its relation to lithology and climate. *Zeitschr. f. Geomorph.*, Bd. 8, H. 1.
Zenkovich, V.P. & Kaplin, P.A. 1965. Podvodnye geomorfologicheskie issledovaniya na Dalmatinskom poberezhye. *Izv. AN SSSR*, ser. geogr., No. 3.

GENETIC TYPES OF SUPERFICIAL KARST FORMS

N.A. Gvozdetsky
(Moscow, U.S.S.R.)

Superficial karst forms include karren, trenches (bogaz), dolines, kettles, poljes, mogotes (residual outcrops), etc. This paper will deal with karren, dolines, kettles and poljes.

In terms of genesis, the following types should be distinguished among karren: (1) forms that originated on exposed surfaces of soluble rocks, and (2) forms that developed under a soil-vegetation cover with its subsequent removal (Cvijic, 1924). Karren of the second type are known to occur in many countries, England among them. "The classic limestone pavements of Malham and elsewhere in the Pennines are thought to have developed under a soil cover which has since been eroded away" (Hanwell and Newson, 1973, p. 148).

In terms of morphology, karren are divided into rillenkarren, wandkarren, lunkas (small hemispherical hollows), tubular karren (observed only in gypsum), kamenitzas, trittkarren, rinnenkarren, mäanderkarren, kluftkarren, etc. (Bögli, 1960; Gvozdetsky, 1972). By their genesis, the first and last of these stand out among all the others. The former, rillenkarren, are noted for the fact that they are formed solely under the effect of atmospheric precipitation, during the first three phases of solution of limestone, according to Bögli, without participation of his phase 4. The rest of the karren types are the work of all the phases of solution. Waters enriched with biogenic CO_2, due to the rain and snow-melt water coming into contact with the soil-vegetation cover, participate in their formation, too. The latter, kluftkarren, differ from the rest in the ways by which the solutes are removed. While with the majority of other types of karren the removal is realized solely through surface runoff, with the development of kluftkarren the solutes are removed underground along fissures.

In our morphological classification of karren there are no sharp spitzkarren and no rundkarren singled out as such by other authors (Bögli, 1960; Sweeting, 1972). The point is that it is only negative surface forms that we attribute to karren, whereas here the ridges separating the furrows or hollows of the karren are dis-

tinguished morphologically.

Kotarba (1970), a Polish scientist, distinguishes three main types of karren in the limestone of the Western Tatra, namely runoff, fissure and egutational karren. Development of the latter is related to the action of water dripping on to the surface of limestone from the snow covers. Runoff karren are divided into those formed by rain water, snow-melt water, and water infiltrating through the soil-vegetation cover. If the nature of the solvent is considered, then some other karren can be singled out, viz. karren formed by river-water solution and sea-water solution, – marine karren (Sweeting, 1972). But in these cases, inadequately studied so far, features of the same morphological types often develop. For example, lunka karren are found to occur in the near-channel karst (Gvozdetsky and Marinin, 1976). They are abundant in marine karst, as seen in the karst along the coast of the Mangyshlak Peninsula (Caspian Sea).

Thus, several genetic classifications of karren are taking shape, that take into account the presence or absence of direct or indirect influence of the soil-vegetation cover, the source and the nature of solvent water, and the ways of removal of solutes. The creation of a single genetic classification is a matter of further investigation.

There are distinguished three main genetic types of dolines (Gvozdetsky, 1954; Corbel, 1957, p. 487). (Nearly the same types are distinguished by Sweeting, 1972). (1) Solutional, or purely corrosional, dolines develop as a result of the rock being leached on the surface and removed along underground channels in a dissolved state. (2) Collapse, or gravitational, dolines are the result of collapse of cave roofs by leaching karst rocks at depth and removal of the material in a dissolved state. (3) Suction, or corrosional-suffosional, dolines are formed by inwashing and sagging of the loose mantle deposits into cavities of the karst base, removal of the particles into the subsurface channels, and their further removal along the channels in a suspended state. A type transitional between types 2 and 3 is of common occurrence.

Besides the three main types and the transitional type, a few others can be mentioned. Corrosion-erosion dolines developing from ponors (sink holes) in the floors of ravines or poljes are genetically rather similar to solution dolines. A rather rare type is that of the dolines produced by the action of non-gravity springs (Gvozdetsky, 1954; 1972).

Dolines of all the genetic types, upon coalescing with their neighbours constitute double, triple and more complicated hollows some of considerable sizes are called uvalas in Yugoslavia. Two main type of uvala are distinguished, namely, complex uvalas formed by coalescence of several large dolines (vrtača), with a number of hollows in the floor, and flat-bottomed "kettles". Genetically, "kettles" can be divided into solutional, collapse, and suction "kettles", and also these types in combination with other processes, e.g. with erosion. Large solution kettles can be formed due to the corrosive action of melt-water from snow and firn patches (Gvozdetsky, 1954). Many of such kettles are an inheritance of the periglacial conditions of the latest ice age (e.g., in the Crimean Mountains and in the Caucasus).

Poljes were divided until recently (Shchukin, 1964) into the following types by their origin: (1) Tectonic poljes, (2) Poljes formed by underground mechanical removal of the insoluble rock interbedded with the limestones or in contact with them, (3) Poljes formed by coalescence of a group of neighbouring dolines and kettles (uvalas) upon their enlarging in horizontal direction, and (4) Collapse poljes. In our opinion, large kettles of purely tectonic origin (grabens, synclinal downwarps, etc.) cannot be considered to be poljes. The development of poljes necessarily involves participation of the dissolution and then removal of solutes along underground channels. Therefore the first type should include tectonic-corrosional and tectonic-corrosion-erosional poljes, where a major part of large poljes in Yugoslavia probably belong. Poljes of the second type are widespread. In the Transcaucasus these are the Shaor and the Akhalsopei Kettles and the Ze-Gvardii Polje (Gvozdetsky, 1954, 1972; Sokolov, 1962), and in Yugoslavia – the Daborsko, the Fatnićke and the Plansko Poljes (Kosmowska-Suffszyńska, 1967). Poljes of the third type, usually small ones and of an irregular lobed shape in plan, are known to occur even under platform conditions, in the north of the Volga-land hills, for example; and in the Crimea the Beshtekne Kettle (according to A.A. Kruber). Poljes of such type, according to Cvijić and V. Barowić, are observed in Montenegro. And the Rak Valley in Slovenia represents a classic example of a polje of the collapse genesis.

References

Bögli, A. 1960. Kalklösung und Karrenbildung. "Int. Beitr. z. Karstmorphol." "Zeitschr. f. Geomorph", Suppl. Bd. 2.

Corbel, J. 1957. Le karsts du Nord-Ouest de l'Europe, Lyon.

Cvijić, J. 1924. The evolution of lapiés. "Geogr. Review". January, 1924, New York.

Gvozdetsky, N.A. 1954. Karst, Izd. 2-e, Moskva.

1972. Problemy izucheniya karsta i praktika. Moskva.

Gvozdetsky, N.A. & Marinin, A.M. 1976. Karst Altaya. "Zemlevedenie", t. 11.

Hanwell, J. & Newson, M. 1973. Techniques in physical geography. Basingstoke and London.

Kosmowska-Suffszyńska, D. 1967. O genezie polji "krasowych" na podstawie badań w Jugoslawii. "Przeglad Geograficzny", t. 39, z.3.

Kotarba, A. 1970. Vertikalnye zony poverkhnostnykh karstovykh protsessov v Zapadnykh Tatrakh. "Problemi na paleogeomorfolozhkoto razvitie na Bulgaria", t. 1, Sofiya.

Shchukin, I.S. 1964. Obshchaya geomorfologiya, t.II, Moskva.

Sokolov, D.S. 1962. Osnovnye usloviya razvitiya karsta. Moskva.

Sweeting, M.M. 1972. Karst landforms. London and Basingstoke.

NEW KIND OF KARST FORMS ON THE CHALK AREA, LUBLIN UPLAND, EAST POLAND

Marian Harasimiuk, Andrzej Henkiel
20033, Lublin, Academika, Poland

The Lublin Upland, East Poland, together with its northern foreland is built of carbonate rocks of the Upper Cretaceous. Siltstones, marls, marly limestones and chalk occur here. A specific type of karst develops in places where marls, limestones and chalk occur on the surface or under a thin cover of Pleistocene deposits. This chalk karst (Maruszczak 1966) is a complex of exclusively surface forms. The typical forms are small, shallow round or oval dolines. They are often in the Pleistocene cover. Numerous dolines are filled with redeposited clay, and peat. There are also short and shallow karst valleys and uvalas, created by combining sinkholes. Specificity of Chalk karst of the Lublin Upland and of its northern foreland is controlled by lithology. The rocks contain from 75 to 95% of $CaCO_3$, and the admixture of clay minerals with a tendency to swelling, and very low resistance to mechanical weathering make the development of underground forms impossible and induce the development of sinkholes (Maruszczak 1966, Harasimiuk 1973).

To the East of Lublin, in the transitional zone between the Lublin Upland and the lowland of Polesie Lubelskie, a different complex of karst forms was found. The central part of the area is occupied by small hills formed from siltstones. Below these, at an altitude of 180 m there are plains of soft marls, upon which a normal type of Chalk karst develops. Within these plains escarpments occur, which separate the lower level of the plains (170 - 175 m above sea level). At this level karst forms which were quite different from the ones described so far were found. These are large depressions, their maximum surface area reaching 0,7 sq.km. In contrast with classic, regular forms occurring on other areas, the depressions of the environs of Milejów have very complex shapes. The border between slopes and floors of the closed depressions is very irregular. Within the floors isolated residual hills occur. Some of the depressions are elongated and tortuous, and resemble anastomosing channels. The width of the channels reaches 100 - 150 m, their length is up to 1500 m. On the whole, the floor area of the depressions occupies up to 50% of the total area. The floors of the depressions are wet and often flooded by ground water. The present depth of the depressions is 2 - 5 m below the surrounding plain. The floor surface is built of peats and muds, whose combined thickness is 1,5 - 5,0 m beneath which lies unweathered marl. The ridges between the depressions are built of marls, covered in some places with 1 - 3 m cover of residual Pleistocene deposits. However, some hills have solid Cretaceous rocks only at a considerable depth, beneath the level of neighbouring depression floors.

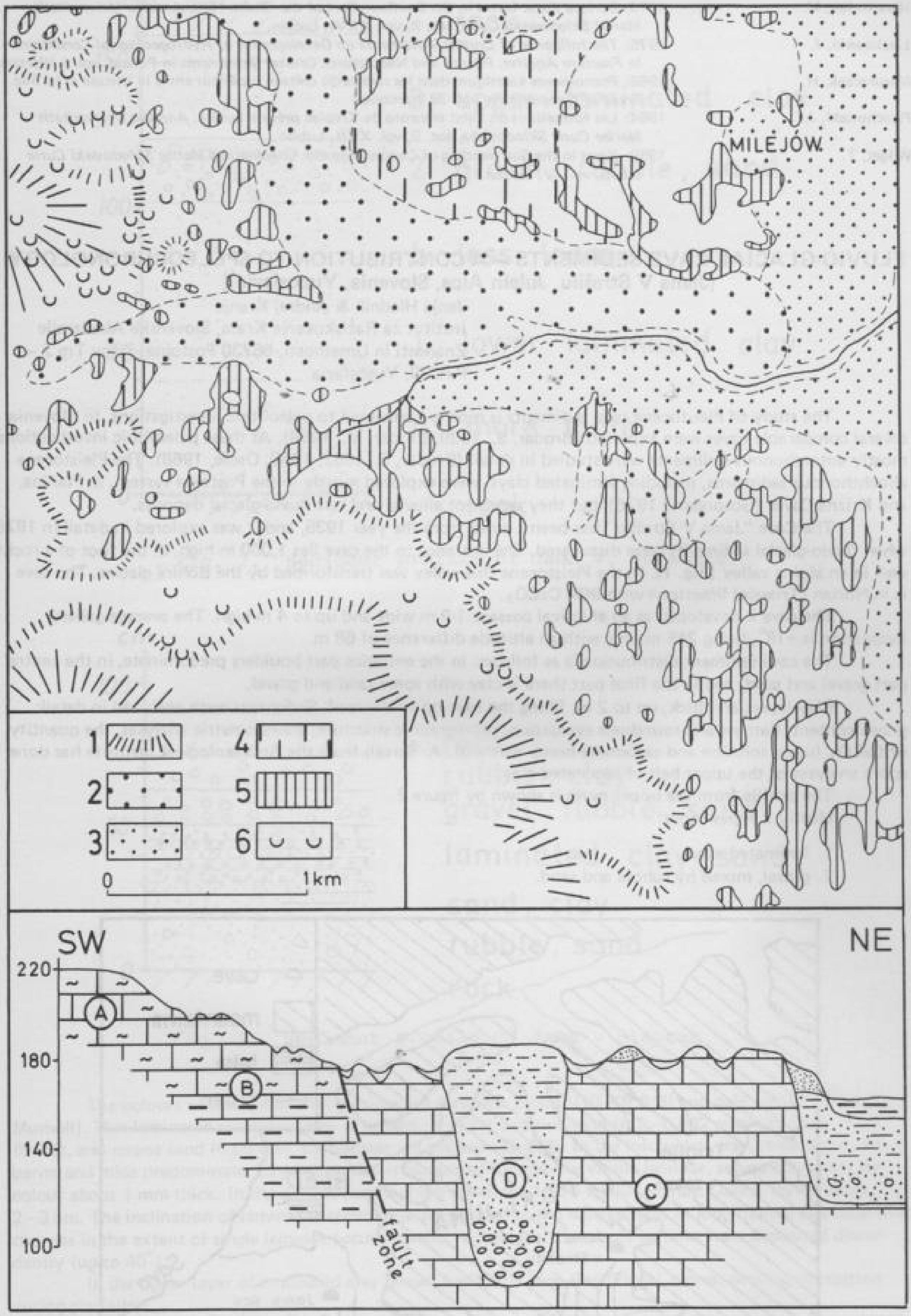
The general morphological situation of the complexes of depressions is that they occur in basins, the base of which is of Cretaceous marls. These basins adhere either to the slopes of hills built of siltstones or to the escarpments of a higher marl level, and are closed by flat hummocks built of sandy and loamy Pleistocene deposits. Under the low hills of Pleistocene deposits there are deep basins cut into the marl basement. These are erosional valleys of over 100 m of depth and of widths reaching a kilometre. So the groupings of the discussed karst depressions occur on isolated blocks of marls and marly limestones confined by faults on one side and by loose deposits filled with fossil deep valleys on other sides.

In the light of the above, the genesis of the landscape may be interpreted as follows. Normal chalk karst of the Lublin Upland develops due to vertical infiltration of rainwater, and the depth of the karst is basically limited to the several meters thick zone of aeration. In spite of the slow infiltration, morphological effects are considerable due to the low resistance of the marls and Chalk. Around Milejów a special type of landscape was controlled by the tectonical-morphological situation of karstified marls and by the conditions of ground water movements. Abundant groundwater in the strongly fissured siltstones has hydraulic gradients to the North and East. Laterally the water is constrained by nearly impermeable marls. The low permeabilities of the marls (due to their lithologies) is further lowered due to their position on the downthrown side of faults (Liszkowski 1975). Underground water flows in blocks built of marls are mainly connected with subsurface zone of fissured weathering type. Fossil valleys filled with permeable Pleistocene deposits play the role of underground drainage zones, along which lateral movement of ground water is accelerated. In this way there may develop depressions of large lateral size, anastomosing shape and minimum depth. Karst corrosion is slightly more intensive in the zones of the contact of karstified rocks with Pleistocene deposits. This leads to the development in these zones of depressions which are slightly larger, deeper and open towards fossil valleys, in some ways resembling (in miniature) marginal poljes.

Lateral lowering of the surface of karst rocks leads to the inversion of relief. The upper part of unconsolidated Pleistocene deposits, originally deposited in deep valleys, now forms hummocks and small hills while the marl surface is lowered by corrosion. The upper part of the lacustrine and river deposits filling these fossil valleys is paleobotanically dated from the Mindel-Riss interglacial (Brem 1954). Above these deposits there is also a cover of fluvioglacial sands and boulder clay, whose combined thickness is up to 10 m and which is dated from the Riss glaciation. The development of the described karst forms and the inversion of relief resulting from it must have taken place after the time of the Riss maximum, in the Riss and Würm interstadials, in the Riss-Würm interglacial and in the Holocene. The average lowering of the marl surface due to karst corrosion must have been between 5 and 10 metres.

References

Brem, M. 1954: Interglacial Flora form Ciechanki Krzesimowskie *Acta Geologica Pol.* vol. 3, Warszawa.



A morphological map of SE part of the Lublin chalk karst area and a schematic cross section.
1. Escarpments. 2. Ridge and hills of Pleistocene deposits. 3. Terrace of Wieprz river. 4. Plain of Pleistocene lacustrine deposits. 5. Karst forms. 6. Small dolines.
A. Opokas (Danian). B. Opokas with interlayers of marls (Upper Maestrichtian).
C. Marls and marly limestones (Upper Maestrichtian). D. Pleistocene deposits

Harasimiuk, M. 1973: Surface Karst forms in the Southern Part of the Chelm Hills. *Annales Universitatis Mariae Sklodowska Curie*, sec. B, vol. XXVI, Lublin.
Liszkowski, J. 1975: *The Influence of Crustal Movements on Development of Hydrogeological Conditions in Fracture Aquifer*, Recent and Neotectonic Crustal Movements in Poland; vol. I, Warszaw
Maruszczak, H. 1966: Phenomenes karstiques dans les roches du crétacé supérieur entre la Vistule et le Bug. *Przeglad Geograficzny* vol. 38 Warszawa.
Rzechowski, J. 1964: Les formations du karst environs de Krepiec prés de Lublin. *Annales Universitatis Mariae Curie Sklodowska*, sec. B, vol. XVII, Lublin.
Wilgat, T. 1950: Karst in the Surrounding of Cyców. *Annales Universitatis Mariae Sklodowski Curie* sec. B, vol. IV, Lublin.

FLUVIO-GLACIAL CAVE SEDIMENTS – A CONTRIBUTION TO SPELEOCHRONOLOGY (Jama V Strašilu, Julain Alps, Slovenia, Yugoslavia)'

Janja Hladnik & Andrej Kranjc
Institut za Raziskovanje Krasa, Slovenske Akademije Znanosti in Umetnosti, 66230 Postojna, Titov Trg 2 – P.P. 29, Yugoslavia

The study of Pleistocene cave sediments is mostly connected to paleolithic investigations. In Slovenia several comparable caves were explored (Brodar, S., 1939; Brodar, M., 1959). At these paleolithic investigations mostly autocthonous sediments were studied in detail (Brodar, S., 1952, 1960; Osole, 1968). The Pleistocene allochthonous sediments, including laminated clays, were explored mostly in the Postojna system, in Planina, and Krizna Caves (Gospodarič 1976), but they represent alluvial and not fluvio-glacial deposits.

The Cave "Jama V Strašilu" has been known from the year 1935, and it was explored in detail in 1976 when fluvio-glacial sediments were discovered. The entrance to the cave lies 1,000 m high, at the foot of a rocky wall in an alpine valley (Fig. 1). In the Pleistocene this valley was transformed by the Bohinj glacier. The cave is in Norian (Triassic) limestone with 96% $CaCO_3$.

The cave is developed as an elliptical passage 1·9 m wide and up to 4 m high. The average gallery inclination is +18°, being 245 m long with an altitude difference of 68 m.

The cave sediment distribution is as follows: in the entrance part boulders predominate, in the central part gravel and sand, and in the final part there is clay with some sand and gravel.

Clay layers are thick, up to 2 m, filling the cave up to the roof. Sediments were analyzed in detail: gravel content, flatness and roundness evaluation, petrographic structure, granulometric analyses, the quantity of $CaCO_3$ (using solution and carbonate-bomb method). A. Šercelj from the Archaeological Institute has done spore analyses of the upper belt of laminated clay.

The profile from the upper caves is shown by figure 2.

Mostly 2 types occur:

1. laminated clay
2. gravel, mixed by rubble and sand.

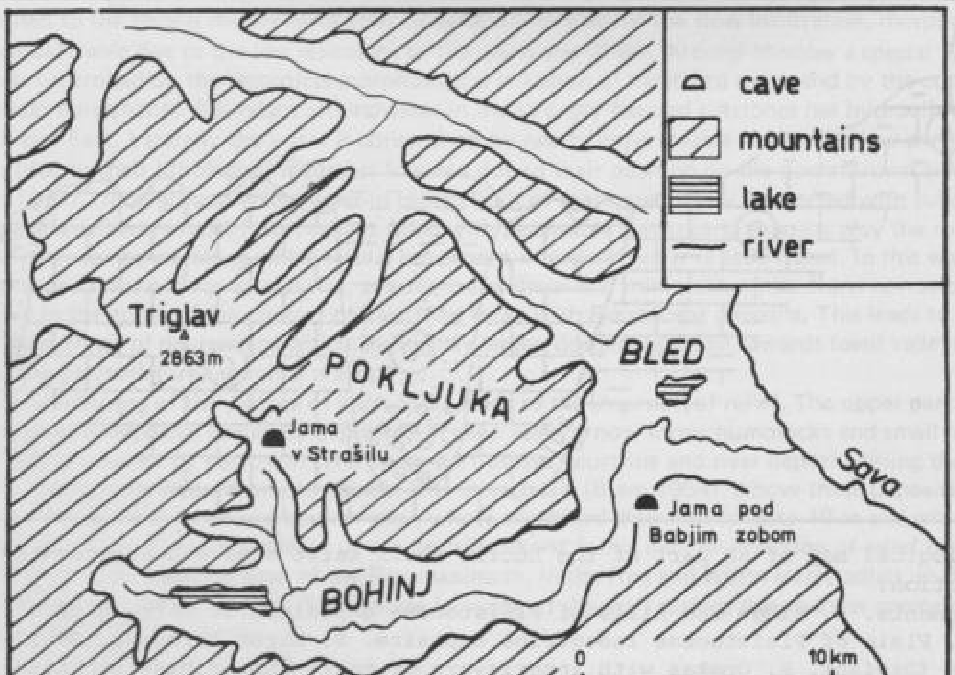


Fig. 1. Location map of the Julian Alps, Slovenia.

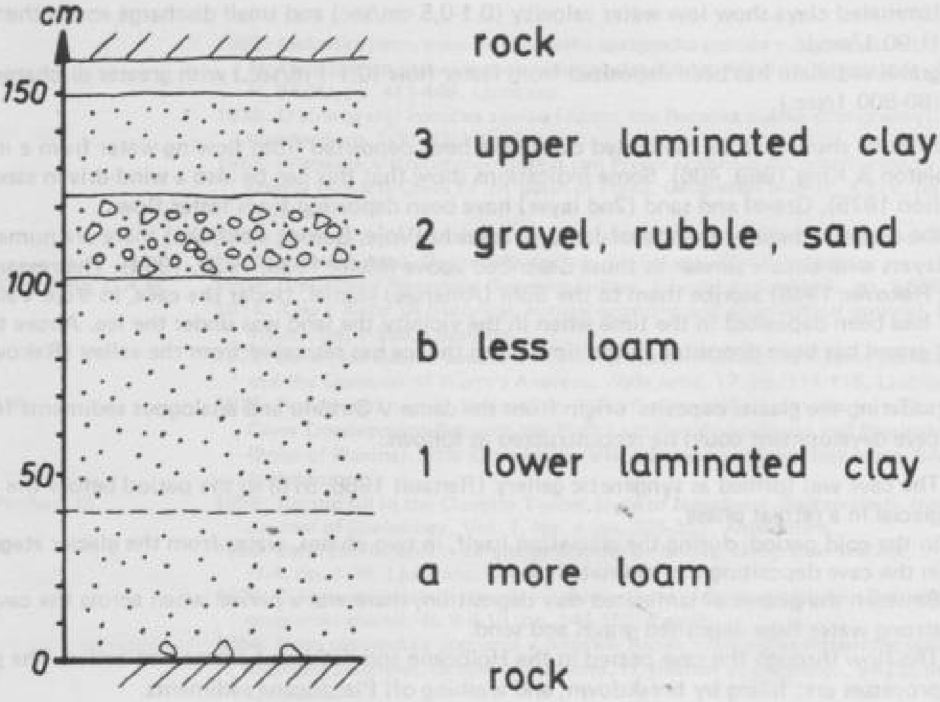


Fig. 2. Sediment profile of Jama V. Strašilu.

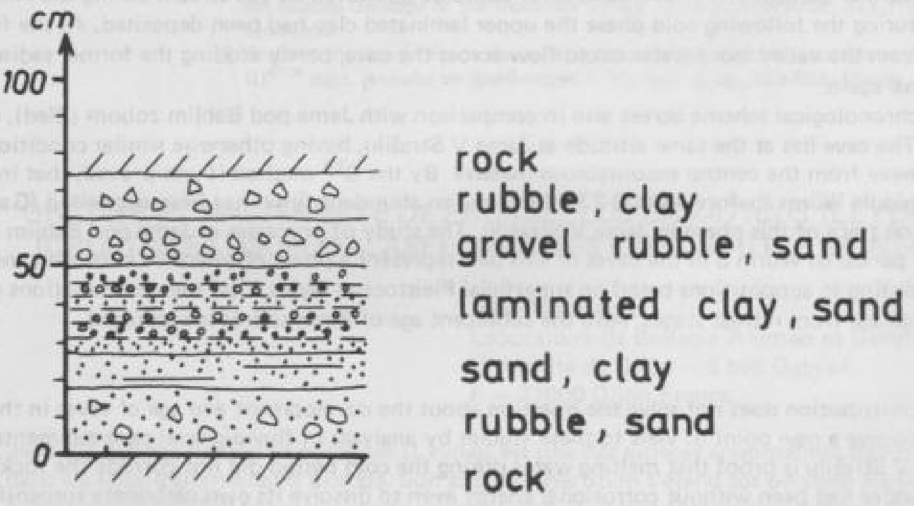


Fig. 3. Sediment profile of Jama v Slapcah

The colours of laminated clay are between very pale brown (10 YR 8/3) and pale yellow (5Y 8/3, Munsell). This laminated carbonate clay is composed of silt and fine sand (0,2 - 0,002 mm) (89-94%), loan (5-7%), and coarse sand (0,05-6%). Carbonates are between 65-86%. In the insolubles, clay, minerals, quartz, barite and mica predominate. Laminated clay is composed by scarcely visible laminae, separated mostly by colour about 1 mm thick. In the natural profile there are about 1,500-1,600 laminae. Darker layers occur 2 - 3 cm. The inclination of laminae is approximately parallel to the cave gallery. In longitudinal direction quick changes in the extent of single laminae occur showing turbulence. The single laminae were deposited discordantly (up to 45°).

In the upper layer of laminated clay Šercelj has found pine-tree (Pinus) spores, proving deposition during glaciation.

The Gravel-rubble layer is composed by 46% of gravel, 31% of rubble, 17% of sand and silt, and 6% of loam. The gravel petrographic composition is: 97.7% of limestone pebbles, 2% sandstone, and 0.3% quartz. The 98% of pebbles have polished surfaces; among them 51% are rounded, 26% subrounded, and 18% well rounded (after Pettijohn). The average flatness (after Cailleux) is 2,03 proving gelivation or fluvio-glacial origin.

The sand from the second layer has poor sorting with a bimodal histogram. The carbonate rate is greater in finer fractions (64-75%) than coarser ones (16-62%).

Based on granulometric composition the average water velocity from which the sediment has been deposited could be deduced, as well as its quantity:

- laminated clays show low water velocity (0,1-0,5 cm/sec) and small discharge across the cave (1-90 1/sec.);
- gravel sediment has been deposited from faster flow (0,1-1 m/sec.) with greater discharge (60-800 1/sec.).

The results show that the laminated clays have been deposited from flowing water from a melting glacier (Embleton & King 1969, 406). Some indications show that this can be also a wind-driven sand and silt (Meia & Pochon 1975). Gravel and sand (2nd layer) have been deposited from faster flows.

In the closer and wider vicinity of Jama V. Strašilu (Voje, Bohinj, Pokljuka) there are numerous Pleistocene layers with details similar to those described above (Melik 1930, 1939, 1954). The researchers (Melik ibid.; Rakovec 1948) ascribe them to the Bühl (Amersee) stadial. Under the cave, in Voje Valley, the "lime loam" had been deposited in the time when in the vicinity the land was under the ice. Above the loam fluvio-glacial gravel has been deposited in the time when the ice has retreated from the valley (Rakovec 1948, 131).

Considering the glacial deposits' origin from the Jama V Strašilu and analogous sediments from the surface, the cave development could be reconstructed as follows:

1. The cave was formed as syngenetic gallery (Renault 1968, 576) in the period before the last glacial in a retreat phase.
2. In the cold period, during the glaciation itself, in two phases, water from the glacier stagnated in the cave depositing the laminated clays.
3. Between the phases of laminated clay deposition, there was a period when across the cave a strong water flow deposited gravel and sand.
4. The flow through the cave ceased in the Holocene and the cave became non-active. The present processes are: filling by breakdown, and washing off Pleistocene sediments.

There are no direct proofs for the cave's age, but on the basis of deposits and their superposition and analogy with the caves in the vicinity it can be deduced. Regarding the anaology of surface layers the lower laminated clays could originate from Amersee stadium. More loam in the base of this layer shows deposition after a longer warmer period. The Gravel-sand layer could be deposited by the stream during the Alleröd warmer period, while during the following cold phase the upper laminated clay had been deposited. At the final retreat of the glacier from the valley more water could flow across the cave, partly eroding the former sediments and opening the cave again.

This chronological scheme agrees also in comparison with Jama pod Babjim zobom (Bled), distant about 30 km. The cave lies at the same altitude as Jama V Strašilu, having otherwise similar conditions but being further away from the central mountainous massive. By the C^{14} method it was proved, that in a warm period in the middle Würm (before 44,000-23,000 years) an abundant sinter has been deposited (Gams 1975, 115). There is no trace of this phase in Jama V Strašilu. The study of processes in Jama pod Babjim zobom shows that the period of Würm 3 in the caves of this belt represent a phase of intensive corrosion and erosion. It follows, according to suppositions based on superficial Pleistocene layers, that the accumulations of laminated clays originate from retreat stages. Also the subrecent age of Pinus spores is accordant.

Conclusions

This contribution does not solve the question about the development and age of caves in the Slovene Alps but tries to give a new point of view to these studies by analyses of fluvio-glacial cave sediments.

Jama V Strašilu is proof that melting water during the cold period did not corrode the rock but filled the cave. The water had been without corrosional energy even to dissolve its own carbonate suspension.

The recent speleological investigations show that there are several caves with similar sediments. Such is Jama v Slapcah (Soča river basin) where superposition is similar to those in Jama V Strašilu (fig. 3).

The detailed studies of such sediments and their mutual correlation would possibly add to better knowledge of speleogenetic processes and conditions in the Pleistocene and at the same time to the caves' chronology.

Periods		Processes	Results
Holocene warm period		sediments erosion, drying up	actual state
	ice advance	accumulation	upper laminated clay
Retreat stades	ice retreat	accumulation + erosion of former sediments	gravel-sand layer
	ice advance	accumulation	lower laminated clay
Glacial (W3) or Interglacial		corrosion + erosion of rock	excavation of rocky gallery

References

Brodar, M. 1959: Mokriška jama, nova visokoalpska aurignaska postaja v Jugoslaviji = Le grotte de Mokrice station nouvelle aurignacienne des Hautes-Alpes en Yougoslavie, *Razprave;* V, SAZU, pp. 417-469, Ljubljana.

Brodar, S. 1939: O stratigrafiji Potočke zijalke (About the Potočka zijalka stratigraphy). *Inavguralna disertacija,* p. 1-33, Ljubljana.

Brodar, S. 1952: Prispevek k stratigrafiji kraških jam Pivške kotline = A Contribution to the Stratigraphy of Karst Caves of the Basin of Pivka. *Geografski vestnik,* XXIV, pp. 43-76, Ljubljana.

Brodar, S. 1960: Periglacialni pojavi v sedimentih slovenskih jam (Periglacial Phenomena in Slovene Caves Sediments). *Geografski vestnik,* XXXII, pp. 33-43, Ljubljana.

Embleton, C, & King, C.A.M. 1969: *Glacial and Periglacial Geomorphology.* Edward Arnold Ltd., pp. 1-608, Edinburgh.

Gams, I, 1974: *Kras = Karst* (A historical, natural-scientific and geographical outline). Slovenska matica, pp. 1-359, Ljubljana.

Gams, I. 1975: Jama pod Babjim zobom in vprašanje razčlenitve wurma = Jama pod Babjim zobom and the Question of Würm's Analyses. *Naše jame,* 17, pp. 111-116, Ljubljana.

Gospodarič, R. 1976: Razvoj jam med Pivško kotlino in Planinskim poljem v kvartarju = The Quarternary Caves Development Between the Pivška kotlina (Pivka Basin) and Planinsko polje (Polje of Planina). *Acta Carsologica,* VII, Inštitut za raziskovanje krasa, SAZU, pp. 5-135, Ljubljana.

Meia, J. & Pochon, M. 1975: Karstic fill in the Clusette Tunnel (Jura of Neuchatel, Switzerland). *International Journal of Speleology,* Vol. 7, No. 4, pp. 325-338, Amsterdam.

Melik, A. 1930: Bohinjski ledenik = Le glacier diluvial de Bohinj. *Geografski vestnik,* V-VI (1929-30) /1-4, pp. 1-39, Ljubljana.

Melik, A. 1939: O kesnodiluvijalnih jezerih v Bohinju (Late pleistocene lakes in Bohinj). *Hrvatski geografski glasnik,* št. 8-9-10, pp. 148-152, Zagreb.

Melik, A. 1954: Nova glaciološka dognanja v Julijskih Alpah = Nouvelles recherches glaciologiques dans les Alpes Juliennes. *Geografski zbornik,* II, Inštitut za geografijo, SAZU, pp. 5-49, Ljubljana.

Munsell, I. 1975: Soil Color Charts, Baltimore.

Osole, F. 1968: Jamski sedimenti Notranjsko-Primorskega krasa kot posledica pleistocenskih klimatskih nihanj = Die Höhlensedimente des Slowenischen Karstes als Folge pleistozäner Klimaschwankungen. I. kolokvij o geologiji Dinaridov, II. del, pp. 197-201, Ljubljana.

Rakovec, I. 1948: O mostniški dolini v Bohinju (Prispevek h glacialni geologiji) = Some Contributions to the Glacial Geology of the Mostnica Valley. *Geografski vestnik,* XIX (1947), pp. 129-138, Ljubljana.

Renault, Ph. 1968: Contribution à l'étude des actions mécaniques et sédimentologiques dans la spéléogenèse, III^eme part. *Annales de Spéléologie,* t. 23, fasc. 3, pp. 529-596, Moulis.

ORIGINE ET ANCIENNETÉ DE *PROASELLUS CAVATICUS* (LEYDIG) (CRUSTACEA, ISOPODA, ASELLOTA DES EAUX SOUTERRAINES)

Jean-Paul Henry
Laboratoire de Biologie Animale et Generale
Universite de Dijon — 6 bvd Gabriel
F — 21000 Dijon France

L'Isopode hypogé *Proasellus cavaticus* (Leydig) est une des espèces anophtalmes de *Proasellus* les plus répandues dans les eaux souterraines d'Europe. Son aire de répartition s'étend sur un vaste territoire qui comprend une grande partie de l'Europe moyenne et occidentale ainsi que le Sud de la Grande-Bretagne. Cette espèce recouvre ainsi à la fois les bassins hydrographiques du Rhin, de la Weser, du Danube et du Rhône et s'étend dans plusieurs massifs hercyniens et dans le chaine alpine. C'est pourquoi, en raison d'une distribution aussi vaste, le centre de dispersion de *P. cavaticus* n'avjamais pu être fixé avec précision. D'autre part, le fait que cette espèce anophtalme ne présente aucune affinité avec les espèces oculées actuelles de surface soulève la question de l'ancienneté de sa pénétration dans les eaux souterraines. Enfin, sa présence en Grande-Bretagne pose le problème de la datation de sa migration sur cette île.

Les recherches que j'ai entreprises sur l'écologie et la biogéographie de toutes les espèces du groupe *cavaticus* (Henry, 1976) apportent des renseignements utiles qui permettent de proposer des hypothèses satisfaisantes sur l'origin et l'ancieneté de *P. cavaticus* et sur la date de son installation en Grande-Bretagne.

I. Origine du groupe *cavaticus*

L'aire géographique du groupe *cavaticus,* telle qu'elle peut être définie à partir des données sur la répartition de chaque espèce, est nettement distincte de celles des autres lignées du genre; il s'agit essentiellement d'une aire continentale alors que les aires des principales espèces anophtalmes de *Proasellus* sont toujours liées à une colonisation des terres ayant occupé autrefois l'emplacement de la Méditerranée. Dans ces conditions, il est douteux que *P. cavaticus* ait une origine mésogéenne, car aucune trace de sa présence ne subsiste dans les péninsules de l'Europe méridionale ou dans les îles actuelles de la Méditerranée.

La connaissance bioéographique de chaque espèce du groupe *cavaticus* permet d'avancer une hypothèse sur la région où ces *Proasellus* souterrains auraient pris naissance. En effet, toutes les espèces *(P.cavaticus P. strouhali, P. valdensis, P. walteri)* sont présentes sur la bordure externe de l'arc alpin (fig. 1): les unes, comme *P. valdensis* dont les stations sont localisées sur les chaînes subalpines de Savoie et du Dauphiné, sont

même strictement alpines; les autres, comme *P. cavaticus* sont plus répandues mais sont néamoins bien représentées dans le domaine alpin où le nombre de leurs stations est élevé. La densité de ces Aselles dans cette région et l'endémisme de certains d'entre eux sont des indices de leur origine paléogéographique. On peut donc avec quelque vraisemblance tenir les Alpes occidentales comme le centre de peuplement du groupe *cavaticus*. La découverte récente de deux nouvelles espèces du groupe, l'une en Suisse (*P. rouchi)* dans les Alpes maritimes (Henry, *in litt)* tend à démontrer le bien-fondé de notre hypothèse.

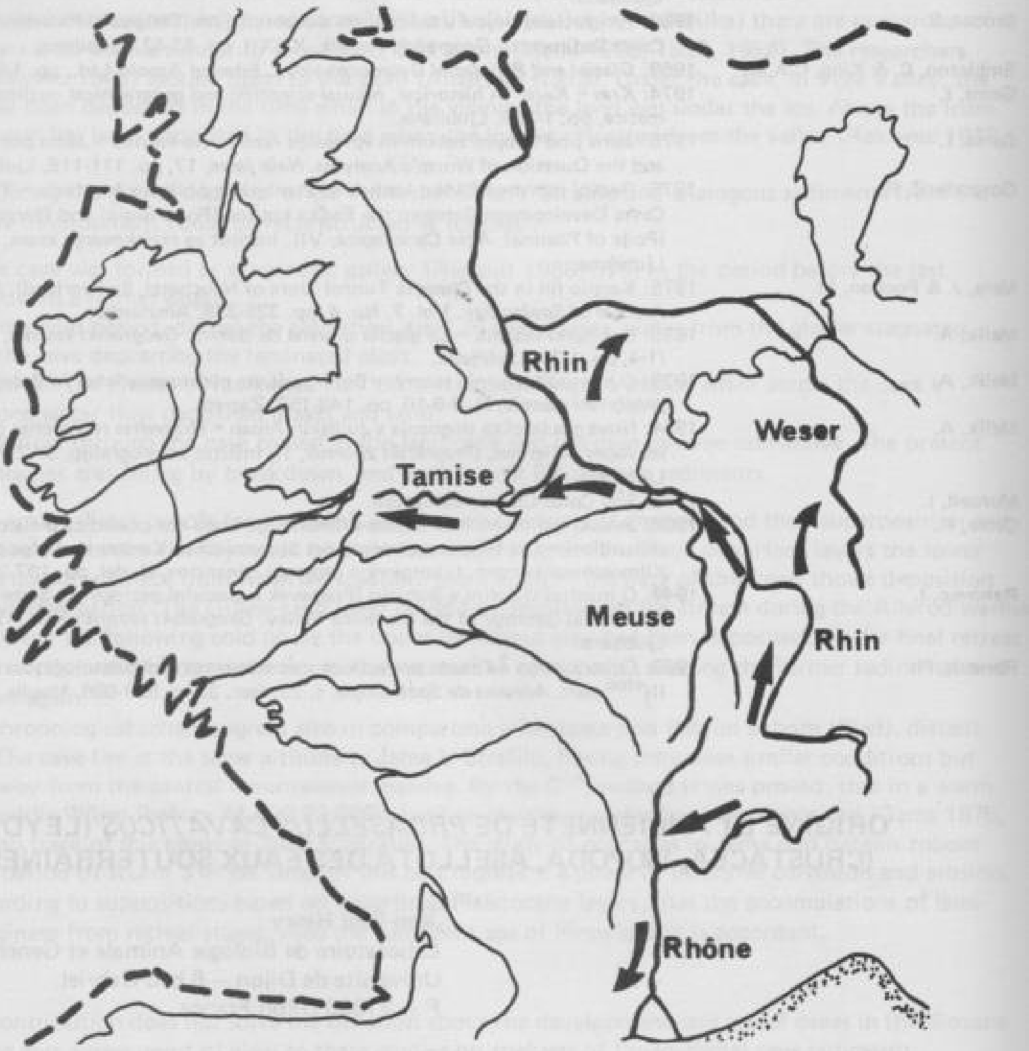


Fig.2 - Carte montrant la configuration probable des terres bordant la Manche et la mer du Nord à l'époque du maximum de la glaciation würmienne. Le trait en tireté indique la limite probable des terres. Le Rhin reçoit la Tamise et la Weser et la Grande-Bretagne est reliée au Continent. Les flèches schématisent l'extension post-glaciaire de Proasellus cavaticus.

II. Ancienneté du groupe *cavaticus*

L'absence d'une forme épigée actuelle proche parente des différentes espèces du groupe empêche de connaître les mécanismes évolutifs qui ont présidé à leur spéciation. Néanmoins, on peut considérer que ces Aselles anophtalmes représentent les relictes d'une faune d'eau douce de surface, ils dérivent par conséquent d'une forme oculée répandue sur la région alpine et qui serait passée des eaux douces épigées dans les eaux souterraines. Cette espèce primitive n'a pu s'installer sur le bord externe des Alpes qu'après le soulèvement alpin, c'est-à-dire au miocène ou à la fin du tertiaire. Il est fort probable qu'il y ait eu dès cette époque parmi les populations de cette espèce, apparition d'undividus dépigmentés puis dissociation écologique entre la forme de surface oculée et pigmentée et la nouvelle forme plus apte à subsister dans le milieu hypogé. On peut justifier cette hypothèse en rappelant les tendances obscuricoles des Aselles épigés actuels dont de nombreuses populations sont inféodées aux eaux souterraines. Mais c'est sans aucun doute les glaciations quaternaires qui ont eu le plus d'influence sur la pénétration souterraine de ces Crustacés. En effet, le changement de climat, qui fut im-

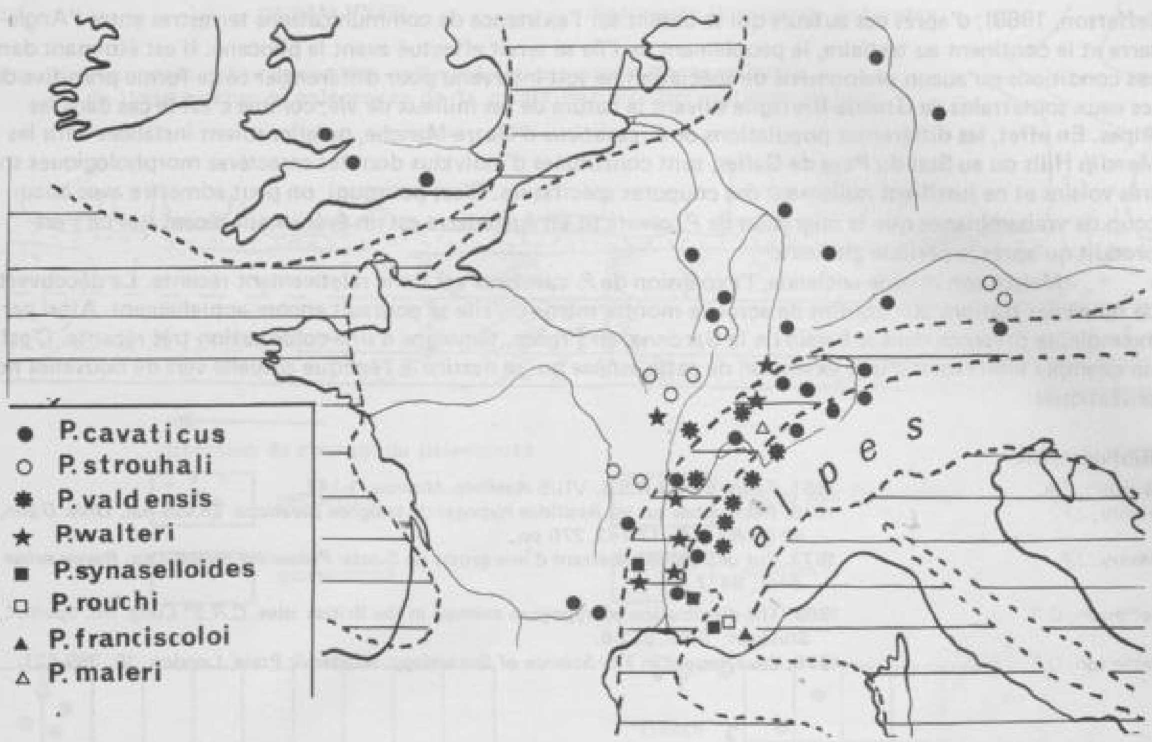


Fig.1 - Carte des terres émergées et des mers au miocène. La bordure externe de l'arc alpin constitue le centre de peuplement de la lignée cavaticus. Les principales stations de chaque espèce sont figurées par des signes différents.

posé par les glaciations lors du pléistocène aux régions alpines, entraîna des modifications considérables de la faune épigée et nombre d'espèces préglaciaires qui vivaient dans les eaux de surface en ont été chassées ou détruites. Ainsi le développement des glaciers, qui au début du quaternaire ont envahi les Alpes, a contraint les Aselles épigés à trouver de nouveaux milieux de vie. Selon certains auteurs, ces animiaux auraient survécu aux transgressions glaciaires en trouvant localement des refuges dans le milieu souterrain; cette survie sous la calotte glaciaire paraît bien problématique. Par contre, il est plausible d'imaginer que les Aselles, refoulés dans les vallées, à plus basse altitude, aient pu subsister en migrant dans les réseaux karstiques ou dans les nappes alluviales, et même poursuivre leur extension lors des phases interglaciaires. Les stations actuelles de *P. valdensis* où cette espèce vit dans des eaux froides (3°C) montrent que ces formes ont pu supporter une baisse considérable de la température et se maintenir par conséquent sur le pourtour des glaciers pléistocènes. Le fait qu'un certain nombre de stations de plusieurs espèces du groupe soient localisées dans des régions recouvertes autrefois par les grands glaciers peut s'expliquer par un repeuplement, après le retrait des glaciers, des zones libérées des glaces. D'ailleurs cette période qui correspond à une reprise générale de l'alluvionnement a été favorable à l'expansion des Aselles hypogés et leur répartition actuelle est le plus souvent le résultat d'une colonisation post-glaciaire, comme le montre par exemple l'étude de l'aire de *P. cavaticus*.

III Signification de l'aire actuelle de *P. cavaticus*

Parmi les différentes espèces du groupe, *P. cavaticus* est celle dont l'écologie est la moins spécialisée; en effet, cet Aselle n'est pas inféodé aux réseaux karstiques, mais il est aussi parfaitement capable de mener une vie phréatique: il se satisfait par exemple de biotopes interstitiels encore très liés à la surface du sol et tout à fait indépendants des régions calcaires. Cette ubiquité écologique lui a permis de s'adapter à une aire géographique variée et vaste en suivant l'évolution paléo-géographique des bassins hydrographiques de la surface du sol et de leurs sous-écoulements hypogés. C'est ainsi que cette forme souterraine a profité de l'alluvionnement intense qui s'est produit après le retrait des glaciers alpins au niveau des grandes vallées alluviales pour s'étendre et se disperser; les populations installées dans les masses de graviers quaternaires des plaines d'Alsace et d'Allemagne témoignent de ce dynamisme colonisateur de l'espèce.

Sa présence en Angleterre pourrait ainsi s'expliquer par son extension dans les alluvions du réseau hydrographique du Rhin dont l'embouchure, à cette periode, occupait l'emplacement actuel du haut fond sableux du Doggerbank. En effet, les Aselles ont pu profiter des liaisons qui se sont établies entre le Grande-Bretagne et l'Europe au cours de l'ère quaternaire à la suite des mouvements eustatiques provoqués par l'extension et la régression des glaciers. Lors du maximum de la glaciation wurmienne par exemple, le niveau marin s'étant abaissé de 90 mètres, l'Angleterre se trouvait réunie au continent et le Rhin, grossi de la Meuse, recevait la Tamise et la Weser et se déversait à peu près à la latitude de Newcastle (fig. 2). Au cours de la phase post-wurmienne, la reprise de l'alluvionnement a permis les migrations de faune et en particulier celle de *P. cavaticus* qui daterait donc d'une époque plus récente que celle qui est généralement admise (Birstein, 1951;

Jefferson, 1969); d'après ces auteurs qui se basent sur l'existence de communications terrestres entre l'Angleterre et le continent au tertiaire, le peuplement de l'île se serait effectué avant le pliocene. Il est étonnant dans ces conditions qu'aucun phénomène de spéciation ne soit intervenu pour différencier cette forme primitive dans les eaux souterrains de Grande-Bretagne suivant la nature de ses milieux de vie, comme c'est le cas dans les Alpes. En effet, les différentes populations de *P. cavaticus* d'Outre-Manche, qu'elles soient installées dans les Mendip Hills ou au Sud du Pays de Galles, sont constituées d'individus dont les caractères morphologiques sont très voisins et ne justifient nullement des coupures spécifiques. C'est pourquoi, on peut admettre avec beaucoup de vraisemblance que la migration de *P. cavaticus* en Angleterre est un événement récent qui ne s'est produit qu'après la période glaciaire.

Malgré son origine ancienne, l'expansion de *P. cavaticus* est donc relativement récente. La découverte de nouvelles stations aux confins de son aire montre même qu'elle se poursuit encore actuellement. Ainsi par exemple, sa présence dans le bassin de la Garonne, en France, témoigne d'une colonisation très récente. C'est un exemple intéressant d'une extension de cette espèce qui se dessine à l'époque actuelle vers de nouvelles nappes phréatiques.

Bibliographie

Birstein, J.A. 1951. Faune de l'U.R.S.S. VII/5 *Asellota. Moscou*, 1-142.

Henry, J.P. 1976. Recherches sur les Asellidae hypogés de la lignée *cavaticus. Th. Sc. nat. Univ. Dijon, n° CNRS A.O. 12 143*, 270 pp.

Henry, J.P. 1977. Sur un Asellide aberrant d'une grotte de Suisse: *Proasellus maleri* n.sp. *Revue suisse Zool.*, 84, 2.

Jefferson, G.T. 1969. The distribution of hypogean animals in the British Isles. *C.R.5° Cong. Int. Speleol., Stuttgart*, 1969, 8, 1-6.

Jefferson, G.T. 1976. Cave Faunas in *The Science of Speleology*. Academic Press, London. 10, 359-421.

FLUVIAL SEDIMENTS AND DEVELOPMENT OF THE FOSSIL BLOCKED SPRING OF THE JEDOVNICE BROOK IN THE MORAVIAN KARST

Dusan Hypr
Cave Club of Brno
Svatopluka Cecha 40
612 00 Brno, Czechoslovakia

In the spring region of the Jedovnice Brook the fluvial sediments in the Barova Cave were investigated. The Jedovnice Brook's cave system is the second greatest system developed by underground waters in the Moravian Karst. The corresponding swallets and karst springs are 4 km away. In the swallet region is the Rudice's engulfment cave, 3.5 km long (Burkhardt, Gregor, Hypr 1975; Hypr 1975a).

The spring region is divided into several levels. The brook appears in the influx siphon of the Bull's Rock Cave (length of the cave 1.5 km). After 200 m flow the brook leaves the main tunnel-shaped corridor through the longest and lowest level which has a canyon-like character; it is possible to follow it along about 150 metres. After another 150 m of unknown course the brook appears in the lowest level of the Barova Cave, where it is known to the length of 265 metres. About 100 m farther it surfaces in three springs (about 4 cu.ft/sec). This level represents a recent blocked spring, and it is characterized by its ruggedness, lake sectors and frequent siphons. The lake sections are separated from each other by siphons and were not explored until recently.

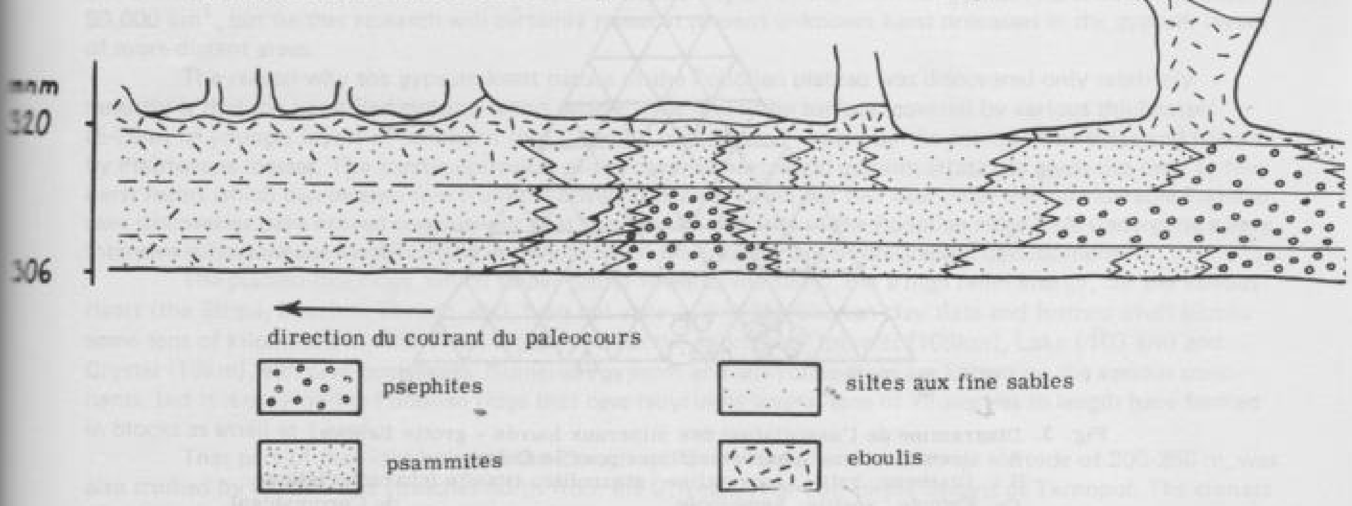
The upper level of the Barova Cave is a tunnel-shaped corridor (8,5 by 11 metres), known to the length of 150 metres. This level is by 90% filled with fluvial sediments. Some parts of the lower level are in the same tectonic elements, and after the relatively thin partition roof was destroyed the two levels were interconnected in six places and part of the upper levels sediments were washed away. In this way, diagonal profiles of fluvial sediments up to 15 metres high appeared there. Textures of the sediments have been studied, stone analyses carried out, statistical characteristics of grain sizes and associations of heavy minerals determined. Based on these (Fig. 1, 2, 3) reconstructions of the fluvial sedimentation development has been carried out, and the importance and function of the Barova Cave in the spring region evaluated.

Fluvial sediments are – according to the age of the overlying deposits, alluvia and scree from zones of vertical circulation – older than Wurm 1/2, possibly Riss/Wurm (Musil, 1959). Determination of the age of the whole fluvial sediment complex and of the periods of development, and an eventual classification in terms of the development cycles of the Quaternary is difficult.

Preceding the sedimentation of the present filling of the corridor a massive erosion phase took place, during which older sediments were washed out and even the rocky bottom of the corridor was eroded – a canyon-like cut up to 4.5 metres deep resulted. Then an accumulation phase followed, dividing into three partial accumulation, and two erosive subphases. Sedimentation took place in the conditions of a blocked spring (Hypr 1975b), as defined by Burkhardt (1972). Its origin is to be ascribed to the filling of the valley below the springs by scree, earth from slopes, fluviatile sediments etc. The erosion phases as well as the partial subphases are reactions to the lowered bases of erosion with regard to the development of the hydrography of the region.

In two places in the cave gravel mounds have grown up (Fig. 1) during the phases where the cross-

Fig. 1. Figuration schematique des sediments et des corps d'accumulation de l'obstruction du paleocours de la grotte Barova. Reconstituee au long.



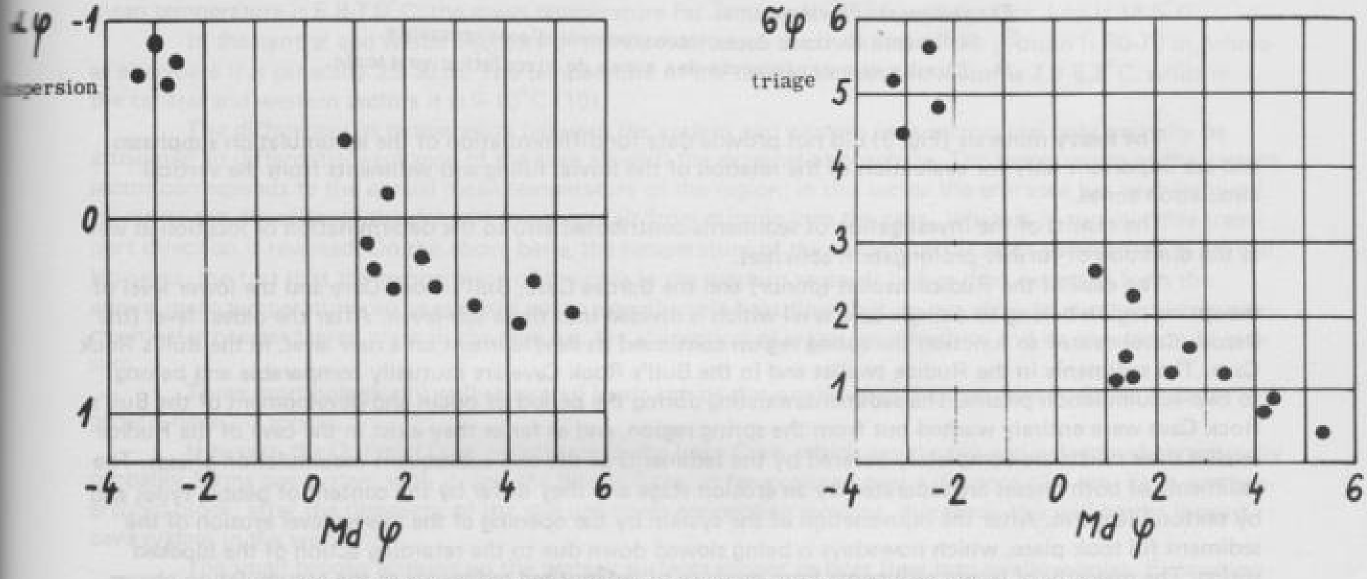


Fig. 2. Relation du mediane et des coeficients de la dispersion et du triage. Sediments fluviaux de l'obstruction du paleocours - grotte Barova.

section profile of the corridor was considerably widened and so the water flow velocity decreased. Psephitic material was brought in and deposited in the cave during floods. Otherwise only erosive shaping of the surface of the gravel banks as well as of the sediments deposited between mounds took place, being followed by deposits of a more fine grain (psamites — pelites). The psephite gravels are from 70 to 90% built up from Lower Carboniferous greywackes and shales, the rest being pebbles of quartz, quartzite, flint and exceptionally of limestones. The psephites are of middle or fine grain, here and there with distinctly oriented pebbles. They are relatively monotonous. The finer grained sediments are marked by a considerable variability and richness of textural features.

Sedimentation was interrupted by two erosive subphases, displayed in an apparent discordance in the complex of sediments. During the first accumulation subphase the grits, and exceptionally also the medium grain gravel was deposited; the psephite bodies were of a smaller extent. The sediments outside of the psephite accumulation have a positive gradation. Here and there on the floor lie broken limestone blocks. In the second accumulation subphase both mounds developed intensively and the corridor was greatly filled up. In the course of the last accumulation subphase the decrease of the flow quantity was shown strickingly. Psephites were deposited only exceptionally and the sediments have a distinct positive gradation. During the previous erosive subphase with greatest probability a new communication route began to come into existence in the spring region — the Bull's Rock cave (Bvci skala). Towards the end of the sedimentation the contribution of material from vertical circulation zones became evident (scree and washed-off masses from chimneys), their mixing took place and even separate banks of these deposits arose. After the corridor has ended its function the deposits of washed-off masses and scree grew and calcite formations formed with possibility of preservation.

The origin of potholes with profiles leading through fluviatile sediments is bound to the youngest stage of the spring region, and this process still proceeds.

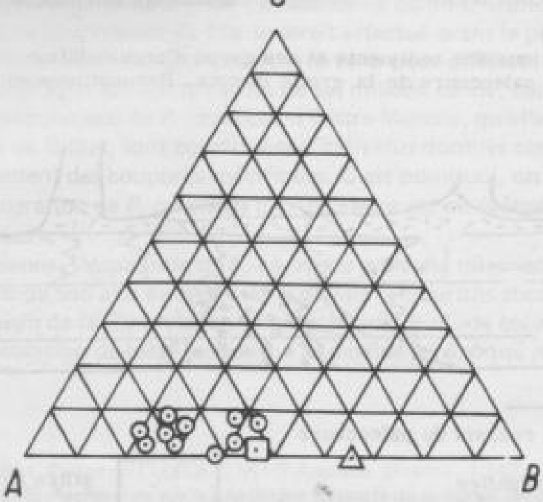


Fig. 3. Diagramme de l'association des mineraux lourds - grotte Braova.
A = Grenat, zircon (characteristique pour le Culm)
B = Disthene, rutile, tourmaline, staurolite, titanite (characteristique du Cenomanien).
C= Epidote, apatite, amphibole.

⊙ sediments fluviaux.
⊡ Sediments fluviaux dotes intensivement d'emergements.
△ Eboulis et emergements des zones de circulation verticale.

The heavy minerals (Fig. 3) did not provide data for differentiation of the accumulation subphases and are important only for evaluation of the relation of the fluvial filling and sediments from the vertical circulation zones.

The results of the investigation of sediments contributed also to the determination of location as well as the direction of further prolongation activities.

The cave of the Rudice swallet (ponor) and the Barova Cave, Bull's Rock Cave and the lower level of the spring region belong to a single cave level which is divided into three sub-levels. After the oldest level (the Barova Cave) ceased to function the spring region continued its development on a new level, in the Bull's Rock Cave. The sediments in the Rudice swallet and in the Bull's Rock Cave are mutually comparable and belong to two accumulation phases. The sediments existing during the period of origin and development of the Bull's Rock Cave were entirely washed out from the spring region, and as far as they exist in the cave of the Rudice swallet their relicts are completely covered by the sediments of the two subsequent accumulation phases. The sediments of both phases are separated by an erosion stage and they differ by the content of pebble types and by textural features. After the rejuvenation of the system by the opening of the lowest level erosion of the sediment fill took place, which nowadays is being slowed down due to the retarding action of the blocked spring. The majority of recent sediments form mixture of redeposited sediments of the accumulation phases mentioned above.

The investigation of sedimentary filling continues further on, its aim being the reconstruction of the whole system and its incorporation into the development cycles of the Quaternary. At present, a detailed and complementary documentation is carried out. We intend also to take advantage of the dating of scree bodies interlayered with the fluvial sediment complex by means of analysis of the malacofauna, and eventually by other methods.

References

Burkhardt, R. 1972. Studie o vyvoji podzemnich toku Punkvy. Sbornik Okres. vlastived. muzea v Blansku, IV, Blansko.

Burkhardt, R. Gregor, V. Hypr, D. 1975. Rudicka plosina v Moravskem krasu – cast II. Geologicka stavba a vyvoj Rudickeho propadani *Acta Musei Moraviae* LX, Brno.

Hypr, D. 1975a. Nové objevy v jeskyni Rudického propadani – Velikonocni jeskyne. *Cs. kras* (en presse), Praha.

Hypr, D. 1975b. Fluvialni sedimenty v jeskyni Barové. *Cs. kras* (en presse), Praha.

Musil, R. 1959. Jeskynni medved z jeskyne Barové. *Acta Musei Moraviae* XLIV, Brno.

GENETIC PROBLEMS OF THE HUGE GYPSUM CAVES OF THE UKRAINE

L. Jakucs and G. Mezosi
Jozsef Attila University, P.O. Box 428,
Szeged, Hungary.

The Podolian plateau in the Ukraine is one of the most extensive, interconnected gypsum karsts on

the Earth (1, 4, 7). To the north of the River Dnyester, in the region of the towns Lvov, Ternopol and Chernovtsi, extending as far as the Pripyach marshes and to Poland, an extensive gypsum karst has developed, undoubtedly the largest in Europe, its surface area far exceeding those of the gypsum karsts of Asia Minor, the Urals or the Harz Mountains of Germany. The central region of the Podolian gypsum karst covers at least 50,000 km^2, but further research will certainly reveal at present unknown karst processes in the gypsum layers of more distant areas.

The reason why the gypsum karst nature of the Podolian plateau was discovered only relatively recently is that the karstified gypsum layers generally lie under the surface, covered by various thicknesses (5-25m) of younger layers of non-karst rocks, and by soils formed in part by the corrosion of these and in part by Pleistocene loesses. The karstic corrosion of the covered horizontal gypsum strata has given rise only to few karst forms which can be seen free from the cover. It is only in the last few years that the considerable Podolian cave discoveries have proved conclusively that the gypsum deposits of the Podolian ridge have undergone a very intensive subcutaneous karstification in the course of their subsurface hydrographic development.

The plateau-like ridge, which slopes gently towards the south, has a high relief energy, for the various rivers (the Stripa, Druzhin, Zbruch, etc), have cut valleys in to the Silurian clay slate and formed small blocks some tens of kilometres in size. These blocks enclose the enormous Optimist (109km), Lake (103 km) and Crystal (19km), etc. cave complexes. Numerous gypsum and anhydrite areas are known on the various continents, but it is only on the Podolian ridge that cave labyrinths several tens of kilometres in length have formed in blocks as small as 1 km^2.

That part of the ridge between the Zbruch and Seret rivers, with an average altitude of 200-350 m, was also studied by us; this area stretches north from the Dnyester, right up to the heights of Ternopol. The climate of this region is temperate and mildly wet. The annual amount of precipitation is 700 mm. The average annual mean temperature is 6.8-7.0°C; the mean temperature for January is -5.5°C, and that for July is 18.5°C.

In the central and western sectors of the Optimist cave the thickness of the gypsum is 60-70 m, whereas elsewhere it is generally 25-30 m. The temperature of the cave in the eastern sector is 7.9-8.2°C, while in the central and western sectors it is 9-10°C (10).

The differences in temperature between the eastern and western cave sectors can only partially be attributed to differential exchange of the cave air with the external atmosphere. The temperature of the eastern sector corresponds to the annual mean temperature of the region; in this sector the entrance has been exposed. In winter the direction of the draught transports air from outside into the cave, whereas in summer this transport direction is reversed. On the above basis, the temperature of the eastern sector must be regarded as normal. However, the fact that the temperature of the cave in the western sector is higher than expected from the annual mean temperature can be ascribed not to a geothermic heat flow, but, in our view, to exothermic physicochemical processes taking place in the cave e.g. the absorption of water by anhydrite and its conversion to gypsum.

Three morphologically well-separated levels can be distinguished in the cave (the Podolian caves in general have 2-3 levels).

However, the Optimist Cave, together with the Lake Cave, which genetically and palaeohydrographically probably forms one system with it, and the Windy Cave, so far explored over a distance of 4 km, lie in one orographic block; after the discovery of the still unknown connecting sections, therefore, this will be the longest cave system in the world.

The small brooks forming on the plateau surfaces sooner or later flow into swallow-holes. Excavation of such a swallow-hole led, among others, to the discovery of the Optimist Cave (Fig. 1). In places one can observe shallow, non-draining, round dolines, which indicate gypsum close to the surface. The area can in general be regarded as typical covered karst. Only in the valley-sides, where the gypsum has been exposed, have karren begun to form. Dye tests of the swallow-hole valleys have shown that the waters flow away primarily areally along the contact of the gypsum and the overlying layer. Because of this, entire "spring-lines" not discrete springs develop in the valleys. This is one of the signs that reticular cave formation has taken place where cave

Earlier, when only the maps of the Podolian gypsum caves were known to us, we considered them to be caves of typical tectonic genesis (5). Our on-site observations, however, convinced us that, although the passages were generally preformed tectonically or atectonically by jointing, nevertheless their final forms were developed by fluvial erosion. The fracture pre-formation may be linked to the weak tectonism of the region in the Pleistocene, connected with the elevation of the Carpathians and the Ukrainian Crystalline mass. The predominating running-water erosion effect is proved by the morphology of the passages and by the stream alluvia, sands and gravels found in the caves.

Pseudotectonic fractures were also formed in the passage system as a result of the roof pressure, since, because of its plasticity, the gypsum was pulled apart and slipped in the direction of the deepened valleys by gravity.

All these genetic fractures are well documented by the ground-plans of the caves. It is mainly due to the development of a pseudotectonic fracture system as a result of the roof pressure, and to the strong preformational effect, that the ground-plan of such a cave differs considerably from that of a limestone stream cave. A significant role was played in this, however, by the fact that the crevice waters flowing predominantly in the NW-SE direction at the end of the Pliocene took part in the formation of the Podolian gypsum caves (the Pliocene fractures were NW-SE (Carpathian) in direction), and that these were subsequently replaced by waters moving in the NE-SW direction in the Pleistocene.

It has also proved possible to find a parallel between the levels of the individual cave systems and the terraces of the Dnyester.

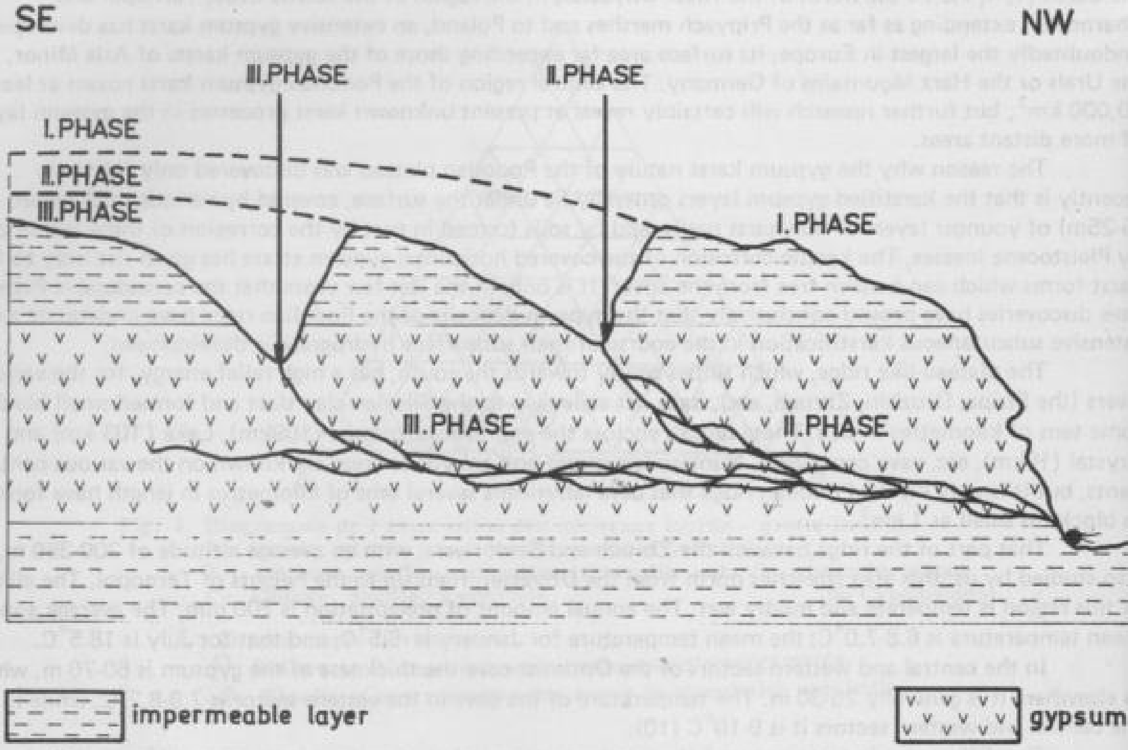


Fig. 1. Hydrographic and genetic correlation between the river valleys, springs, swallow-holes and cave passages on the Podolian plateau. In phase I of the hydrologic development the side-streams still had a surface course. In phase II the gypsum stratum tapped the stream by depression from below (bathycapture) and the upper level of the caves developed; later, the swallow-hole was shifted back to the upper section of the stream valleys, and the lower (active) level of the caves was produced (phase III). The type of this genetic correlation is materialized in the connection of the Optimist Cave (phase III) and the Windy Cave (phase II).

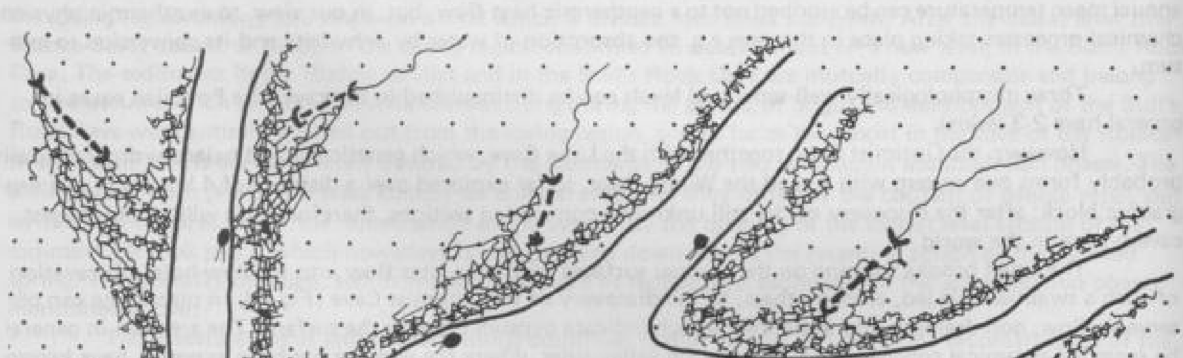


Fig. 2. Sketch map of river valleys splitting the plateau, streams flowing on the surface of the individual blocks, swallow-holes, caves and springs in the Podolian gypsum karst.

References

1. Chikishev, A.G. 1973. Caves of the Soviet Union. Moscow, p. 132 (in Russian).
2. Dublyansky, W.N. 1966. Karst caves of the central Dnyester region. (chapter in Questions of karst research on the Russian Plain) Moscow, (in Russian).
3. Dublyansky, W.N. & Somolnyikov, B.M. 1972. Karst geophysical investigations on the Dnyester region of Podolia. Simferopol, p. 140. (in Russian).
4. Herak, M. & Stringfield, V.T. 1972. Karst. Amsterdam-London-New-York, pp. 355-416.
5. Jakucs, L. 1971. The morphogenetics of karsts, Budapest, 1971. p. 130 (in Hungarian).

6. Jakucs, L. 1974. Special giant caves. Fold es Eg, 2, pp. 34-38 (in Hungarian).
7. Maksimovich, G.A. 1969. Gypsum karst caves. Peshcheri, pp. 24-29 (in Russian).
8. Savchin, M.P. & Kochkovsky, N.V. 1971. The Optimist cave. Peshcheri, pp. 84-89 (in Russian).
9. Savchin, M.P. & Oshttyanova, N.N. 1972. The Optimist cave: one of the largest caves in the world. Pescheri, pp. 197-198 (in Russian).
10. Tatarinov, K.A. 1965. Karst caves in the central Dnyester region (a chapter in Karst types in the Soviet Union). Moscow, pp. 106-121 (in Russian).

CONSTRUCTION OF SHAFTS IN METAMORPHOSED KARSTIC FORMATIONS

M. Kala, G. Cubuk, H. Salm, O. Ondrousek
and E. Coufalik
MRC Clinical Research Centre, Watford Road,
Harrow, Middlesex. HA1 3UJ

A fractured and collapsed limestone mass formed a serious obstruction to our explorations of the subterranean rivulet, Bila Voda, near Holstejn, which is one of the main NE tributaries of the subterranean river Punkva in the Moravian Karst. We decided to make a horizontal and vertical clearing through this obstruction. A horizontal tunnel was driven through rocks slipped into the valley towards a fault located between compact rocks. This fault was found to be filled with gravel and crushed rocks. We decided therefore to construct a vertical shaft in the fault deep into the limestone massive in the next stage.

The construction of a horizontal and of a vertical shaft shows the application of mining engineering methods together with the knowledge of spelaeology and karstology. "The Spirale Cave" was the name given to this artificial passage, from its final profile, which gave access to the top of a 70 m high cavity containing the underground stream which we expected.

Retrospectively, the technical project consisted of 3 stages: (i) The construction of a horizontal shaft through the crushed rocks to the fault located between compact rocks (ii) The construction of a vertical shaft between two solid limestone formations which we followed downwards along the one solid rock. (iii) The half-circular horizontal approach to the top of a dome and the installation of a solid iron ladder, 70 m long to the bottom of the dome. It was our conservational interest to preserve the spelaeological character of karstic phenomena, and the geological character of the damaged formation.

We know that the mining work under such conditions is submitted to the laws of physics, particularly those of statics and of spelaeology. It was our rule that a compact rock supported the shaft from two or at least from one side of the shaft. The opposite one or two sides of the shaft were supported. The work had to be done very carefully when three sides had to be supported and we nearly abandoned the work at one stage. The statistical powers of the boulders clenched together were not violated!

The vertical shaft which had to be opened was small, of 1.5x1.5 m in average size. According to our experience this size was sufficient for the transport of the necessary equipment.

The building materials we used were fresh fir-wood, which was debarked to prevent moulding and rotting, and band-iron. The diameter of beams was 20-25 cm only, and they were 1.5-2 m long. Such beams safely supported the rocks for 4-5 years at the entrance of the horizontal shaft exposed to atmospherical conditions of the climate outside, or 10-15 years safely in the humid underground. In dangerously exposed places, band-iron were always used together with fir-wood. Beams made of concrete were expensive and they did not prove as safe as fir-wood.

The beams were inserted horizontally and vertically and kept the rocks apart. They were joined together where the vectors acted. For the work to be carried out, it was important to use our mining experience, coupled with geometrical and physical consideration in order to find the proper vectors on which to act. The beams were checked daily or at least weekly by knocking on them with a hammer. A high pitched, resonating sound signified that the rocks were safe and the vectors were not changed. A slightly dull sound signified loosening of the beams in the frames. The position of the beams was corrected immediately and the proper action of the vectors restored if the beams were found loose, otherwise we would not have been able to avoid collapse of the constructed shaft.

The spaces in between the beams were secured by timber boards, fixed between the frames and broken stone. The gravel heaped behind them helped to keep them in position. The removal of the remaining stone, gravel and sediments from the vertical shaft was assured by means of a bucket which was mounted on a winch or a hoist and checked each time before use.

The use of explosives is not safe as the blast could damage either the construction made of beams or the shaft or violate both their stability. Sometimes, when the blast could not be avoided, a small quantity of dynamite was used.

The firmness of the wooden frames and of the rocks was examined after blasts by each man in the team by knocking them with a hammer and by listening to their resonance and high pitched sounds. These checks were repeated each day. Any cracks in the rocks were followed up cautiously by sticking them together with a sticking ribbon, selotape or plaster of Paris. We did not notice any of them come off due to widening of the crack, but should this have happened, the shaft would have had to be left instantly by the whole team. The es-

cape from the shaft must always be upwards. A hiding place in a recess may be fatal. These precautions have always been kept since then.

As soon as the shaft was 20 m long and deep another important sign was noticed. The air-drafts from underground, intensified and grew colder as we descended. They blew from the underground up to the entrance during the day and vice versa at night. We stopped the excavation directed vertically and downwards as we were aware of the danger that the bottom of the shaft may fall down into the top of the cavity. A small horizontal passage, which followed the maximum air-draft, was made through the rocks and finally opened at the top of the 70 m deep cavity. At the top of the cavity security points for hands and feet were nailed into the rocks.

A safety landing in the form of a bridge was built in the opened top, and a wire net was spread to protect us from falling stones coming from above.

The dome was descended by means of a temporary wire ladder which was soon exchanged for a solid band-iron ladder screwed together from parts 1.70 m long and 30 cm wide. The screws holding the parts of the ladder were 2 cm thick and were preserved with vaseline. The ladder 70 m long was fixed to the bottom of the dome and to its walls. The way to the exploration of the underground and its beauties was opened.

Reference

Ceskoslovensky Kras 1960.

GLACIOKARSTIC DEVELOPMENT IN ORDOVICIAN CARBONATES – WESTERN NEWFOUNDLAND

Marika S. Karolyi (Bourque),
Department of Geography,
McMaster University, Hamilton, Ontario, Canada

This paper is a report on karst development in the Ordovician limestones/dolomites of Western Newfoundland, emphasising a complex glaciokarstic-karstiglacial (For, 1977) terrain between Goose Arm and Bonne Bay Big Pond (lake). The area is located at 58°35′ Long., 49°10′ Lat., covering approximately 180 km^2.

Newfoundland is part of the Appalachian Fold Belt System, and the island may be divided up into three tectonic divisions: Western Platform, Central Mobile Belt, and Avalon Platform.

The major karst areas are found on the Western Platform in Ordovician rocks, the St. George (Mohawkian) and Table Head (Chazyan) Formations. The Western Platform evolved upon a continental basement which is well exposed as the Long Range Mountain Complex (Stevens, 1970, Williams *et al* 1972). The Ordovician rocks are predominantly shallow water carbonates, represented by limestones and dolomites with minor sandstones and shales of the St. George Formation (=122-458m), and by fossilliferous limestones and dolomites of the Table Head Formation (183-336m) (Stevens 1970; Lilly 1963-1967; McKillop 1963).

Large karst basins covering several tens of km^2 are found north of Deer Lake in the St. George Formation. Smaller karst areas are found south of Deer Lake in the Corner Brook area and around Sops Arm in the Doucer Formation. Several other areas have minor karst features in the form of short underground drainage or in small, partly collapsed caves.

In the Goose Arm – Bonne Bay Big Pond region extensive folding and faulting complicates the geology. Extensive glaciation has produced a rugged totpography with intricate ice-moulded type of rounded and streamlined hills, steep U-shaped valleys, and large closed depressions. From the Last glaciation ('Wisconsinan' = Würm) there is a deep, almost continuous blanket of till of highly irregular thickness (1-25m).

This multiple-glaciated limestone terrain is unlike other glacio-karstic terrains reported in the literature, because of the intense, high relief ice-moulded forms. In other instances (e.g. Co. Clare of Eire) the limestone is the regional "strong rock" forming highlands. Here, although the rocks are massive-crystalline, and as strong as those of Yorkshire, Eire, etc., they occupy a broad vale subject to repeated multidirectional ice scour from glaciers from yet harder and stronger rocks of the enclosing Long Range Mountains. A consequence is that the karst type and distribution is singularly complex and in almost every instance the researcher faces the problem of determining whether a given feature now displaying karstic drainage is of glacial scour in origin modified by karst processes post-glacially or of karst origin modified by glacial scour and deposition.

Obvious post-glacial karst forms (such as karren, some sinkholes, small stream caves and all karst springs) have a patchy distribution and the drainage areas vary in size from less than 1km^2 to 2km^2. Karren forms are found generally along lake shores and are rills of varying size and shape. Sinkholes may be divided into two kinds, those found in till and those found in limestone. Sinkholes in till vary in size from 1-30m, have a circular form and are of collapse or suffosion origin. Sinkholes in limestone are solutional in origin, circular in form, and may range up to 50m in diameter.

Short, apparently simple linear caves are also found at a number of localities; they are usually of unexplorably small dimensions, draining modern lakes. Maximum length of less than 3 km is typical.

The distribution of these post-glacial karst forms is sporadic and highly irregular, a function of variation of depth of local till cover, of favourable geologic structure, and local high hydraulic gradient created by glacial derangement of drainage.

Distinct pre-glacial karst forms are cave fragments found at mountain tops, and in sediment-filled caves where extensive mineralisation is taking place.

This limestone terrain has numerous large closed depressions, the majority of which contain lakes drained underground. Some of the depressions display distinct ice-scour. Three major closed depressions receive drainage from 5-7 km^2 and discharge underground. Depressions displaying ice moulding and scouring forms are elongated in the direction dictated by ice flow or geologic structure.

An interesting situation is found at Nameless Pond and Brown's Pond area where the predominant structure indicates a uniform and steep dip to the north. Nameless Pond is situated in an elongate closed depression; it sinks at its northern end and reappears about 3 km north at Bonne Bay Big Pond. Brown's Pond, just east of Nameless Pond has a similar situation but is not in a closed depression. This lake sinks at its southern part and reappears 5 km south at North Lake.

Canal Pond (15 km southwest of Bonne Bay Big Pond) is a large complex depression draining an area 7 km^2. The water sinks at its northeastern edge and reappears ≈1.5 km east. The cave that connects the sink point and the rising is utilized to its fullest capacity in flood times.

Distribution of these karst areas is irregular, but in aggregate 60% of the limestone terrain, in between Goose Arm and Bonne Bay Big Pond, is drained underground via closed depressions.

Summary

The area between Goose Arm and Bonne Bay Big Pond is a multiglaciated limestone terrain, surrounded by higher and stronger rocks of the Long Range. Karst type and distribution is complex and irregular, but it is obvious that both glaciokarstic and karstiglacial development is present. Cave fragments and sediment-filled caves indicate development before glaciation. The majority of karst forms point to a glaciokarstic development, where previous karst forms have been modified by ice. Karstic processes continue to operate today, modifying the scoured basins and creating new karst forms.

References

Lilly, H.D. 1963, *Geology of the Hughes-Brook, Goose Arm Area, Western Newfoundland.* Unpub. Msc. thesis Memorial University, St. Johns, Newfoundland, 122pp.

Lilly, H.D. 1967, Some notes on stratigraphy and structural styles in Central West Newfoundland. *Geol. Assoc. Can. Spec. Paper* # 4, p. 201-212.

McKillop, J.H. 1963, *Geology of the Corner Brook area, Newfoundland, with emphasis on the carbonate deposits.* Unpub. Msc. thesis Memorial University, St. Johns, Newfoundland. 102pp.

Stevens, R.K. 1970, Cambro-Ordovician Flysh Sedimentation and Tectonics in West Newfoundland and their possible bearing on a proto Atlantic Ocean. *Geol. Assoc. Can. Spec. Paper* #7, p. 165-177.

Williams, H. & Kennedy, M.J. & Neale, E.R.W. 1972, The Appalachian Structural Province. *Geol. Assoc. of Canada Spec. Paper* #11, p.182.

KARST LANDFORMS AND SPELEOGENESIS IN PRECAMBRIAN GRANITE, LLANO COUNTY, TEXAS (U.S.A.)

Ernst H. Kastning
Department of Geological Sciences,
The University of Texas at Austin,
Austin, Texas 78712, U.S.A.

Physicochemical weathering processes have produced a diverse variety of karst landforms on exposed coarse-grained, pink granite in the Llano Uplift region of central Texas (U.S.A.). Several uncommon karst and pseudo-karst features have developed on Enchanted Rock, Llano County, the largest in a chain of domed inselbergs of Precambrian granite of the Enchanted Rock Batholith. Of particular interest is Enchanted Rock Cave, located on the northwestern side of the inselberg and near its summit.

Minor Karst and Pseudokarst Landforms

Many geomorphic features on Enchanted-Rock resemble forms developed in limestone karst and are considered karstic where dissolution of granite has been the dominant process. As a precise definition of the term "pseudo-karst" is currently in question (Otvos, 1976), forms due principally to processes other than dissolution are herein termed pseudokarstic. Most karst-like features on Enchanted Rock are the product of granular disintegration of bedrock through grusification and physical erosion. Many of these landforms have been previously described (Blank, 1951a, 1951b; Kastning, in press) and are briefly noted here.

Gnammas — Numerous shallow depressions, ranging in diameter from 0.3 to 15 m, are found on gentle slopes of the inselberg, particularly near its summit. These have developed through differential weathering of mineral aggregates, in many places along joints. Flaking of the upper surface of the rock mass and the destructive influence of lichens seem to have augmented chemical weathering as well. Slightly acidic waters which have accumulated in the gnammas following rainfall have altered feldspar minerals to kaolin and biotite to vermiculite. Gnammas on slight slopes are periodically flushed by heavy rains, but on level surfaces they may accumulate coarse and fine residual debris. The finer material may be later removed by deflation, the coarser material by attrition.

Rock doughnuts — Several gnamma-like features are encircled by a raised rim of granite 20 to 30 cm in width and up to 15 cm high. Blank (1951b), who originally described these features, hypothesized that either

(1) water in gnammas had indurated the surrounding rock, case-hardening it, or (2) water flow was checked on its downhill movement by gnammas, thus reducing its velocity and corrosive effect in the vicinity of the gnamma. Twidale and Bourne (in press) indicate that raised platforms (plinths) may develop beneath boulders on sloped, smooth surfaces as the neighboring rock is weathered away. Gnammas may form on these raised surfaces where moisture under boulders is protected from solar heating and is retained for longer periods. As the boulders disintegrate by further weathering, the doughnut is left behind as a remnant.

Granitrillen and channels — Incised flutes and channels have formed on the dome surface, particularly on flared slopes and where drainage from gnammas has been integrated into flow networks. Most are several centimeters deep and 10 to 20 cm wide; however, on steeper slopes, higher-order channels may be as much as 50 cm deep. Chemical and physical removal of biotite and plagioclase feldspar has left rough quartz - and microcline - studded channel beds. Consequently, the summit area of Enchanted Rock has been etched into a fluviokarst landscape by channels and gnammas.

Tafoni, arches, and pedestals — Water running down the dome surface during heavy rains has physically and chemically weathered the basal parts of many exfoliated blocks. Cavernous weathering (tafoni) is common where blocks have been undercut at their contact with the bedrock. Larger openings are enterable and qualify as caves. Tafoni commonly attain more mature forms such as arches or pedestals as weathering progresses.

A-tents — Pressure-release structures in the form of A-tent-shaped pop-ups are found on various granite domes of central Texas. A few examples are found at Enchanted Rock. Jennings and Twidale (1971) suggest that exfoliated sheets pressed upward into small tent caves, are expressions of compressional forces within the inselberg. It is also likely, in some examples, that arrest of down-slope movement of exfoliated sheets may produce sufficient compressional forces from still sliding up-slope blocks to produce A-tents. The small caves thus formed are ephemeral pseudokarst features of purely physical origin.

Enchanted Rock Cave

Enchanted Rock Cave is one of the longest caves to have formed within an inselberg mass. It is the product of four processes: (1) fracturing of the bedrock mass, (2) grusification, (3) removal of detritus by piping, and (4) talus accumulation and roofing. More than 300 m of passageway have been surveyed and although there are over 20 entrances to the cave, there is one large passage (2 to 3 m high and 70 m long) on a lower level where artificial light is necessary for exploration (Smith, 1974).

Fracture formation — A long northeast trending fracture extends for approximately 500 m parallel and near to the northwest face of the inselberg. The fracture formed prior to exhumation of the inselberg and Enchanted Rock has subsequently developed along the fracture plane.

Grusification — Chemical enlargement of the fracture may have begun prior to exhumation, as groundwater seepage attacked the upper surface of the buried rock mass. Grusification has weakened the fracture wall rock considerably, especially where the nearly vertical fracture has intersected an extensive exfoliation fracture plane of relatively shallow dip. At the depth of this juncture the vertical fracture was still closed sufficiently to perch water as it moved along the fracture strike. As exhumation of the dome progressed, seepage became more rapid as did the removal of chemically decomposed and dissolved minerals such as oxidized biotite and "chalked" plagioclase. Orthoclase and quartz grains were left behind as disaggregated grus to be later removed largely by physical erosion and further dissolution.

A large weather-pit began to form adjacent to and southeast of the fracture, beginning perhaps as a small gnamma and enlarged by exfoliation along its margins. At present this structure is approximately 20 m in diameter. Runoff from a large area of the dome surface is concentrated by this amphi theatre-like pit and is channelled directly into the cave fracture.

Piping — Disaggregated grus has been removed from the cave through mechanical suffosion (piping). The cave has been flushed periodically by catastrophic storms typical of the central Texas region, and water remaining ponded temporarily at the levels of fracture closure had time to further weather the adjacent bedrock, forming a zone of grus along the cave walls. Grus was later removed through spalling and erosion. The fracture width at that level enlarged and formed the cave.

Talus accumulation and roofing — Enlargement of the host fracture had progressed substantially to allow breakup of the upper fracture walls. Large granite blocks, weathered out along smaller joints and fractures, had dislodged and were displaced downward into the fracture. In addition, some slabs of exfoliated sheets from the dome surface accumulated within the fracture, sealing many of the interstices among larger blocks and roofing large sections of the cave.

Conclusions

Several types of minor granitic landforms are located on Enchanted Rock. Some forms, such as gnammas and rock doughnuts, have developed through grusification and are essentially karstic. Other forms, such as granitrillen, channels, tafoni, arches, and pedestal rocks are products of physicochemical processes and may be termed karstic, but with pseudokarstic modification. The A-tent caves are the result of physical processes and are pseudokarstic.

At Enchanted Rock Cave, chemical weathering (dissolution) has weakened and enlarged the host fracture. Physical erosion (spalling and piping) has removed grus from the walls and floor of the lower passages. As a result, this cave is in part a karst feature and in part a pseudokarst feature. A unique relationship between the host fracture and a contributive drainage basin has produced one of the largest known granite caves.

References

Blank, H. 1951a, Exfoliation and weathering on granite domes in Central Texas: *Texas Journal of Science*, v.3, p. 376-390.

1951b, Rock doughnuts, a product of granite weathering: *American Journal of Science*, v. 249, p. 822-829.

Jennings, J.N. & Twidale, C.R. 1971, Origin and implications of the A-tent, a minor granite landform: *Australian Geographical Studies*, v.9, p. 41-53.

Kastning, E.H. in press. Granitic karst and pseudokarst, Llano County, Texas, with special reference to Enchanted Rock Cave: Proceedings of the 1976 Annual Convention of the National Speleological Society.

Otvos, E.G. Jr. 1976, "Pseudokarst" and "pseudokarst terrains": problems of terminology: *Geological Society of America Bulletin*, v. 87, p. 1021-1027.

Smith, A.R. 1974, A cave — Enchanted Rock: *Texas Caver*, v. 19, p. 78.

Twidale, C.R. & Bourne, J.A., in press, Rock doughnuts: Revue de Géomorphologie Dynamique.

THE SYSTEMS APPROACH TO THE PROBLEM OF CAVE TRANSFORMATION FOR TOURISM AND RECREATION

Rufat M. Kasumov
Institute for Economics,
Gosplan of the Azerb. S.S.R.
Baku, U.S.S.R.

Caves as an important element of the environment have been subject to intensive development for tourism and recreation for the last few years. Utilising caves conserves and maintains them but unplanned caving and tourism leads to great changes in the regime of the systems and to their devastation.

The problem of conserving caves for the purposes of tourism is now a question of prime concern, taking into account the quantitative growth of tourism and the inclusion of caves amongst tourist attractions. Scientifically the problem falls into two categories, (1) the conservation of caves by reserving them for future utilization for tourists; and (2) the maintenance of caves already adapted to receive tourists.

We consider that the systems approach is the best method of approaching this problem. If we imagine a cave system to be a multi-level structure linking the elements of living and inanimate nature, each element forms a functional box developing independently in time. Each box is a macro-system, its outputs reflecting specific processes obeying specific laws. We should note that separate boxes of the cave system appear and function at specific stages in its development. We can say that the cave system is in a process of structural transformation, continually becoming more complicated, leading to an increase in the number of levels and in the complexity of relations between elements.

The most important boxes influencing the general functional processes of a cave system are "climate", "water system", "fauna" and "geological structure". The latter box includes the aqueous elements too. It should be noted that at any definite phase of the development of the system, these boxes interrelate closely and control the subsequent development of the entire system. The process of transformation of the cave structure results in the creation of new cave systems.

A cave system passes through the following stages in the process of its development: (1) the creational period of structural elements; (2) the period of development and transformation of elements into boxes; (3) the period of the appearance of new boxes which complete the building of the structure of the full cave systems; (4) the period of the detachment of new, simpler cave systems.

We can distinguish between two forms of cave systems: closed and open. A cave system unaffected by the three important disturbing agents; air, water and man, is called a closed system. The presence of any of these agents will make the system an open one. In the further course of the development every factor will form a separate box and thus the level of development of the cave will be higher. Practically and logically all caves which have been examined by man are open ones.

From this point of view there appears the problem of control of the transformation process of a cave system. Since man does not appear in this system as a structural element, or as an *in situ* controlling influence, then the problem arises of how to determine the role and the degree of man's influence upon the natural transformation of caves in time and space. In practice man studies caves or uses them for recreation and tourism. In the first instance man more or less tries to influence cave development; in the second he tries to adapt it to its present normal condition for use for leisure purposes. Here we can clearly see the social aspect of cave exploration in different countries. In some the caves change almost completely and they have entertainment functions, in others its apparent modification is minimized in order to optimize the visual appeal and to render them safe for visitors and to control pollution. Thus using caves for tourism and recreation directly depends upon the intentions of the users. The control of cave transformation can be treated as a system of external influence upon elements of the system with a view to bringing it to a required condition. This may lead to different structural changes in functional boxes by way of combining both output flows and direct interference with the development process. Concretely these may result in change in the heat and moisture exchanges, modification of geological structures, changes in the environment of cave-fauna, etc. In the end these forms of management cause changes in the development of the cave and the building of new functional relations between such elements.

The tourist movement is making use of caves for sightseers to a gradually increasing extent. At the VIth Congress of the International Speleological Union at Olomouc, Czechoslovakia in 1973 I proposed the ranking of a cave system as one of the group of information services. On the same occasion proposals were submitted to assign caves to the supply and accommodation services. My studies of recent years have shown that a cave system is an independent element can be assigned in practice to the group of entertainment services.

After being examined by speleologists caves become tourist features; therefore in a community, the problem of linking these two basic forms of human activity will present itself. Caves which are the subject of scientific research cannot be opened to masses of tourist visitors. These caves are usually ones that have only recently been explored and hardly visited by man, and where his impact is minimal. The conservation period should last until the complete examination of it is completed. One of the questions to be answered will be the possible form of tourist utilization of the cave. Such an investigation should aim to show the stage of development of the cave, the rate of transformation of its various sections and the level of influence of external factors.

As an element of the system of tourist services, caves must be developed and improved without any damage to the functional processes. In other words, man's impact upon each part of a cave system should be minimized. The natural development of caves takes a long time and this enables the regular restoration of elements subject to degradation.

The history of tourism has shown that the utilization of cave systems in many regions has become an important factor in the local development of tourism. This means that there is the problem of maintaining and supporting the functioning of the cave regime for the purpose of attracting visitors. The inclusion of caves amongst the tourist attractions of an area leads to the development of infrastructures directly related to the cave region. The uniformity of conditions within caves enables them to be used throughout the year, but unfortunately they are seldom used except in summer.

Thus the problem of cave transformation for tourist and recreational purposes demands a special approach in accordance with the stage of development of a cave and this it is submitted, is only possible by the utilization of the method of systems analysis.

SOLUTION VELOCITIES ON FACETS: VESSEL EXPERIMENTS

Stephan Kempe & Rainer Hartmann
Geol-Pal. Institut University of Hamburg,
Bundesstr. 55 D-2000 Hamburg 13,
West Germany.

Caves developing in standing water bodies ("Laughöhlen", Biese, 1932) display specific morphological elements: the flat solution roof ("Laugdecke") and the plane, sloped sidewalls ("facets"). In the ideal case the passage profile forms a tip down triangle. If the water table has been relatively constant, these caves do not have larger depths than several meters. Standing or very slow not turbulent moving water bodies can occur (i) along valley sides, (ii) where small creeks enter large cavities at groundwater level, or (iii) where water invades soluble rock from below.

As gypsum is much more soluble than limestone, this cave type is best developed in gypsum (f.e. South Harz Mountains, Germany) though some fine examples are also known from limestone (f.e. Na Spicaku near Supikovice CSSR, or Lascaux in France).

The developing processes of facets and Laugdecken, however, are still not known in detail. Facets have been explained in the past (i) as planes of repose, inactive to solution because of a residual sediment cover (Goodmann, 1964, 1969; Reinboth, 1968, 1974), and (ii) as forms of active solution (Kempe, 1970, 1972), created by dense under-water films running down the facet and maintaining a material flux into the water body (Kempe & Seeger, 1972; Kempe *et.al.*, 1975; Brandt *et.al.*, 1976). This latter theory views sediment covers only as a secondary hindrance. Furthermore dense water films have in fact been discovered to move down the facets in cave pools (Kempe *et.al.*, 1975; Brandt *et.al.*, 1976) and complex water structures have been measured (Kempe, 1973).

Vessel Experiments

To measure the gypsum-flux off the facet, vessel experiments were conducted. Three litres of water were filled into a glass container 17.5 cm wide and the foot of the plaster of Paris facet was placed 10 cm from the opposite wall. Table 1 gives the data for three runs with 30°, 45° and 60° inclined facets evaluated so far.

TABLE 1

Experiment	*1*	*2*	*3*
Temperature in °C	15	15	15
Volume of water (V) in cm^3	3000	3000	3000
Angle of facet in °	30	45	60
Water depth in vessel (H) cm	18.86	15.61	14.53

Facet area (A) in cm^2	330.05	273.18	254.28
V/A	9.09	10.78	11.80
$A_x/A_{45°}$	1.2082	1	0.9308
Numbers of measurements	15	16	19
Exponential fit curve, C_{sat}	600 mgCa/1	600	600
C_{sat}-C=C_{sat} exp(-t/T) T	35.04	27.14	31.75
Correlation of data and fit	0.97	0.86	0.89

With a fixed pipette 1 ml samples were drawn from water body about every hour. These samples were analysed with atomic absorption spectroscopy for calcium.

Experimentally it is difficult to keep both the volume of the water and the area of the facet constant. We kept the volume constant and corrected for the larger (at 30°) or smaller (at 60°) facet areas by prolonging or shortening the time axis of the runs with the factor $A_x/A_{45°}$. Graph 1 plots the results of the three runs together with interpolated curves (SPLIN-interpolation, standard deviation = 40 mg ca/l).

Discussion

Dissolution processes are described by exponential functions:

$$C_{sat}\text{-}C_i = C_{sat}\exp(-t_i/T) \qquad (1)$$

where C_{sat} is the saturation and C_i the actual concentration, t_i is the time of measurement and T the time constant. For the experiments conducted (15°C, $pPCO_2$ 3.5) C_{sat} is 30 mval Ca/l (29 mval/l from the gypsum and one mval/l from calcite impurities (Wigley, 1972) or 600 mg Ca/l. By calculating the regression (time in hours) for

$$t_i = 1n\,(C_{sat}\text{-}C_i) \qquad (2)$$

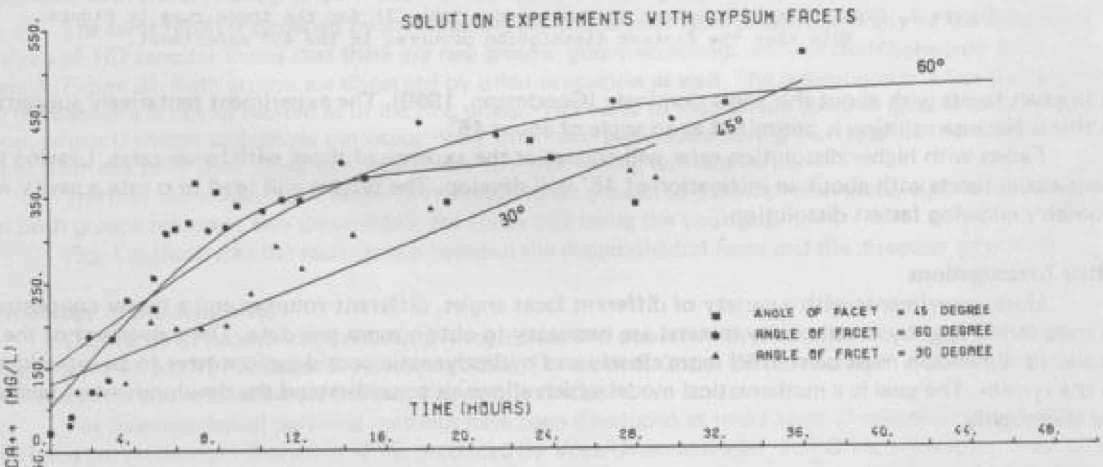


Figure 1. Concentration-time diagram of three runs with 30°, 45° and 60° inclined facets. Curves are SPLINE-interpolations with a standard deviation of 40 mg Ca/l.

the actual start time can be found by the intersection of the linear regression function with t_0 = 1n (600 mg Ca/l). Adding t_0 to the time values of the data one now can calculate an exponential quadratic best fit for the measurements, the values of these functions are given in Table 1 and the functions are graphed in Figure 2.

Two features of the data are interesting to note: (i) the correlation between data and fit curves (see Table 1) is not very large, concentrations very often do not increase for hours, they even decrease a couple of times, (ii) the 60° facet has not the largest dissolution as one should expect intuitively.

The first phenomenon may have two reasons. Either the analyses are not accurate enough (samples had to be stored three months refrigerated before processing), or convection within the vessel does not work like a mechanical stirrer, i.e. homogenizing the concentration at any moment. We rather have to be aware of stratification in the water body. The dense water film runs down the facet. This causes relative water movement towards the facet at the water surface and away from the facet, at the bottom of the vessel. It is very possible that this dense bottom water forms a separate layer of distinctly greater density than the layer above it. This layer is stable, as long as the dense facet film can penetrate the bottom layer. If the film is not dense enough it will be diverted half way down the facet into the upper layer. At the interface mixing will occur, which soon mixes the total volume. This model can explain why, at a fixed point where the samples were taken, the concentration can stagnate and even decrease.

The second phenomenon, the large dissolution at the 45° facet correlates well to the long known fact

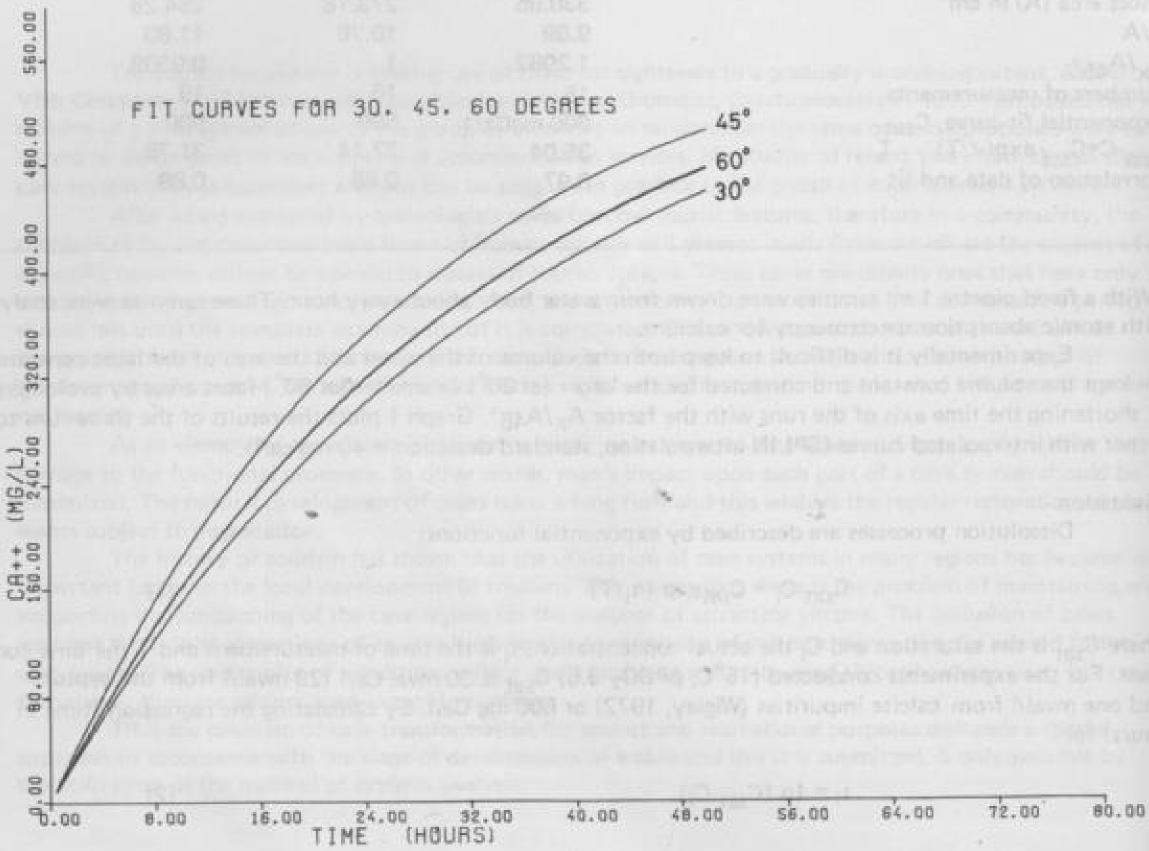


Figure 2. Exponential fit curves (parameter see Table 1) for the three runs in Figure 1. Note that the fastest dissolution occurred in the 45° experiment.

that in caves facets with about this angle dominate (Goodmann, 1969). The experiment tentatively suggests, that this is because solution is optimized at an angle of about 45°.

Facets with higher dissolution rates will enlarge at the expense of those with lower rates. Leaving the system alone, facets with about an inclination of 45° will develop. The system will tend to create a cavity with a geometry allowing fastest dissolution.

Further Investigations

More experiments with a variety of different facet angles, different volumes and a better concentration monitoring (e.g. by conductivity meters) are necessary to obtain more raw data. The movement of the film and its dimension must be studied more closely and hydrodynamic considerations have to be introduced into the system. The goal is a mathematical model which allows us to understand the development of facets more thoroughly.

References

Biese, W. 1931. Über Höhlenbildung, I. Teil, Entstehung der Gipshöhlen am südlichen Harzrand und am Kyffhäuser. — *Abh. Preuss. Geol. Landesanst.* Neue Folge (137): 1-71, Berlin.

Brandt, A., Kempe, St. Seeger, M. & Vladi, F. 1976. Geochemie, Hydrographie und Morphogenese des Gipskarstgebietes von Düna/Südharz. *Geol. Jb.* C15: 1-53, Hannover.

Goodmann, L.R. 1964. Planes of repose in Höllern (Germany). — *Cave Notes,* 6, (3): 17-19.

1969. Ein Beitrag aur Frage der Laugung bei gleichzeitiger Anwesenheit von Sediment: Enstehung von Ruheflächen in Höhlen. — Abh.5. *Intern.Spel.Congr. 2,* 30: 1-9 München

Kempe, St. 1970. Beiträge zum Problem der Speläogenese im Gips unter besonderer Berücksichtigung der Unterwasserphase. — *Die Hohle 21,* (3): 126-134, Wien.

1972. Cave genesis in gypsum with particular reference to underwater conditions — *Cave Sci. (Journ. Brit. Spel. Assoc.) 49:* 1-6.

1973. Höhlenbildung und Wasserkörper im Stillwasserbereich. — Proc. 6th Intern. Speleol. Congr. Ca 019, Praha.

Kempe, St & Seeger, M. 1972. Zum Problem der Höhlengenese im Stillwassermilieu. — Mitt. Verb. Dt. Höhlen — u. Karstforscher *18* (3): 53-58, München.

Kempe, St, Brandt, A. Seeger, M. & Vladi, F. 1975. "Facetten" and "Laugdecken", the typical morphological elements of caves developing in standing water. — *Ann. Speleol. 30* (4): 705-708.

Reinboth, F. 1968. Beiträge zur Theorie der Gipshöhlenbildung — *Die Hohle 19* (3): 75-83, Wien.

1974. Untersuchungen zum Problem der Höhlenbildung im Gips. — Mitt. Verb. Dt. Höhlen— u. Karstforscher *20* (2): 25-34, München.

ECCENTRICS: THEIR CAPILLARIES AND GROWTH RATES

Stephen Kempe & Christian Spaeth
Geol-Pat Institut, University of Hamburg,
Bundesstr. 55, D2000, Hamburg 13.
Germany

Introduction

When we started work for this paper on eccentrics, we were convinced capillarists. We are not anymore. The existence of a capillary in every eccentric (synonym: helictite) is beyond doubt, the function of it, however, and the role it plays for the growth of this speleothem is more mysterious for us than before.

Eccentrics, winding in all directions, agglomerated into fields of icy needles are the most intriguing sights a caver can enjoy underground (Plate 1, Fig. 1).

Although eccentrics occur in many caves, they are considered to be scarce. This is not only because larger clusters are in fact rare, but also because the more common smaller specimens are often not identified as eccentrics.

This state of affairs is responsible for the confusion about the genesis of these cave formations. Though already some of the earliest authors have noticed the capillary (Merril, 1894; Blatchly, 1896) others have developed theories neglecting the capillary to explain the phenomenon of eccentrics. Göbel and Reinboth (1972) and Reinboth & Göbel (1975) gave a good review about the different theories developed. Concerning the existence of the capillary they settled this question once and for all, in a study of 1038 specimens from the Winterberg.

In our eyes, the definition of eccentric speleothem must include the existence of a capillary vessel. Everything else looking similar but having no capillary is something different.

Crystallography of the Winterberg-eccentrics

Eccentrics are monocrystalline calcites. Monocrystal-x-ray diagrams (courtesy Prof. H. Saalfeld, Mineralogical Institute of Hamburg), showed that no twinning occurs and that the direction of growth tends to coincide with the crystallographic C-axis (if the eccentric is straight and untwisted).

The same result is obtained by investigating the free crystal faces present on many of the specimens. Analysis of 157 samples shows that there are two groups: glassy eccentrics without rhombohedron faces (Plate 1, Figure 3). Both groups are discerned by other properties as well. The second group is less transparent and the capillary is not so twisted as in the first group. This leads to much more screwed growth in the glassy group, where U-shapes and spirals can occur. Very often two individuals have grown together by epitaxy or sprout from the same base. Once one crystal was observed having two capillaries.

Thirteen individuals start out with rhombohedron growth to continue with glassy tips. This proves, that both groups represent two generations, the glassy one being the youngest.

Fig. 1 a illustrates the relationship between the rhombohedral faces and the direction of growth.

Morphology of the capillaries

Capillaries of eccentrics have been photographed and published by several authors (Kramm *et. al.*, 1969; Kramm *et. al.*, 1970; Göbel & Reinboth, 1972; Reinboth & Göbel, 1975). Because of the large birefringence sharpness and resolution are limited, even in thin sections.

For paleontological purposes methods have been developed to make casts of microhollows. A slow solidifying polyester-resin (Polyester GTS, produced by Voss/Uetersen/Holst, F.R.G.) is allowed to creep under vacuum into the voids under study. With this method it was possible to obtain casts of the eccentric capillary longer than 8 mm. After casting the calcite is dissolved in dilute HCl and the sample can be handled for scanning electron microscopy (Plate 1, Figures 4-6).

The main feature of the capillary is its pearl-string morphology. This can be seen already under the light-microscope. The pearls have conical forms which seem to have a distinct up and down (with respect to the base of the eccentric). The thicker end is pointing to the base of the crystal, while the smaller end points upwards. The maximal width found is 0.08 mm and the minimum 0.03. The mean cross-section width measures about 0.06 mm. Eccentric of other areas have comparable channel sizes or larger openings: Dordogne 0.06 mm to 0.4 mm (Andrieux, 1965), Söhnstettener Excentriqueshöhle/Schwäbische Alb 0.03-0.3 mm (Kramm *et. al.*, 1970).

Intriguing is the rough surface of the capillary. In two specimens, prepared for scanning electron microscopy, tiny ledges run parallel to the centre channel. They must be connected to some sort of alteration in the crystal-structure parallel to prism- or steep rhombohedron faces (Plate 1, Figure 4). Another capillary is marked by irregular projections with smoother contours. (Plate 1, Figure 6). More investigation is needed to reach conclusions from these structures.

Capillaries and eccentric growth

The ubiquitous pearl-string morphology of the capillary reflects periodic growth. The most pronounced periodicity in the soil hydrology is that of the seasons. In winter, frost will hinder the seepage water infiltrating the karst rock below and biological CO_2-production is at a minimum. In spring with the onset of the vegetation both water and CO_2 become available again and deposition is resumed. We correlate the smaller ends of the conical pearls with winter- and the broader ends with spring-period. At some places the cones have shallow trans-

verse incisions midway as well, possibly connected to water shortage during the intense evapotranspiration of the summer.

With a time scale at hand marked in the capillary we can calculate the growth rates of eccentrics for the first time. In a three millimetre segment 80-100 years were counted, while a 0.34 mm piece of capillary yielded 20 years. This gives growth rates between 0.02 and 0.04 mm/a. The longest specimen recorded from the Winterberg measured 20 cm (Reinboth & Göbel, 1975). It would then have needed 5000 - 10 000 years for its completion. This would cover the total Holocene, not reaching the late glacial, during which no sintering occurred because of lack of vegetation and soil on the Harz Mountains.

Fig. 2 shows the relation between length and weight for a number of eccentrics. There is no significant order in the distribution, the heavier pieces (vermiforms) are underrepresented in the collection. They do not grow in densely populated patches, like the lighter eccentrics (filiforms). In the data a minimum relation exists, below which eccentric growth seems not to occur. The weight/length ratio for this minimum is 0.02 g/cm, while the bulk of the eccentrics studied displayed a ration of about 0.15 g/cm.

The annual minimum increase in weight amounts then to

$$\frac{0.02\text{g} \times 0.002\text{ cm}}{\text{cm} \qquad \text{a}} = 0.000\,04\text{ g/a or } 0.04\text{ mg/a.}$$

Considering that the length of the capillary is estimated to be 25% longer than the length of the crystal the rate reduces to 0.03 mg/a. Assuming a little larger mean growth rate of 0.003 cm/a and a weight/length ratio of 0.15 g/cm we obtain growth rates of about (25% capillary surplus included) 0.34 mg/a.

By estimating the geochemical boundary conditions within the Winterberg-caves it is possible to calculate the flux rates necessary to ensure the calculated growth rates. Seepage water has a $pPCO_2$ (neg. log of CO_2 partial pressure) of 2.0-2.5 allowing 140-220 mg $CaCO_3$ (Wigley, 1972) per litre to be carried in solution. As the humidity is very high, not evaporation but pressure difference in CO_2 will cause calcite precipitation. Cave air has mostly CO_2-pressures near the atmospheric values of about 3.5 (70 mg $CaCO_3$/1). So the difference between both pressures will furnish 70-150 mg/l. To maintain the minimum growth rate 0.2-0.43 ml solution is needed per year. With a mean capillary width of 0.06 mm the resulting flux is

$$\frac{0.2-0.43\text{ cm}^3}{\pi \times 0.03^2 \times \text{mm}^2 \times 100} = 7\,000 - 15\,000\text{ cm/a}$$

$$\text{or } 20 - 40\text{ cm/day!}$$

For the mass of the filiforms (growth rate 0.34 mg/a) the flux is ten times larger, i.e. 200-400 cm/day. For the vermiforms the flux rate is increased again by one order of magnitude (compare ratios in Graph 2).

These calculations show that it seems not possible to think of the capillaries as main transportation channels. Flow velocities of several meters per second are unrealistic to us. Capillary pressure will never force water out of a capillary, it will just fill it. The existence of an adequate hydrostatic pressure within the clefts nourishing the eccentric is questionable, too. Very often eccentrics grow out of the sidewalls of active straw stalactites. The hydrostatic pressure will tend to press the water out of the larger opening, not through the capillary with its enormous inner friction (consider the roughness of the walls). Andrieux (1965) assumes that the water in the capillary is pulled out by the capillarity of the water film outside on the crystal surface, without specifying what processes might be responsible for this. Diffusion (due to the CO_2-gradient between seepage water and cave air) also fails to account for these transport rates, as a simple calculation can demonstrate.

Possibly the capillary has only a pilot function, just terminating the direction of growth. Very often eccentrics end in tiny spirals or slender tips (Plate, 1 Figure 2), which carry the capillary mouth. Thickness is gained later by other modes of transportation. This may be transport along the outside, which leaves the cylindrical form of the crystals unexplained, or by transport through the air as suggested by other authors.

Conclusions

Capillaries exist in eccentrics. How they are formed, however, and what their significance is for transport of $CaCO_3$ needed to obtain the observed growth rates remains questionable. These intriquing problems will need more investigation, especially with intact specimens in the undisturbed cave atmosphere. Water films, their movement, concentrations and transport rates are possibly the key for a better understanding of the phenomenon of eccentrics.

References

Andrieux, C. — 1965. Morphogenèse des hélictites monocristallines. – *Bull. Soc. franc. Miner Crist. 88:* 163 pp.

Blachley, W.S. — 1896. Indiana Caves and their fauna – *Ind. Geol. Surv.* 21 Ann. Rept: 160 pp.

Göbel, F. & Reinboth, F. — 1972. Excentriques, eine wenig bekannte Form des Calcites – *Der Aufschluss 23,* 113-124.

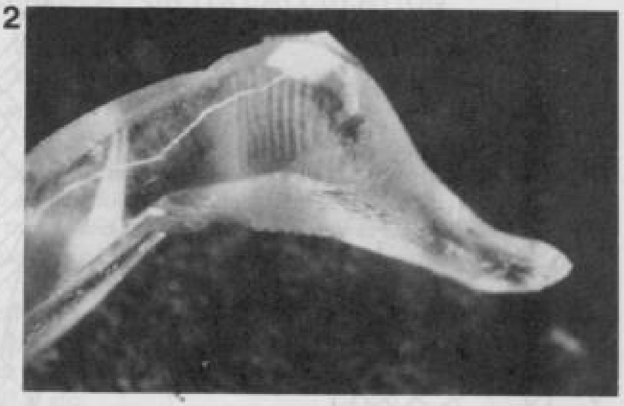
Kramm, U. & Linder B. — 1969. Beitrag zur Entstehung von Excentriques – Mitt. Verb. Dt. *Höhlen – u. Karstforscher 15,* 48 pp.

1970. Untersuchungen an Excentriques der Söhnstetter Excentriqueshöhle – Jber. u. Mitt. Oberrh. geol. Verh. *52:* 27-31.

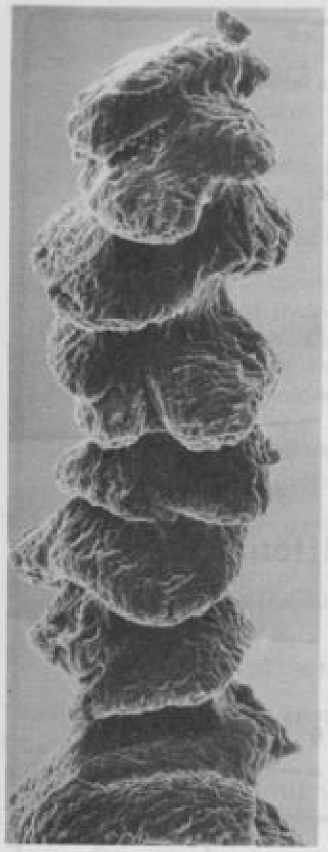
Merrill, G.P. — 1894. On the Formation of Stalactites and Gypsum incrustations in Caves – *Proc. U.S. Nat. Mus. 17,* 77 pp.

Reinboth F. & Göbel, F. 1975. Bemerkungen zum Excentriques problem – *Die Höhle 26,* 123-130.
Thiner, G., Tercafs, R. 1972. Atlas de la vie Souterrain – Paris.
Wigley, T.M.L. 1973. Chemical Evolution of the System Calcite-Gypsum-Water. – Can. J. *Earth Sci.* 10 (2): 306-315.

1


2


3


6


5

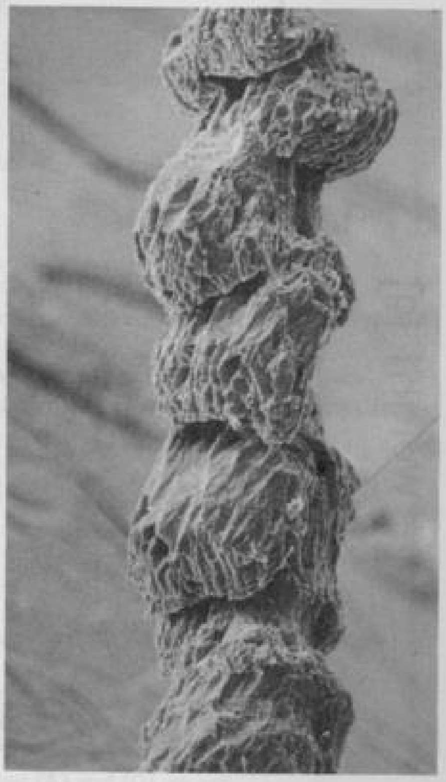

4


Fig. 1 Eccentric patch in Winterberg cave (Harz Mountains, Fed. Rep. of Germany) approxim. 40-60 cm.

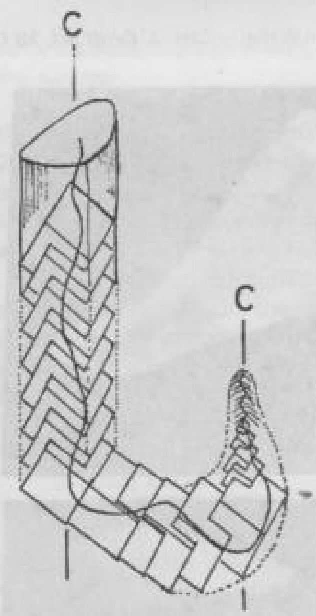
Fig. 2 Tip of glassy eccentric, approxim. 2 mm long; note capillary, upper left.

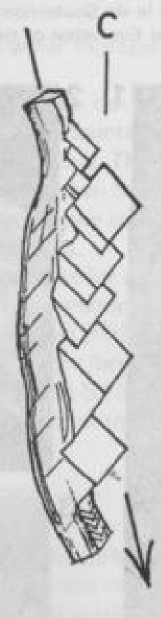
Fig. 3 Eccentric with rhombohedral faces, approxim. 2x1 cm.

Fig. 4 Capillary cast with pearl-string morphology and ridges orientated parallel to growth direction (tip at top), section length: 0.22 mm.

Fig. 5 Capillary cast, section length: 0.4 mm.

Fig. 6 Detail of Plate 1.5 (tip at top) with less rugged capillary walls, section length 0.3 mm.





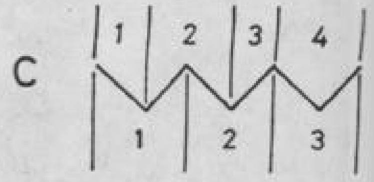


Figure 1C. "Belly"-edges of a rhombohedron. In the trigonal eccentric form all sides are equivalent in their symmetry (bottom), while in the pseudo-tetragonal form all sides are different.

Figure 1A. Eccentric with faces of the steep rhombohedron (not identical with the calcite cleavage rhombohedron which is less steep). By stacking rhombohedrons along the C-axis the eccentric assumes a trigonal shape (see cross-section at top). The capillary is shown as well as growth caps (at the tip) which are sometimes visible in the ccentric. Drawing modified after THINIER & TERCAPS (1972)

Figure 1B. If rhombohedrons are stacked in other growth directions (arrow) than parallel to the crystallographic C-axis, pseudo-tetragonal cross-sections appear. Often the rhombohedron faces are developed on one side of the crystal only.

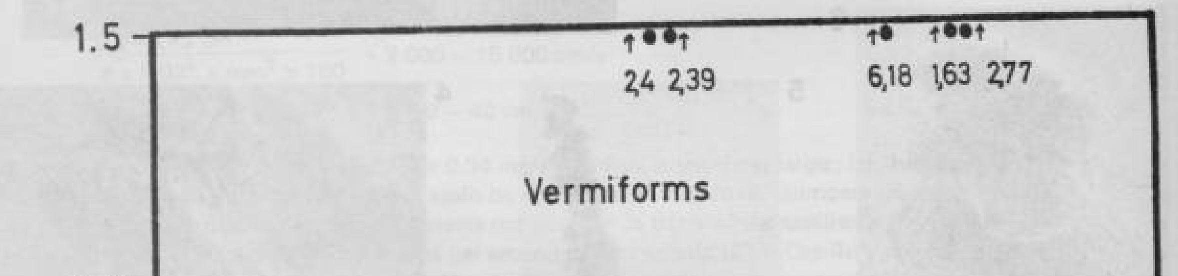


Figure 2. Length to weight relation of 77 eccentrics from the Winterberg. The thin and light forms are called Filiforms, while the heavier and thicker specimens are termed Vermiforms. The border between both groups has not yet been defined quantitatively, obviously all transitions exist.

SOME CONSIDERATIONS ON THE KARST DENUDATION AND NEW MODIFICATION OF THE FORMULA FOR ITS CALCULATION

Tamaz Kiknadze
Dzerjinskogo 8, Academy of Science of Georgian S.S.R.
Tbilisi, U.S.S.R.

In studies of the dynamics of the karst processes the main part belongs to the quantitative determinations of the karst denudation rates, as it allows us to predict further development of the karst. It is of great importance from the point of view of karstogenesis theory and the national economy as well. These determinations may be applied to establish the approximate age of the karst.

To determine the values of the denudation in the carbonate rocks, different hydrochemical, volumetric, and karst-hydrometric balance and other methods are used (see A. Kruber (1915), F. Laptev (1939), N. Rodionov (1949), G. Maksimovich (1955), J. Corbel (1957, 1959), P. Williams, (1963), M. Pulina (1966, 1971), A. Chikishev (1967, 1973) etc.). The methods of these authors have been described by N. Gvozdetsky (1970, 1972), A. Chikishev (1973), T. Kiknadze (1972) etc.

In the last ten years, in the USSR – the formulae offered by Corbel and Pulina have been most widely used. I was lucky to work with these investigators in the French karst as well as in Poland, the USSR, the Caucasus and, for the karst of one of the regions in the Caucasus the values of the karst denudation were determined with their methods.

While making calculations with the methods of the above-mentioned investigators quite frequent unconformities of topographic and hydrogeological drainage systems in the karst regions cause a number of difficulties. We also take into account that in the USSR hardness of water is expressed by mg. equiv/l so we offer one more modification of the method of calculating the values of karst denudation in the carbonate rocks for both surface and underground karsts. We give the following formulas:

$$Dk_1 = 0.63 \times M \times H \quad \ldots. (1)$$

$$Dk_2 = 0.63 \times M_1 \times H_1 \quad .. (2)$$

where:

Dk_1 – Surface karst denudation in m^3/km^2/year (mm/1000 years)
Dk_2 – Underground karst denudation in m^3/km^2/year (mm/1000 years)
M – The modulus of the surface run-off in $1/sec/km^2$
M_1 – The modulus of the subsurface drainage in $1/sec/km^2$
H – The total hardness of surface waters in mg-equiv./1
H_1 – The total hardness of underground waters in mg-equiv./1

The above-mentioned formulae (1) and (2) were obtained by means of the following values:

S – the area of topographic drainage system in km^2
S_1 – the area of hydrogeologic drainage system in km^2
A – the volume of water supplied by surface inflow in m^3/year
Q – the volume of water supplied by subsurface inflow in m^3/year
Hx – the total hardness of the atmospheric precipitation and the transit drainage (in the presence of the latter)
Hy – the total hardness of surface waters including the total hardness of atmospheric precipitation
Hz – the total hardness of subsurface waters including the total hardness of atmospheric precipitation

These result in the following relationships:

$H = Hy - Hx \ldots.. (3)$. $\quad H_1 = Hz - Hx \ldots.. (4)$

$A = 31.5 \times M \times H \times 10^3 \ m^3/\text{year} \ \ldots.. (5)$

$Q = 31.5 \times M_1 \times H_1 \times 10^3 \ m^3/\text{year} \ \ldots.. (6)$

(1 mg-equiv./1 of the total hardness = 20 cm^3 Ca+Mg)

Therefore, to calculate the karst denudation of the surface (7) and underground (8) we will obtain the following formulae:

$$Dk_1 = \frac{A \times 20 \times H}{S \times 10^6} \ \ldots.. (7) \qquad Dk_2 = \frac{Q \times 20 \times H_1}{S_1 \times 10^6} \ \ldots.. (8)$$

By putting the formulae (7) and (8) into the corresponding values (A) and (Q) we get

$$Dk_1 = \frac{31.5 \times M \times S \times 10^3 \times 20\,H}{S \times 10^6} \ \ldots... (9)$$

$$Dk_2 = \frac{31.5 \times M_1 \times S_1 \times 10^3 \times 20H_1}{S_1 \times 10^6} \ \ldots. (10)$$

After the corresponding reductions we get the final formulae:

$Dk_1 = 0.63 \times M \times H \ldots.. (1)$. $\quad Dk_2 = 0.63 \times M_1 \times H_1 \ldots.. (2)$

The present method helps us to calculate the values Dk_1 and Dk_2 for the karst basins of the South slope of the Great Caucasus. For comparison we also used the formulae of Corbel and Pulina. From the present table we can see that the values obtained by various formulae are quite comparable.

TABLE 1

The karst Basins	*Karst denudation in m^3/km^2 year (mm/1000yr)* by T. Kiknadze Dk_1	by T. Kiknadze Dk_2	by J. Corbel Dk_1	by J. Corbel Dk_2	by M. Pulina Dk_1	by M. Pulina Dk_2
The mountain range of Gagra						
Akh - Ag	82.0	31.7	79.2	33.1	84.5	32.4
Sandripsh	92.6	31.8	86.0	33.0	91.6	32.2
The mountain range of Bziphi						
Upshara	103.9	47.5	101.2	48.0	103.9	48.0
Akh – Ibokh	114.6	56.7	112.5	56.4	112.6	56.7
The mountain range of Kodori						
Tsebelda	110.6	30.0	109.2	33.2	110.5	31.2
Rechkhi	164.4	54.1	170.0	54.4	168.0	53.1
Olori	113.0	66.0	113.0	66.1	112.4	66.0

As for the problem of karst denudation, it should be noted that Corbel's opinion about the variation of deep-seated solution in mountain karst from 50 to 80% of the total karst denudation is not confirmed in the Caucasus by our investigations. The total karst denudation is made up of the values of surface, deepseated and mechanical denudations. If we take 50% of the total karst denudation as the Soviet karstologists (Kostin, Kiknadze et. al) did in their works, it will turn out that the surface denudation on an average of 50% as a rule will exceed the surface karst denudation and it does not correspond to the facts. On the contrary, the present table shows that in most cases the underground karst denudation is 40 - 50% less than surface solution which is quite natural, as with depth the aggression of waters weakens and their highest activity is observed in the upper part of the section.

Not the least of the factors in the karst regions, is the formation of the drainage system in which meteoric, surface and underground waters take part. Studies of the hydrogeochemical balance of the USSR area has shown that in underground chemical drainage (278.9 x 10^6 t/year) the main part (54%) of the soluble substances were brought into the rivers and afterwards were carried out into the oceans and the inland seas.

The difference between the whole drainage of the soluble substances and its other parts are for the surface drainage. 14.4% of the whole drainage of the soluble substances is found with the atmospheric precipitation (158.3 x 10^6 t/year) (Zverev, 1973). It follows that in the formation of chemical drainage atmospheric precipitation takes a great part and we must pay great attention to it for calculating the values of karst denudation.

References

Corbel, J. 1957. Les karsts du Nord-Ouest de l'Europe et de quelques regions de comparison. Lion.

Corbel, J. 1959. Erosion en terrain calcaire. *Annales de Géographie,* LXVIII année, No. 366.

Chikishev, A. 1971. The comparative analysis of the quantitative methods for the valuing of the karst processes. *Geomorphology,* No. 4, Moscow.

Chikishev, A. 1973. The methods of the studies of the karsts. *Univ. of Moscow.*

Gvozdecki, N. 1970. Employment of quantitative methods for the determination of velocity of karst denudation. *Bull. MGU,* ser. V, Geogr., No. 4 Moscow.

Gvozdecki, N. 1972. The problems of emploiment of the karst and practice, *Publ. House "Misl",* Moscow.

Kiknadze T. 1965. The hydrogeological charakteristics of karst phenomena in the massifes of Arabika (Caucasus, West Georgia); "Karst and caves of Georgia", No. 3, *Publ. House "Metsniereba",* Tbilissi.

Kruber, A. 1915. Karst of the region of the Mauntaine Krimea. Moscow.

Laptev, F. 1939. The aggressive influence of water on the carbonate rocks, gypsums and concretes. Transactions of the All-Union Offices of the special geological mapping. Publ. 1, "GONTI".

Maksomovich, G. 1955. Chemical geography of the Land waters. *"Geographgis,"* Moscow.

Pulina, M. 1966. Ziawiska krasowe w Zachodnim Kaukazie. *Czasopismo Geograficzne,* XXXVII, 4, Warszawa.

Pulina M. 1971. Observations on the Chemical denudation of some Karst Areas of Europe and Asia. *Studia Geomorphogica Carpatho-Balcanica,* Vol. V, Krakow.

Rodionov, N. 1949. Some datas about karst development velocity in the carbonate rocks. *Transak. of the Laboratory of the hydrogeological problems.* T.V.I. Moscow.

Williams, P. 1963. An initial estimate of the speed of limestone solution in County Clare. *"Irish Geogr."* No. 4.

Zverev, W. 1973. Hydrogeochemical kriterion and quantitative valuing of the mobilization of substance in processus lithogenesis. I *Inter. Geochemical Congress,* 1971, Vol. IV, book, 1, Sedimentary processes, Moscow.

GENERAL OUTLINES ABOUT UNDERGROUND KARST WATER BASINS OF ALPINE FOLDED SYSTEMS

Tamaz Kiknadze
Dzerjinskogo 8, Academy of Science of Georgian S.S.R.
Tbilisi, U.S.S.R.

Among a large number of problems of karst investigation the problem of determination of real borders of the karst water basins and the conditions of karst water circulations in those basins is of great importance. The study of these problems is particularly difficult in the limestone karst of the Alpine highland-folded systems. The successful solving of these problems requires complex methods, including the research of geological, tectonical, geomorphological, hydrogeological, climatic conditions, the establishment of intercommunication between soluble and unsoluble rocks, the roles of folds and faults in distributing atmospheric waters, the establishment of the influence between general and local karst basins, between theoretical and actual runoffs and other numerous factors.

The formation of separate karst massifs or karst basins according to their division of water conduits in most cases carries a truly geomorphological character and from the point of view of karst hydrogeology this does not reflect the real picture, which may be seen in the karst regions of the Alpine highland-folded systems. The local karst bases (the bottoms of the rivers) are often used as discharging zones of karst waters of the upper part of the sections of the karst thick layers, but intermediate insoluble horizons lead to the formation of overhead water streams; these horizons form the local karst base situated above the impervious rocks and discharge waters occurring in the river valleys.

The basic insoluble horizon sometimes shades the influence of the general karst basis (sea level or oceanic level and etc.).

As a rule the contours of the surface basins in karst regions do not coincide with the boundaries of the actual drainage systems of underground karst waters, that are caused by different genesis of hydrogeological and topographic basins.

In small karst basins as well as in high karst massifs, hydrogeological watersheds in anticlinal folds and faults determine the borders of both topographical and hydrogeological basins. To neglect these principles we can make erroneous conclusions about the water balances, about the nature of the underground karst water circulation, about the intensity of the karst processes, about the karst denudation quantity, about the age of the karst etc.

In some cases if the main river has not yet cut through the karst sections to the insoluble horizon, karst water can circulate under the river bed. In that case shall have connected karst water basins. In that case the karst region divided into isolated karst massifs or basins by the transit river is really a united whole.

Investigation of karst on the south slope of the Great Caucasus has revealed typical features of the hydrogeological structure of the karst basins and karst massifs, which may be typical of the rest of the Alpine highland-folded regions. Among these features the main traits are the following:

If there are normal synclinal and anticlinal folds and insoluble horizons with exposed outcrops, the boundaries of the karst basins pass along the outcrop of the base insoluble horizons. Concentration of karst waters occurs along synclines and movement is in the direction of the structured slope.

If there are intermediate insoluble horizons there may be a multistorey arrangement of karst water basins.

The greater part of atmospheric waters is received by the upper horizons of the karst water basins. In conditions of the nonstructural relief the supply of water to the lower floors is limited, as the zones of infiltration in those cases are determined by the exposed karst thickness of these floors.

In new karst regions the leading role in the process of the formation of the karst basins belongs to folds, where in crumpled synclinal structures isolated basins of karst waters may form. In more ancient karst, faults play a greater role. In this case, in blocks limited by ruptured planes unified levels of karst waters may form.

Within the limits of the recent Alpine karst karst basins, karst water containing systems and artesian basins of karst-stratum waters may be dinstinguished (Tolstichin, 1959; Maksimovich 1968, 1969; Kiknadze, 1972; Maksimovich and Kidnadze, 1973).

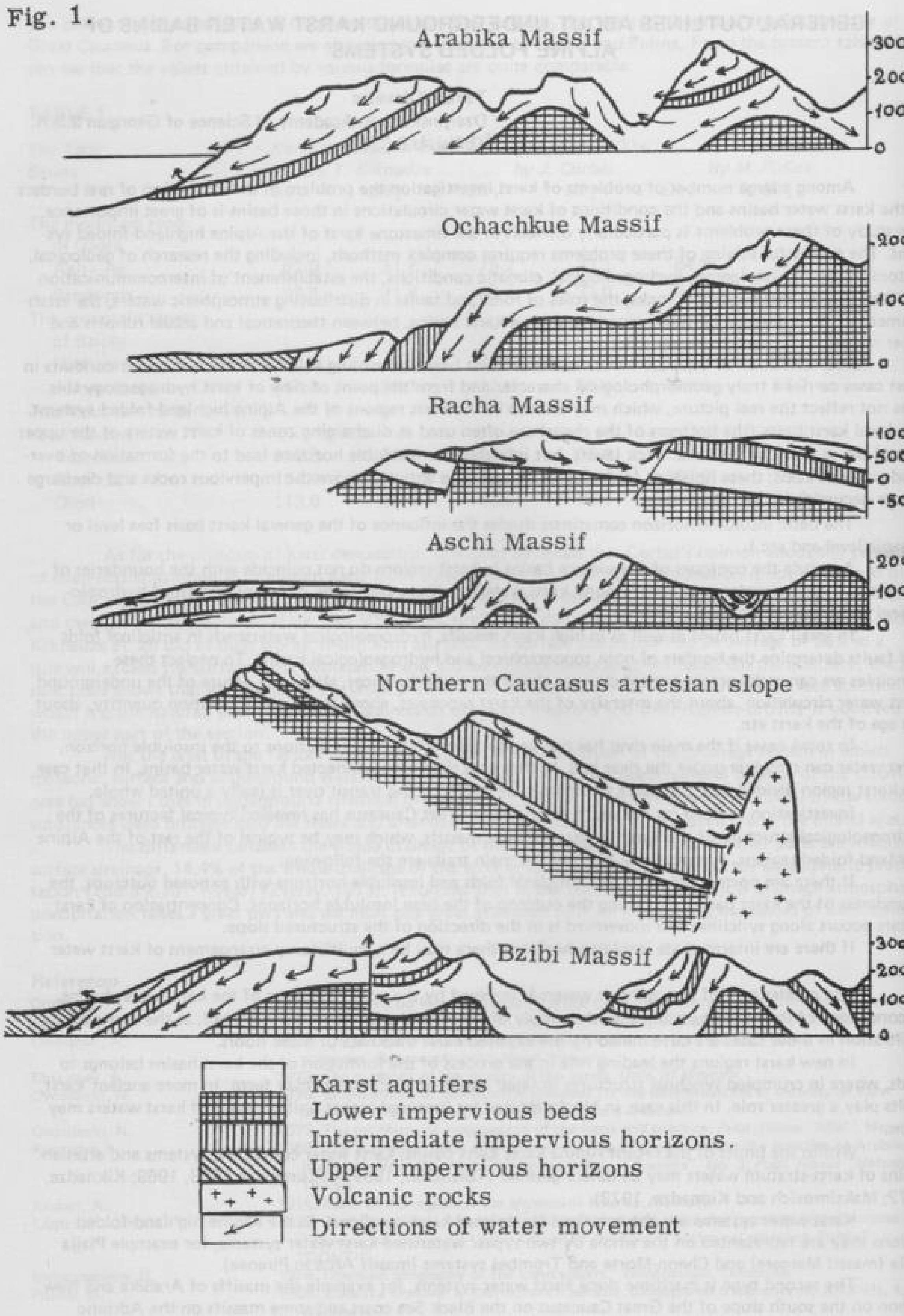
Karst water systems are characterized by isolated karst overflows. In the Alpine highland-folded regions they are represented on the whole by two types: watershed karst water systems, for example Piajja Bella (massif Margare) and Chenn-Morte and Trombes systems (massif Arba in Pirenea).

The second type is maritime slope karst water systems, for example the masiffs of Arabika and New Athon on the south slope of the Great Caucasus on the Black Sea coast and some massifs on the Adriatic Sea coast. The main typical feature of this type is submarine discharge of the karst waters. It is necessary to note that this second type may be complicated by imposed basins of other types; for example, in the Arabika massif there is the first type too. Here the analogous system of Henn-Mort and Trombes, there is a watershed karst water system of the Blue Lake and the Gega waterfall.

The most widespread basins in the Alpine-folded regions are continental slope basins of karst waters. Their discharge areas are on land. To this type belong the majority of the karst massifs and karst basins of the Great Caucasus, of the North part of the Krimea Mountains and Western Europe. There is a diversity with synclinal, anticlinal and monoclinal basins, which on the periphery develop into artesian basins.

In Alpine-folded systems besides those mentioned there are other karst basins also, but in a short

Fig. 1.



report it is impossible to describe their variety. On Fig. 1 we give sections of the more typical karst basins for the Caucasian karst regions.

In conclusion one can enumerate some general characteristic features of the karst water circulation of the Alpine-folded systems: the main direction of the karst water movements is determined by tectonic structures. The hydrogeological watersheds and the boundaries of the underground basins do not coincide with the contours of surface basins in most cases. The movement of the karst waters is checked by the conditions of occurrence of the rocks, of the tectonic fissures, their arrangement and the degree of their opening.

References

Kiknadze, T.Z. 1972. Karst of the Massif Arabika. *"Metsniereba"*, Tbilissi.

Maksimovich, G.A. 1968. Types and areas of the mauntine karst basins, basins of the stratum-karst waters and karst water systems. *Abstracts of the lectures on the VIII*, sci. session of *Speleology "Metsniereba"*, Tbilissi.

Maksimovich, G.A. 1969. Fundamentals of Karstology. Vol. II, Perm.

Maksimovich, G.A. & Kiknadze T.Z. 1973. Hydrogeological percularityes of the Arabika karst massif. *"Georgian Caves"*, vol. 5, Tbilissi.

Tolstikhin, N.I. 1959. Some problems of the hydrogeology of the mountine areas. Transactions of II conference about underground waters and engineer geology of the Eastern Siberia. Publ. 1, Irkutsk.

STUDY OF UNDERGROUND KARST BY MEANS OF SURFACE RADIOMETRIC SURVEYS

M.V. Komarova and E.S. Shtengelov
Problem Laboratory of Engineering Geology,
University of Odessa, Shampansky 2,
Odessa 270 015, U.S.S.R.

The principal purpose of the various investigations in karst regions is recognition of uneven distribution of karst phenomena especially delimiting maximum karst zones.

Our research included the analysis of physical and chemical anomalies of karst rocks in zones of intensive karsting. It was carried out in the different karst regions of the European part of the USSR, in the 20 areas within the limits of which the position of karst zones was established by means of detailed hydrogeological and engineering-geological works. There have been selected the control series of monoliths of karst rocks and soil samples by profiles crossing these zones. All samples have been analysed by their physical properties and chemical, spectral, granulometric (for soils and unsoluble residia) analysis and flame photometry have been made.

The data have shown that the rocks in the intensive karstic zones differ from the analogous rocks outside these zones where karst phenomena are developed poorly or practically absent. The geochemical differences show most distinctly: in all areas the rocks of karstic zones are characterised by a decrease of concentration of a great number of accessory elements irrespective of their geological, hydrogeological and geographical conditions. For example, in the karst zones there is a decrease (2-10 times) (fig.1) of concentration of K, Na, Li, Cr, Y, V, Co, Ga and other elements in the Upper Jurassic limestones of the Mountain Crimea, Sarmat Coquinas of Tarhancute peninsula, and Upper Cretaceous marls of the South-West Ukraine. The decrease of content of the accessory elements in soils is less than in carbonate rocks.

The decrease of concentration of element mixtures mainly results from removal of the fine-fraction of the insoluble residium, confirmed by the high correlation coefficient (0.89-0.97) between the concentration of these elements and content of clayey and silt fraction. In the central parts of the most large zones the content of clay particles in the insoluble residuum is decreased by 54-96% and dust particles by 30-68%. It is observed the tight connection between the clayiness of rocks and karst intensity index (density of surface and underground karst forms, well capacity, quantity of downfalls of drilling instruments in holes, etc).

There are radio-elements (K^{40}, U, Th) among the element-mixtures; in connection with these the natural gamma-radioactivity of karst rocks within the limits of intensive karsting zones is less than that for the same rocks of poorly karsting zones. The study showed that in different regions the scale of this decrease is directly proportional to logarithms of indexes of fissure-karst permeability of rocks (filtration index, water-conduct, specific yield), i.e. connected with them by exponential dependence as:

$$q = q_o e^{-b\gamma} \text{ where}$$

q – specific yield of hole in the rock with gamma-activity – γ
q_o – specific yield of hole in conditional rock with zero gamma-activity
b – proportionate coefficient.

For example, in the northern part of the Novoselovskoe uplift, in the Crimea plain this dependence (shown on fig. 2, characterised by correlation coefficient 0.83) is:

$$q = 34.5\, e^{-13\gamma}$$

This connection is also representative of other regions. The correlation coefficients between the parameters of joint-karst permeability and gamma-activity of rocks calculated on the 42 karst areas varies from 0.59 to 0.99 average – 0.81. For all these regions the contrast of gamma-minimum data corresponding to karsting zones is enough for their fixation with the help of modern radiometers on condition of maximum precision of measurings. So, for the Neogene limestones of the Crimean plain it reaches 78% (from 4.75mcr/h for the nonkarst areas to 1.5mcr/h for the areas of maximum development of karst) and for Titon limestones of the Crimean Mountains – 79% (from 5.4 mcr/h to 1.2 mcr/h).

In particular, gamma survey of exposures of Tithonian limestones in the Dolgorukov Yaila, in the Crimea, have shown that karst zone, in which most of the well known Red cave (Kisilkoba) is situated, is

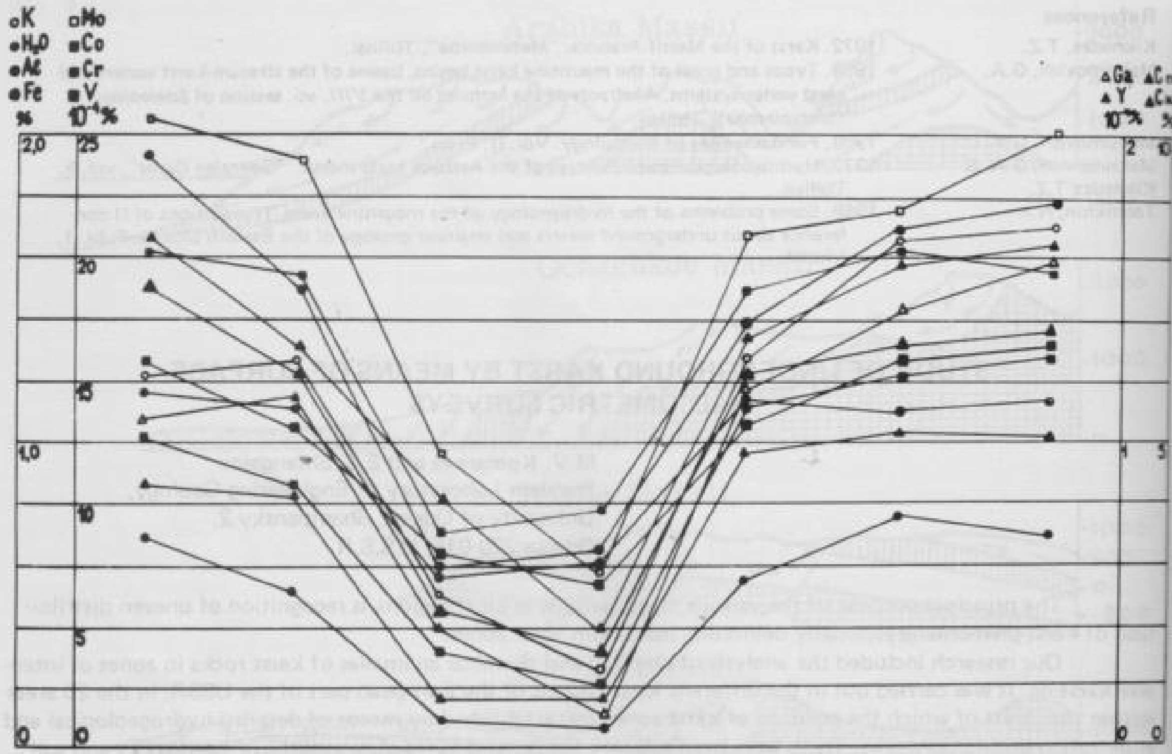


Fig. 1. Variation of concentration of some elements and compounds in Sarmatian limestones along a profile across the Crimean karst.

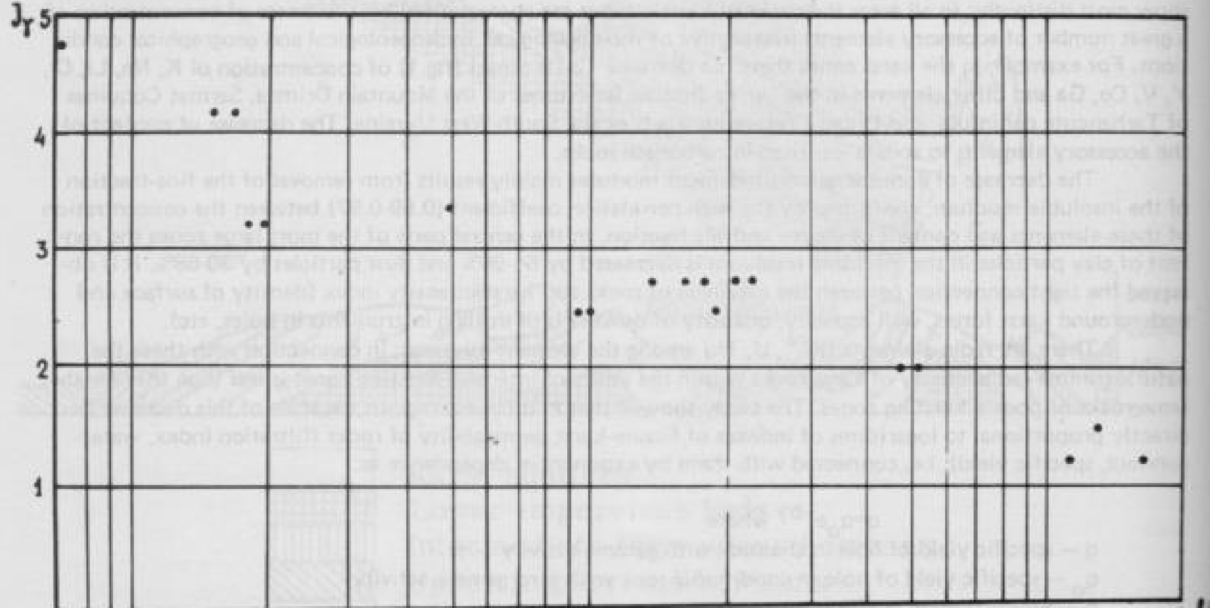


Fig. 2. Relation between the specific yield of wells and gamma-activity of water-bearing limestones.

characterised by gamma-activity of the limestones — 1.5-3mcr/h, whereas outside of this zone it increases to 5-6mcr/h (fig. 3) and more. The contrast of gamma-minimum for soils is weaker than for the rocks. For the studied area over the Red cave it is only 38% (from 8mcr/h to 5mcr/h).

An inverse proportional connection between the gamma-activity and permeable properties of carbonates and other rocks was shown by some investigations (1,3). However, they are based on the opinion that this connection depends on the change of permeability of rocks under the influence of lithofacies variability of degree of their clayness. On the contrary our data show that the local decrease of clayness within the limits of lithology-identical rocks is not the cause but the effect of increasing permeability on the areas of yawning fissures in which washes the fine material.

These data are:

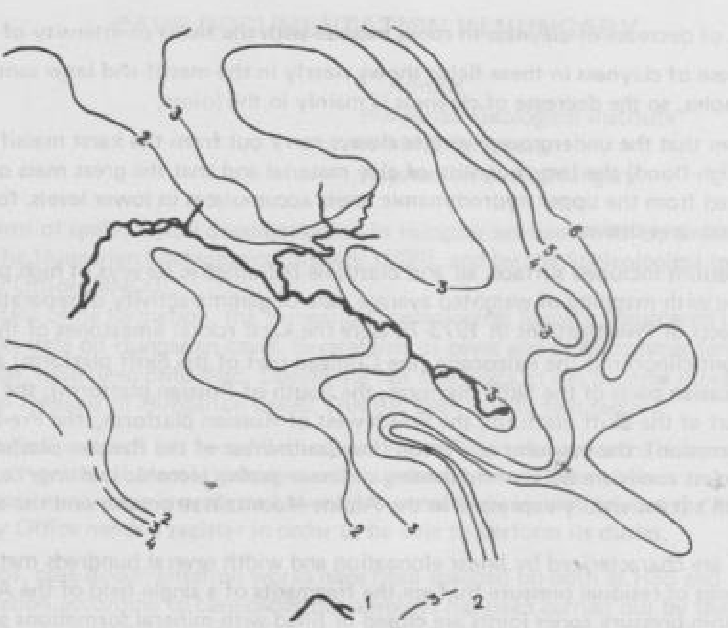


Fig. 3. The gamma-activity of Tortonian limestones in the region of the Red cave (Crimea Mountains).
1. Red cave. 2. Isogammas (mcr/h).

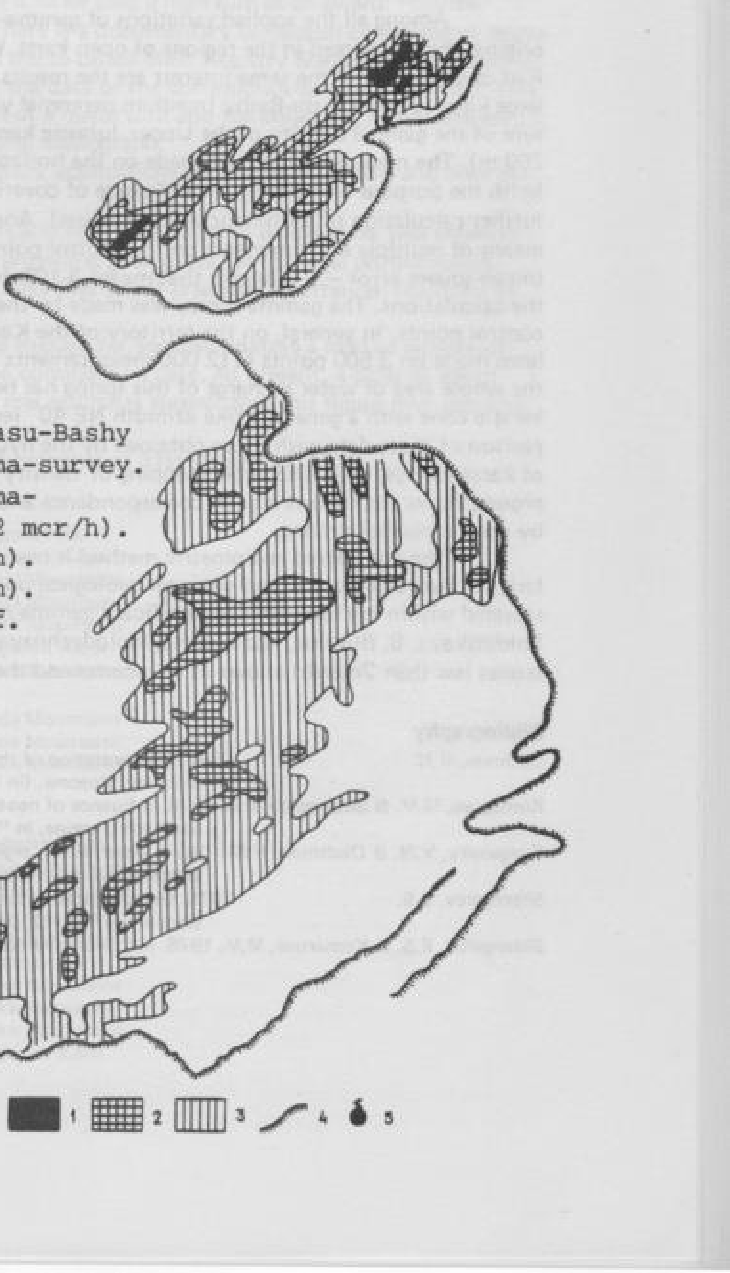


Fig. 4. Area of water recharge of the Karasu-Bashy spring outlined by means of a gamma-survey.
1. Very high karst districts (gamma-activity of limestones less than 2 mcr/h).
2. High karst districts (3-4 mcr/h).
3. Middle karst district (5 mcr/h).
4. Contours of the mountain massif.
5. The Karasu-Bashy spring.

1. the fields of decrease of clayness in rocks include with the fields of intensity of tectonic fissure;
2. the decrease of clayness in these fields shows clearly in the massif and large samples and less in the small samples, so the decrease of clayness is mainly in the joints;
3. it is known that the underground waters always carry out from the karst massif (especially in the time of high-flood) the large quantity of clay material and that the great mass of terrigene material transported from the upper hydrodynamic levels accumulates in lower levels, for example in horizontal karst cave-drains.

Our investigations included surface, air and blasthole radiometric surveys of high precision and evaluation of gamma-logging with mapping of weighted average data of gamma-activity of separate lithofacies complexes. The basic objects of investigations in 1973-76 were the karst rocks: limestones of the Upper Jurassic age (the Crimea meganticlinorium) the Paleocene (the Crimean part of the Skiff platform) and the Neogene age (the Crimea and Caucasian parts of the Skiff platform, the South of Russian platform), the marls of Upper Cretaceous (the Crimea part of the Skiff platform, the South-west of Russian platform, the Pre-Karpathian foredeep, the Dnieper-Don depression), the gypsums of Torton (the South-West of the Russian platform). Analysis of the data shows that the karst zones are belts of thickening of linear gaping tectonic jointing, i.e. areas of a modern extension of the Earth's crust vividly expressed in the Alpine Mountain structures and the adjacent territories (2,5).

These fields are characterized by linear elongation and width several hundreds metres or a few kilometres divided by zones of residual pressure that are the fragments of a single field of the Alpine horizontal stress in the past. Within pressure zones joints are closed or filled with mineral formations and rocks are characterised by a low permeability or are impermeable. The data from the deep boreholes show that the plain zonality of modern tensional deformation state of the Earth's crust extends very deep; the configuration of the zones on the depths 3-5km corresponds well to their configuration on the ground surface (2,4). Naturally, the intensity of horizontal pressure near the surface decreases the tensional state of rocks; but the difference of zones of stress and extension state clearly shows in the upper part of the geological section which are then expressed in different intensities of karst.

Among all the applied variations of gamma-methods the most effective is the surface gamma-survey of original rocks, adopted in the regions of open karst. We have mentioned the results of survey in the region of Red cave (fig. 3): of the same interest are the results received by a study of the district of water recharge of the large karst spring Karasu-Bashy (medium perennial yield — 1.7m^3/sec) in the Mountain Crimea. Here the measure of the gamma-activity of the Upper Jurassic karst limestones was made on the base of the direct nets (150-200 m). The measurements were made on the horizontal and slope exposures with surface more than 1 m^2 (with the purpose of avoiding the influence of covering soils). On each point there are 30 measurements with further calculation of arithmetic average values). Analysis of the regime of cosmic gamma-rays was made by means of multiple measurements on the control points. The variation of intensity of cosmic rays was minor (mean-square error — 0.22mcr/h that means 3-10% from gamma-activity of limestones) and is not taken by the calculations. The gamma-survey was made by the use of some radiometers systematically collated on the control points. In general, on the territory of the Karasu-Bashy spring the measurement of gamma-activity has been made on 3 500 points (112 000 measurements including the control points) for 2 months. In the result the whole area of water recharge of this spring has been outlined: it is a large complex composed of a joint-karstic zone with a general strike azimuth NE 40° length of about 25 km and width from 1.5 to 6 km. A comparison of these data with those obtained by the hydrogeological and karst methods (as yield of wells, situation of karst springs, their discharge, mapping of density of surface and undersurface karst forms, tracing of underground flows etc.) shows a good correspondence and, what is most important, these results have been proved by special control drilling.

The considered radiometric method is useful in all kinds of investigation in the karst regions, particularly, in hydro-geological and engineer-geological purposes. The established fact that all known karst caves situated within the limits of the significant gamma-minimum (for example, in the Karaby massif the caves: Soldatskaya, B. Busuluc, Kara-Mursa, Molodezhnaya, Egis-Tinah placed on the areas with γ-activity of limestones less than 2mcr/h) allows us to recommend the radiometric method for special speleological studies.

Bibliography

Dachnov, V.N. 1962. Interpretation of the results of a geophysical investigation borehole. State Geotechnics. Moscow. (in Russian).

Komarova, M.V. & Shtengelov, E.S. 1976. Influence of neotectonic jointing upon the hydrogeological conditions of the southern Ukraine. in "Hydrogeology of Great Sedimentary basins", Budapest.

Kurgansky, V.N. & Dachniok, V.M. 1974. Determining argillaceous and carbonaceous deposits of Upper Devonian basins. Geophysical reports on the USSR. No. 61. Kiev. (in Russian)

Shtengelov, E.S. 1976. Geochemical fratures of permeable cracks in a zone of rigid basement sediments. Geochimia. No. 12, pp. 117-1183.

Shtengelov, E.S. & Komarova, M.V. 1976. in "Geodynamica" (in Russian). Moscow pp. 113-115.

CAVE DOCUMENTATION IN HUNGARY

L. Kordos
Hungarian Geological Institute
H-1143, Budapest
Nepstadion u. 14, Hungary

The problems of speleological documentation in Hungary are dealt with by a non-governmental technical organisation, the Hungarian Speleological Society (HSS), and by the Speleological Institute of the National Nature Conservancy Office (NNCO).

From the date of its formation, the Hungarian Speleological Society considered its main objective to be to collect and register data on Hungarian caves. Several lists of caves and brief commentaries, each devoted to a single mountain range, have been published. During the last five years, it has become more and more urgent to establish a Cadastrial Register of Hungarian Caves. This has been due to two factors:

1. Speleological research has been handicapped by the great dispersion of data, mostly left in a very great variety of places, unknown or of uneasy access to the public.
2. In Hungary every cave is protected by nature conservacy legislation, but the National Nature Conservancy Office needs a register in order to be able to perform its duties.

For the above reasons, cave documentation works have been speeded up both at HSS and NNCO. At HSS the country's regionalization according to cave-cadastrial numbers has been carried out by the method adopted in neighbouring Austria. The cadastrial numeration of caves has been started. The official approval of cave names is under way and each approved cave name is registered together with the cadastrial number, on an aluminium plate which is placed at the entrance of the corresponding cave. Beside consulting the relevant literature, the Hungarian speleologists are accelerating the procedure of data collecting in the following way: A "Speleographic Field Report", i.e. a questionnaire concerning the characteristics of each particular cave, has been instituted as a means of collecting data on the field. HSS and NNCO have jointly launched a competition on the subject of cadastrial cave registration. The winner of this competition is to be paid a high sum as an award. HSS has solved the problem of data storage in the following way: There is a documentary collection consisting of manuscripts, maps, speleographic field reports, photographs and the so-called Main Registry Sheets of the Cadastrial Register of Hungarian Caves. On each sheet of this kind all the data of the corresponding cave is codified. This is virtually the cave register. Once the technical elaboration of a major unit and the collecting of its data are completed, the resulting document is published in a cadastrial monograph.

NNCO's files include expert speleologists' compulsory applications for research licences and their reports and other relevant data.

There is a collaboration agreement between NNCO and HSS, according to which these two organisations exchange the manuscript reports submitted to them, providing guarantees for the legal protection of copyrights. HSS runs a scientific data bank, while NNCO's data files are of practical orientation, intended to serve to the purposes of State administration.

According to Hungarian legislation, any cavern big enough for accommodating a man or women of normal size, i.e. a cavern exceeding 2 m in height, should be considered a cave. At present, a total of about 1200 caves of this kind are kept on record in Hungary and real estimates suggest that this figure may increase to about 3000 in the long run.

The longest and deepest Hungarian caves are listed below as of 31st December, 1975.

The longest caves of Hungary:

1. Baradla-Domica Cave System	25 000	m Aggtelek Karst
2. Béke Cave (Peace Cave)	8 743	m Aggtelek Karst
3. Matyas-hegy Cave	4 200	m Buda Mountains
4. Ferenc-hegy Cave	4 000	m Buda Mountains
5. Istvan-lapa Cave	2 940	m Bukk Mountains
6. Szabadsag Cave (Freedom Cave)	2 717	m Aggtelek Karst
7. Letras-teto Cave (Sinkhole-cave)	2 000	m Bukk Mountains
8. Solymari Ordog-lyuk (Devil's Hole of Solymar)	2 000	m Buda Mountains
9. Szemlo-hegy Cave	1 962	m Buda Mountains
10. Letras-teto Cave	1 660	m Bukk Mountains

The deepest caves of Hungary:

1. Vecsembukk Shaft	245	m Aggtelek Karst
2. Istvan-lapa Cave	240	m Bukk Mountains
3. Alba Regia Cave	170	m Bakony Mountains
4. Letras-teto Cave	166	m Bukk Mountains
5. Borokas No. 4 Sinkhole-cave	160	m Bukk Mountains
6. Meteor Cave	150	m Aggtelek Karst
7. Fekete Cave (Black Cave)	140	m Bukk Mountains
8. Penzpatak Cave (Sinkhole-cave)	130	m Bukk Mountains
9. Banyasz Cave of Kozepberc	130	m Bukk Mountains
10. Baradla-Domica Cave System	116	m Aggtelek Karst

HOLOCENE VERTEBRATE STUDIES IN HUNGARIAN CAVES

L. Kordos
Hungarian Geological Institute,
H-1143 Budapest
Nepstadion u. 14, Hungary

In recent years excavations have been undertaken in 12 caves aimed at determining the variation of vertebrate faunas during the last 10 000 years, i.e. during the Holocene. The information gained on the changes of the fauna has been sufficient to establish the vertebrate bio-stratigraphy of the Holocene and for paleoclimatological interpretations.

The following localities have been explored:

Aggtelek Karst: Tücsök-lyuk, Ocsisnyatetö, Vass Imre Cave, Baradla Cave, Nagyoldal Shaft.

Bükk Mountains: Petényi Cave, Rejtek -I. Rock-Shelter, Kulyuk-II. Cave, Kis-kőhati Shaft.

Pilis Mountains: Hosszuhegy Shaft.

Gerecse Mountains: Jankovich Cave.

Bakony Mountains: Rigo-lyuk at Bodajk.

As suggested by the faunas recovered, the general trend of faunal evolution has been:

Pre-Boreal (10 200 - 9000 B.P.): *Lagopus, Rangifer, Microtus nivalis, Microtus gregalis* and *Microtus oeconomus* are frequent.

Boreal (9000 - 7500 B.P.): The cold-enduring elements decline, while the continental species proliferate.

Atlantic (7500 - 5000 B.P.): Characteristically the Pleistocene species (*M. gregalis, Cricetulus, Ochotona*) definitely disappear and new immigrants appear (*Rhinolophus euryale, Asinus, Crocidura, Tetrastes bonasia*). Forest-dwelling species expand at the expense of field-dwelling ones.

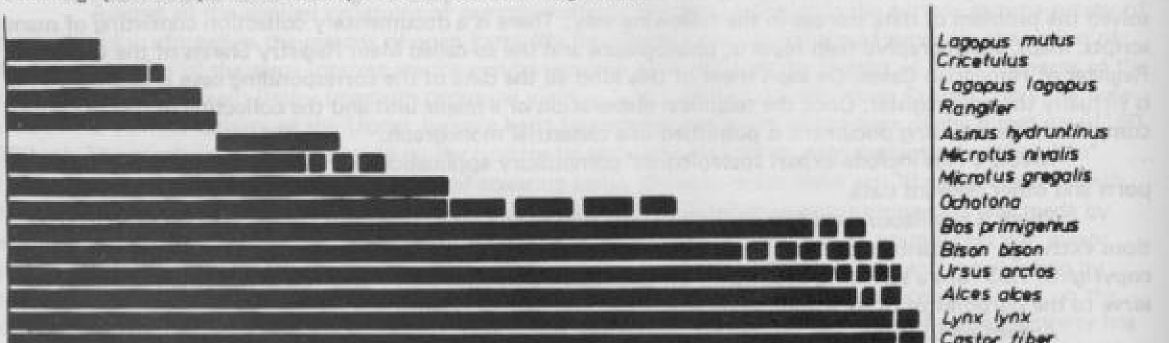


Fig. 1. Animal species which became extinct or appeared during the Holocene in Hungary.

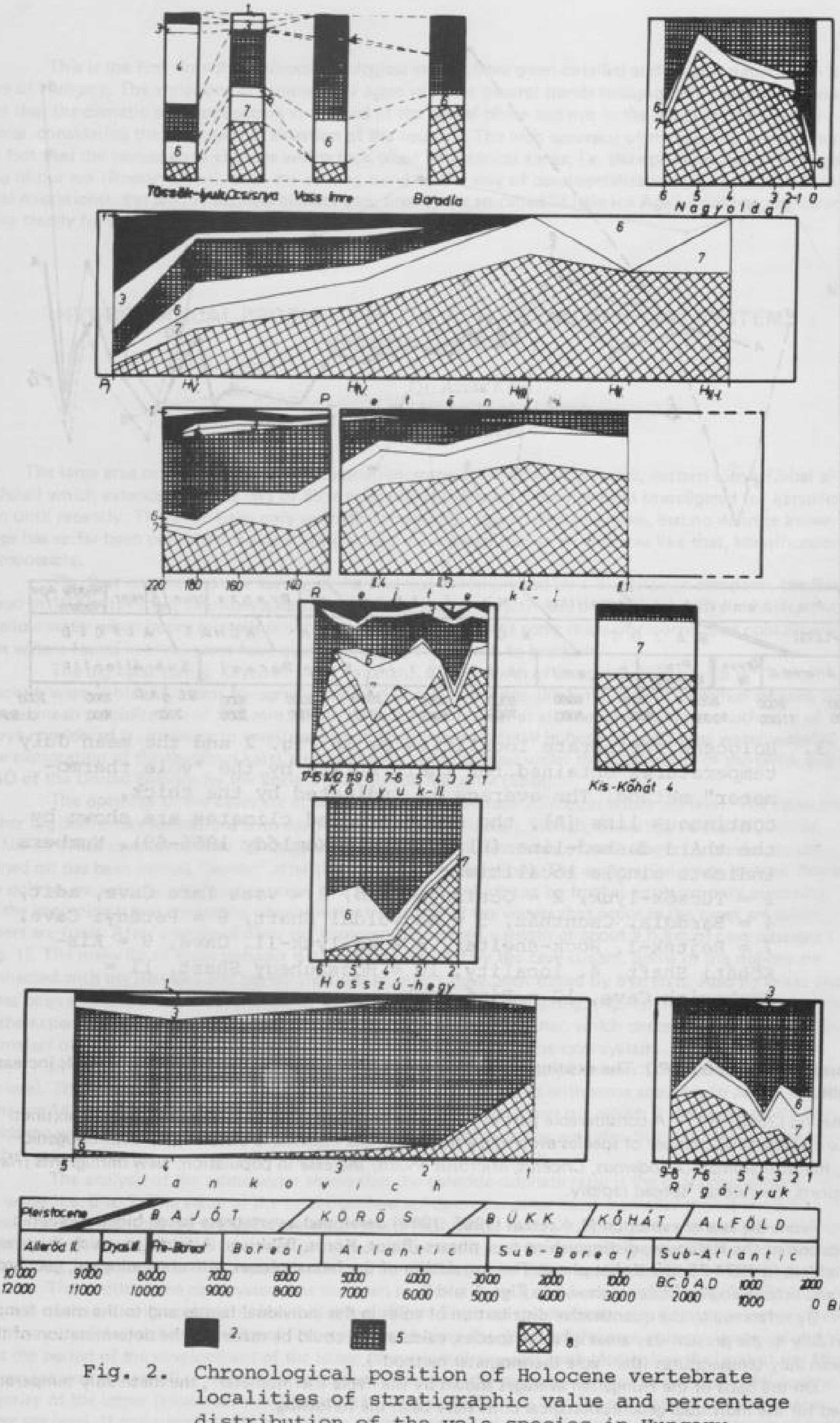


Fig. 2. Chronological position of Holocene vertebrate localities of stratigraphic value and percentage distribution of the vole species in Hungary. 1 = Microtus nivalis. 2 = Microtus gregalis, 3 = Microtus oeconomus, 4 = Microtus agrestis, 5 = Microtus arvalis, 6 = Arvicola terrestris, 7 = Pitymys subterraneus, 8 = Myodes glareolus.

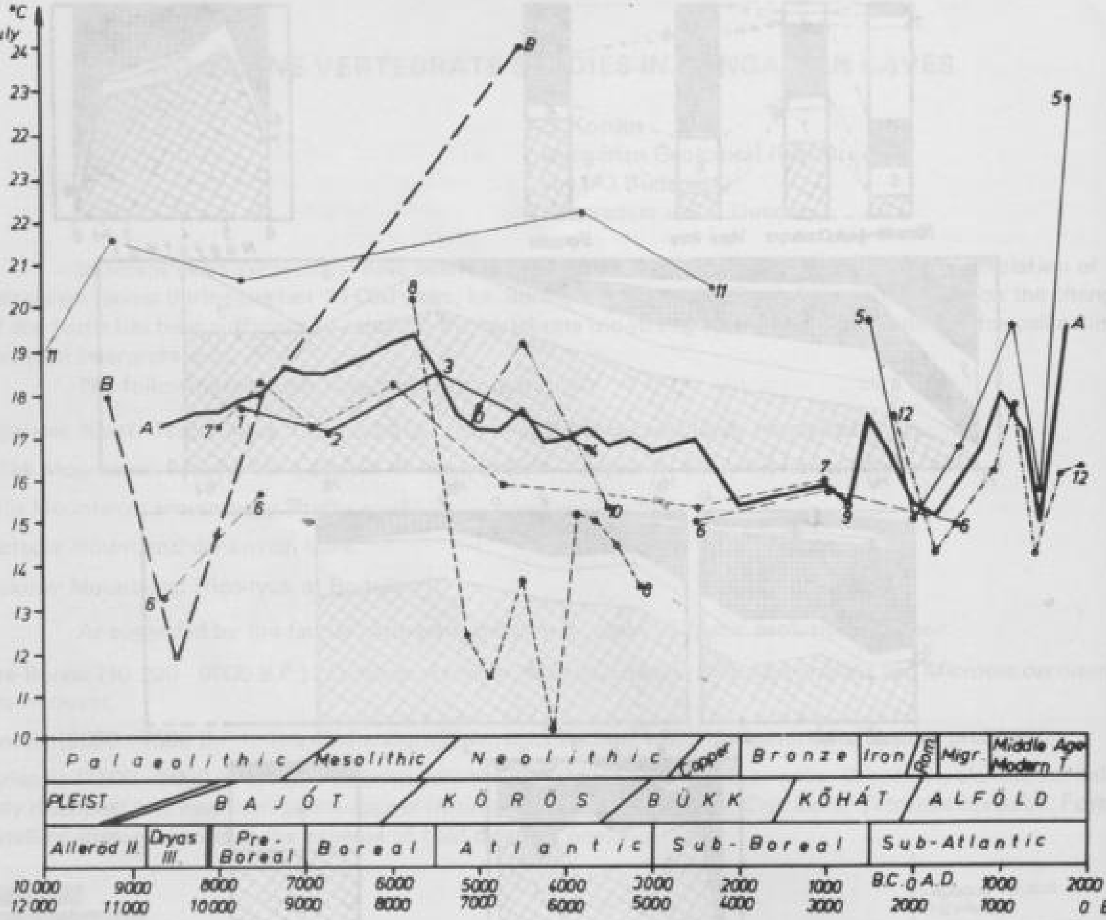


Fig. 3. Holocene vertebrate localities as in Fig. 2 and the mean July temperatures obtained for their strata by the "vole thermometer" method. The average is indicated by the thick, continuous line (A), the reconstructed climates are shown by the third dashed-line (B) (M. Járai-Komlódy 1966-69). Numbers indicate single localities:
1 = Tücsök-lyuk, 2 = Ocsisnya-tetö, 3 = Vass Imre Cave, adit, 4 = Barddla, Csontház, 5 = Nagyoldal Shaft, 6 = Petényi Cave, 7 = Rejtek-I. Rock-shelter, 8 = Kö-lyuk-II. Cave, 9 = Kis-Kőháti Shaft, 4. locality, 10 = Hosszuhegy Shaft, 11 = Jankovich Cave, 12 = Rigó-lyuk.

Sub-Boreal (5000 - 2500 B.P.): The existing specific composition is established and domestic animals increase in number.

Sub-Atlantic (2500 - B.P.): A considerable part of the big game (*Ursus, Canis lupus, Lynx*) became extinct. The share of the total number of species evolved by the end of the Atlantic is distorted by anthropogenic effects, harmful animals (*Apodemus, Cricetus, Microtus arvalis*) increase in population. New immigrants (*Rattus*) and imports (*Ondathra*) spread rapidly.

From the faunal evolution M. Kretzoi (1965, 1969) developed a vertebrate-based biostratigraphic classification of the Holocene, distinguishing four phases (Bajot, Körös, Bükk and Alföld), to which the present writer added, in 1974-75, the Kohat phase. The correlation of the faunal phases with chronological, geochronological and archaeological scales is shown in Figs. 1 and 3.

By reference to the quantitative distribution of voles in the individual faunas and to the mean temperatures in July in the present-day areas of these species, calculations could be made for the determination of the past mean July temperatures (the "vole thermometer method").

On the basis of the Hungarian averages shown by the "vole thermometer", the mean July temperatures obtained for the individual geochronological units have been the following:

Pre-Boreal	17.9°C
Boreal	18.8°C
Atlantic	15.9°C
Sub-Boreal	16.8°C
Sub-Atlantic	16.9°C

This is the first time that paleoclimatological studies have given detailed and reliable data on the Holocene of Hungary. The variations of temperature agree with the general trends recognised in Europe. It is significant that the climatic optimum occurs at the end of the boreal phase and not in the Atlantic phase, which is logical, considering the geographical situation of the country. The high accuracy of the method is indicated by the fact that the temperature changes which took place in historical times, i.e. the optimum about the beginning of our era (Roman times), then the cooling trend on the way of continentalisation (the centuries of the great migrations), the warm medieval climate and, finally, the so-called "Little Ice Age", could be registered quite clearly by several data independent of one another (Fig. 3).

HYDROLOGICAL PROBLEMS IN THE AYN ZAYANAH KARST SYSTEM, BENGHAZI, LIBYA

Dr. Attila Kosa
University of Al-Fateh
Tripoli, Libya

The large area occupied by Middle-Miocene limestone in Northern Cyrenaica, eastern Libya (Jabal al-Akhdar) which extends from the bay of Sirte to the Egyptian border has not been investigated for karstification until recently. There has been only sporadic information about karst and caves, but no definite knowledge has so far been published. Some scientists have even stated that in an arid area like that, karstification is impossible.

The first recconnaissance survey of the area was accomplished by a Yugoslavian company, the Geozavod in 1972. Its report describes a karst area located east and north-east of Benghazi with sinkholes, that swallow water when heavy rainfalls occur. The report also contains some maps of caverns, that contain water. The waters found in these caves have qualities ranging from fresh to brackish.

The big karst spring, Zayanah (Ayn Zayanah), 20 km north of Benghazi discharges 5 m^3/sec of brackish water which is useless for agricultural or domestic purposes. Since the area of Benghazi receives an annual mean precipitation of 300 mm but no surface streams exist at all, the General Water Authority of Libya considered it necessary to investigate karst phenomena in detail in hope of additional water supplies. The exploration of the Benghazi karst area have been accomplished under the supervision of the GWA and the FAO of the United Nations by the Societe des Eaux de Marseille (SEM).

The openings of the caves are at an elevation of an average 25 metres above sea level. The caves are rather big doline-like formations with cavities, namely the Al-Jabah, Satirah, Bukarma, Al-Habibi, Jumar, Al-Mirisi. These caves have been investigated thoroughly by the methods of speleology. (A previously unnamed pit has been named "Jumar" after the method of exploration). The exploration made it clear, that all the dolines are actually collapsed passages of a cave system, which can be further explored only by diving. At the beginning it was a puzzling phenomenon that some of the waters that occur in the caves are saline, others are fresh. After a series of dives the explorers discovered a length of about 4.5 km of cave passages I (fig. 1). The majority of these passages is completely flooded by the cave stream. Some of the dolines are connected with big passages and the connections of others have been traced by dye tests. Also by water tracing it has been verified, that the resurgence of the system is the Zayanah spring, (fig. 1). The most important find of the expedition was the discovery of two pits in Bukarma and in Jumar, which descend about 80 m (with diameters of up to 18 m in Bukarma) and which supply sea water to the cave system.

In these caves, with pools at their bottoms, the water levels vary between 1.20 and 1.50 metres above sea level. The hydraulic heads of the sea water, which can be measured with some accuracy in Jumar and Bukarma are 14 and 6 m respectively below the fresh water head. The Jumar pit, which is the lower of the two, yields sea water in a cyclic way. This phenomenon can be related to the sea tides, but this has not been proved with certainty. The sea water overflow of Bukarma is perennial (Fig. 2).

The analysis of the saline water shows that the chloride-sulphate ratio is the characteristic ratio of the sea water, i.e. 5 to 7. The value of the total dissolved solids on the other hand is smaller than it should be in sea water. This proves, that the intruding sea water meets fresh water before it upsurges in the two particular shafts. Without proper interpretation of the origin and development it may be misleading and, as it happened in the SEM report, interpreted as if the saline water was the discharge of a saline aquifer under artesian head.

The depth of the cave system has not been properly investigated because of technical difficulties, i.e. the lack of deep diving equipment, but it is at least 80 m. Since no solution cave can develop below sea level as the sea water lacks the capability of limestone dissolution, the depth of the cave system clearly indicates that the period of the development of the lower (unexplored) passages took place when the level of the Mediterranean sea was at least 80 m lower than at present. That puts the probable time of origin in the Pleistocene. The majority of the upper (explored) passages being below sea level shows that it has also been developed at a lower sea level. If one supposes the occurrence of only two stages of development and the existence of only two levels of the cave system, the explanation of the origin and development becomes clear.

The upper passages developed at a lower than the present sea level and possibly with higher than recent precipitation. At a further lowering of the sea level the corresponding water table dropped and the lower passages developed. With the rise of the Mediterranean level sea water intruded the lower passages and consequently reactivated the fresh water flow in the upper passages. Rising to its present level sea water now in-

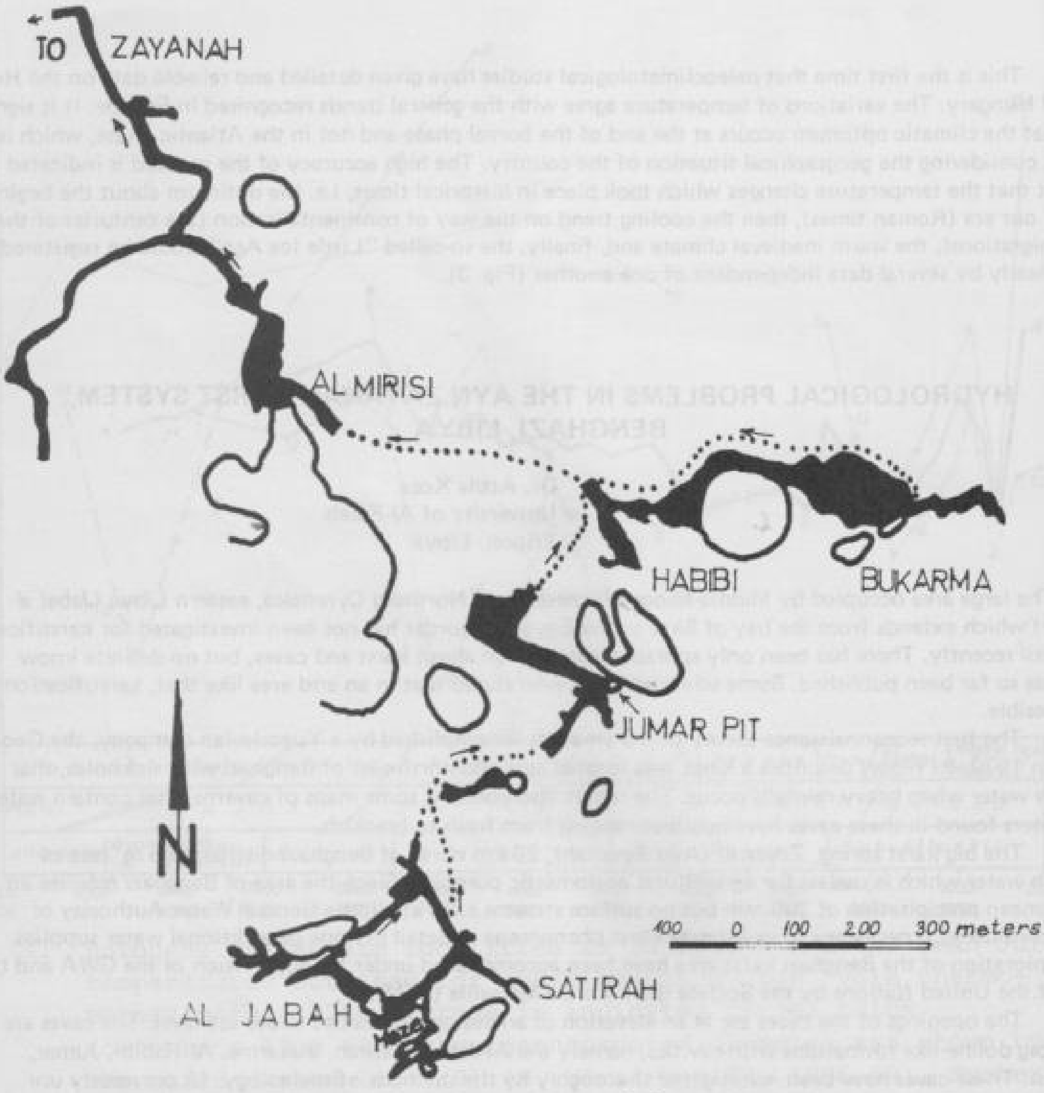


Fig. 1. Plan of the Ayn Zayanah karst system.

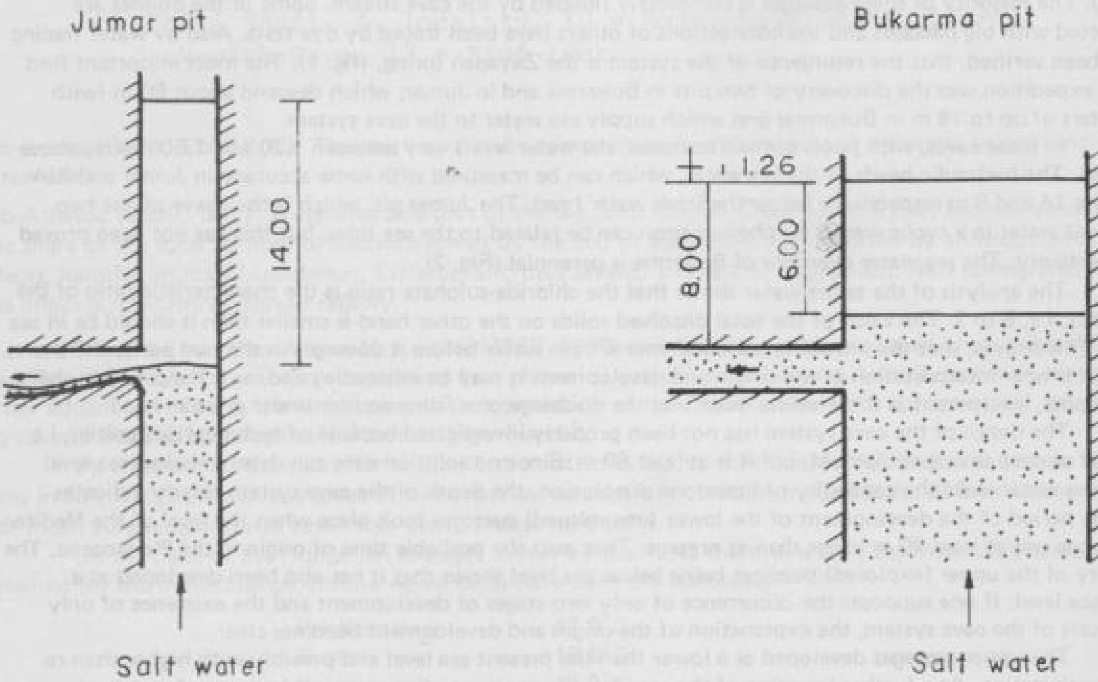


Fig. 2. Sections of the Jumar and Bukarma pits showing salt water levels.

trudes the upper passages as well, contaminating the fresh water flow. This process might happen more than once in cycles of glaciations. The origin and development of the Ayn Zayanah cave system seems to be much the same as that of the caves in the Greek islands and other places in coastal Mediterranean and Adriatic karst areas.

As mentioned before, the costly and difficult exploration of the Ayn Zayanah cave system has been performed for the purpose of obtaining water supplies. The SEM offers a method of clear hydraulic nature for the separation of fresh water from saline intrusion. If the hydraulic head of the two phase flow, i.e. fresh and saline water, can be increased, the individual head of the fresh water may be enough to lower the saline phase and prevent its overflow to the upper passages. According to the calculations made by SEM, one metre rise in the hydraulic head of the flow would cause 11 m lowering of the saline phase. The increase can be performed by damming that passage which is thought to be the solitary conduit to the Zayanah spring. The construction and operation of the dam would be a very interesting experiment, but also it would be very costly and the results are unpredictable. For this reason it has been proposed by the author to continue and complete the exploration, investigate the still unknown upstream parts, the relations to the functional sinkholes and to screen out obvious contaminations other than sea water.

The explorations of the Ayn Zayanah karst system may lead to a greater interest in karst investigations in Libya. It is vital for a country of extremely arid climate, that in those parts, where there is considerable precipitation, every drop of water should be saved. As a rough estimation 80% of the precipitation is being lost in the Jabal Akhdar area due to karst infiltration. These waters are now discharged in undersea resurgences.

References

1. Hydrogeological and Speleological investigation, carried out in Benghazi Area. Geozavod 1972. GWA Documentation Center, Tripoli.
2. Investigations on the Subterranean flow in the karst area near Benghazi, 1975. GWA-FAO-SEM. GWA Docu. Center, Tripoli.

EIN MIT FAKALSCHLAMM GEFÜLLTER ALPINER SCHACHT – CHEMISCHE UND BAKTERIOLOGISCHE WIRKUNGEN

Walter Krieg
Fischbachgasse 20, A-6850 Dornbirn, Germany.

Summary

An inactive karst pothole is connected to large springs and is filled with x 1000m^3 of faecal mud. Investigations of the bacterial content of the spring show a very high germ content, e.g. *Bacillus coli*, of organic material and nitrite, and it is not fit for drinking water. The decomposition of the faecal particles may take place as a result of oxygen lack chiefly under anaerobic conditions, which is favoured by soil temperatures in the summer. Long continued bacterial contamination of the spring may cause methane to emanate from the faecal mud at the cave entrance. The oxygen level in the streams is sufficiently low for bacterial decomposition.

Im Kleinwalsertal (Österreich) hat eine Gemeinde den Ladstattschacht (1140 m Seehöhe, 47, 6 m Tiefe) mit etwa 1000 m^3 Fäkalschlamm völlig gefüllt. Die Wirkungen dieses unbeabsichtigten Großexperimentes sollen abgeschätzt werden.

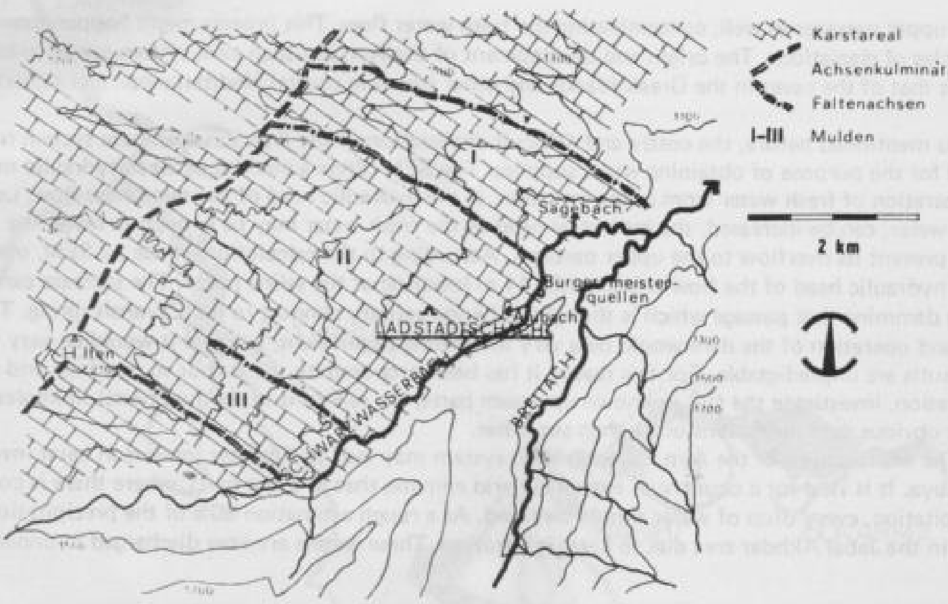
Dieser Schacht im Gebirgsstock des Hohen Ifen durchstößt den maximal 120 m mächtigen, streng verkarsteten Schrattenkalk (Helvetische Kreide) bis zur Karstbasis. Das Karstgebiet ist in WNW-ESE-streichende Faltenzüge gegliedert. Da die Achsen gegen Osten abtauchen, entstehen geschlossene Mulden, deren Tiefstes jeweils am Schwarzwasser-Bach liegt.

Wegen der relativ geringen Mächtigkeit des verkarsteten Kalkpaketes und seiner großzügigen Neigung zum Tal fließt das Wasser den geologischen Strukturen folgend an der Kalkbasis gegen Südost zum Vorfluter ab. Somit gehört fast der gesamte Schrattenkalk der vadosen Zone an, es handelt sich um "Seichten Karst".

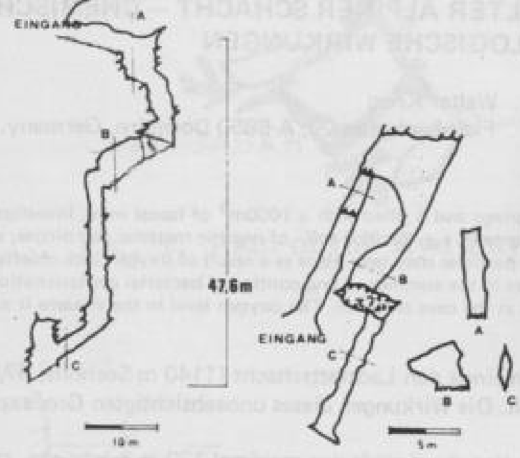
Die Niederschläge liegen zwischen 2500 und 2800 mm, die mittlere Abflußspende ist ca. 8,3 l/s/km^2. Insgesamt sollten somit aus dem Karstgebiet von 17,3 km^2 (das ist gerade die Hälfte des gesamten Einzugsgebietes des Schwarzwasser-Baches) 143, 2 l/s abfließen. Die bedeutendste Quelle des Kleinwalsertales ist die Sägebachquelle in 1040 m: sie schüttet im Mittel 100 l/s und geht bei Niedrigwasser auf 50 l/s zurück. Die Aubachquelle in 1080 m schüttet maximal mehr als 1 m^3/s und geht in Trockenzeiten auf 60 l/s zurück. Die Bürgermeisterquellen in 1050 m rechtsuferig am Schwarzwasser-Bach schütten im Mittel 20 l/s. Der theoretischen Abflußspende stehen somit Quellschüttungen von insgesamt ca. 180 l/s gegenüber. Die Verhältnisse deuten darauf hin, daß jede Quelle eine Mulde entwässert, daß aber in einem gewissen Ausmaß Karstwasserübertritte in der Gegend des Schwarzwasser-Baches zwischen den einzelnen Mulden stattfinden.

Derzeit leben im Kleinwalsertal etwa 5000 Einwohner und gibt es etwa 12000 Fremdenbetten. Das betrachtete Gebiet macht 18% des gesamten Kleinwalsertales aus und daraus erhellt die wasserwirtschaftliche Bedeutung des Eingriffs in das karsthydrographische System.

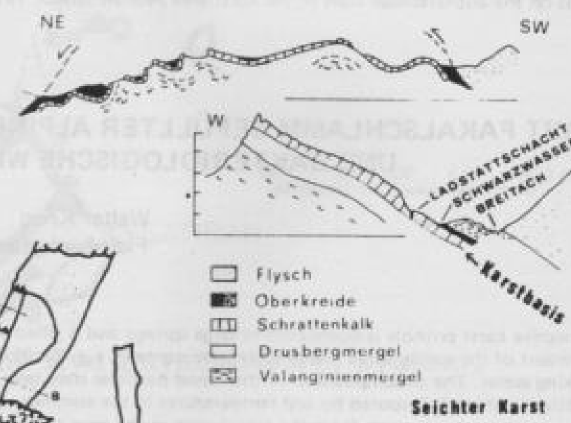
Die Höhle wird als ein Schachtsystem mit hydrisch modellierten Wänden, mit Sickerwasserdurchsatz und mit Stauerscheinungen an der Karstbasis beschrieben. Sie ist ein "inaktiv gewordener Wasserschlinger, dessen Schachtgrund zwar durch Schutt angehoben ist, den Spuren periodischen Wasserrückstaus nach zu schließen aber mit dem Karstwasser in unmittelbarer Verbindung steht." Danach findet im Ladstattschacht



Die karsthydrographische Position des Ladstattschachtes



Ladstattschacht



Seichter Karst

nach H. CRAMER R. LANGE und P. SCHMIDT-THOMÉ

keine schwallartige starke Wasserführung von der Oberfläche her, wohl aber eine ständige Sickerwasserführung und eine episodische Durchfließung mit Wässern der Karstbasis statt.

Natürliche Biotope von Trockenhöhlen sind extrem nährstoffarm, Nahrungsgrundlage sind fast nur die spärlich von außen eingetragenen Partikel. Neben hochangepaßten Tierarten werden Stygobionten in der Höhlen — wie auch in der Quellenfauna angetroffen. In der Höhle lassen sich verschiedene Lebensräume unterscheiden, von denen im konkreten Fall die flächig überfeuchtete Höhlenwand der wichtigste ist. In dieser "faune hygropétrique" dominieren Würmer und Amphipoda. Überall in Bereichen von Biomasse gibt es heterotrophe, also auf die Aufnahme organischer Substanzen und Sauerstoff angewiesene Bakterien. Auf gleichem Substrat leben parasitische und saprophytische Pilze. Somit erweisen sich im Höhlenbiotop Abbauleistung und Biomasse insgesamt als gering. Außerdem ist zu beachten, daß die herrschende niedrige Temperatur die biochemischen Abbauvorgänge behindert und die anaerobe Schlammfaulung durch psychrophile Mikroorganismen relativ begünstigt.

Hinsichtlich der Bedeutung des Ladstattschachtes für den Wasserhaushalt ließen sich konkrete Angaben über die Folgen der Verfüllung machen. Danach ist die Beeinflussung des Schwarzwasser-Baches unterhalb der Einmündung des Aubaches, eventuell noch eine Beeinflussung der Breitach unterhalb der Einmündung des Schwarzwasser-Baches, sicher eine Beeinflussung des Aubaches und seiner Quelle, der Bürgermeisterquelle und des Säge-Baches durch Karstwasser zu erwarten, das mit der Füllung des Ladstattschachtes in Berührung kommt. Zur Überprüfung der karstmorphologischen Vorstellungen wurden die in Frage kommenden Quellen zu zwei verschiedenen Jahreszeiten bakteriologisch untersucht.

19.1.1976

	Ladstattschacht a)	*Burgermeisterquelle b)*
Coliforme	20.000/g	36/100
Escherichia Coli	1.000/g	
Gesamtkeimzahl	440,000.000/g	1.600/ml
Anaerobia	10.000/g	
Enterokokken		0/100

a) Fäkalprobe aus dem obersten Bereich des Fäkalkörpers entnommen.

b) Der Befund weist Anzeichen einer Verunreinigung auf. Der Gehalt an oxydierbaren organischen Stoffen und die Gesamtkeimzahlen sind für sauberes Quell- und Trinkwasser zu hoch. Auch coliforme Keime wurden nachgewiesen.

30.3.1976.

	Aubach c)	*Burgermeisterquelle b)*	*Aubach d)*	*Sagebach e)*
Coliforme (/100 ml)	0	20	2	0
Escherichia Coli (/100 ml)	0	2	33	20
Gesamtkeimzahl (/ml)	944	47	66	1010
Anaerobia (/100 ml)	0	20	100	20
Enterokokken				
Thermophile (/100 ml)	330	500	330	1000
Salmonellen				nachweisbar

c) Die Entnahme erfolgte nahe der Aubachquelle. Der unterschiedliche Befund zur 100 m bachabwärts liegenden nächsten Entnahmestelle d) zeigt, daß in der Zwischenstrecke weitere bedeutende Karstwässer in das Bachbett aufdringen, wie auch der Augen schein ergab. Die sehr starke Belastung dieses Karstquellenwassers, das auch etwas Nitrit enthält, wird durch die hohe Gesamtkeimzahl dargestellt.

b) Gleiche Entnahmestelle wie im Jänner. Auch der Gehalt an oxydierbaren organischen Stoffen ist für ein Quellwasser etwas erhöht.

d) Etwa 150 m bachabwärts der Aubachquelle.

e) Knapp vor der Einmündung in den Schwarzwasser-Bach. Der Befund zeigt den starken Einfluß durch Beherbergungsbetriebe im Oberlauf dieses kurzen, wasserreichen Baches. Der Gehalt an oxydierbaren organischen Stoffen ist etwas erhöht. Das Wasser enthält etwas Ammonium und Nitrit.

Daraus ergibt sich, daß sämtliche Wässer der Entnahme vom 30. 3. als Trinkwasser nicht genutzt werden dürfen.

Eine Interpretation zeigt, daß zwischen hochwinterlichen und Vorfrühlingsverhältnissen die absolute Belastung der Wässer allgemein ansteigt. Das Anspringen der Karstenwässerung bewirkt eine Spülung der Wasserwege und den Transport von Keimen. Eine Vermehrung dieser Keime im Fließwasser selbst ist angesichts der niedrigen Wassertemperaturen und der kurzen Laufzeiten wahrscheinlich noch unbedeutend. Die Anaerobia und das Nitrit weisen auf Belastung durch Fäkalstoffe hin. Die Verhältnisse sind mit sehr hoher Wahrscheinlichkeit auf die Füllung des Ladstattschachtes zurückzuführen, sodaß der Karstabfluß eines Einzugsgebietes von ca. 10 km^2 verunreinigt wurde.

Der Fäkalschlamm im Schacht ist zur Hauptmasse organische Substanz, der Wassergehalt wird mit 80% angenommen. Die Abbauvorgänge beruhen einerseits auf den heterotrophen Bakterien des Höhlenmilieus, andererseits auf den milieufremden Keimen, die im Fäkalschlamm enthalten sind.

Grundsätzlich geht der Abbau von Eiweiß durch Bakterien zu Aminosäuren und weiter zu Ammoniak und zu Nitraten vor sich. Die reduzierten Stoffwechselprodukte sind CH_4, H_2S und NH_4. Bei der Oxydation ergibt sich ein erheblicher biochemischer Sauerstoffbedarf. Deshalb wird im nichtdurchlüfteten Fäkalkörper sehr bald der unerhebliche freie Sauerstoff verbraucht sein under der Abbau auf anaerobe Bakterien umschalten. Nur an jenen Stellen, an denen an der Oberfläche des Fäkalkörpers Sickerwässer erosiv tätig sind, können sich oberflächliche lokale aerobe Bakterienrasen ausbilden, von denen in Analogie zur Tropfkörpertechnik zu erwarten ist, daß sich eine optimale Schichtdicke von etwa 0,3 mm entwickeln wird. Deshalb wird abgeschätzt, daß der oberflächliche aerobe Abbau des Fäkalkörpers im Vergleich zum internen anaeroben Abbau sehr unbedeutend ist.

Bei den Anaerobiern könnte es sich auch um thermophile Keime handeln. Zwar werden die Temperaturen innerhalb des Fäkalkörpers jahreszeitlich nur wenig um ein Mittel von $7^\circ - 8^\circ$ schwanken, doch sind die Sickerwässer und die Karstwässer, welche erodierten Fäkalschlamm unterirdisch abtransportieren, etwas stärkeren Temperaturschwankungen zwischen 0° bis etwa 12° unterworfen. Die hauptsächlichen Abbauvorgänge werden somit im Sommer ablaufen und es werden an den Wiederaustrittsstellen des beeinflußten Karstwassers im Sommer höhere Keimzahlen zu erwarten sein als im Winter.

Die Konsistenz des Fäkalschlamms ändert sich über die gesamte Abbaudauer wahrscheinlich nicht. Denn an allen Klüften und Schichtfugen eintretendes Sickerwasser durchfeuchtet ihn weiter und durch randliche Erosionen werden interne Sackungsvorgänge zu gelegentlichen lokalen Durchmischungen führen. Die mit

der Gärung verbundene Gasentwicklung kann zur Ausbildung einer Brodelstruktur führen. Vor allem Methan sammelt sich zu Blasen, die in der breiigen Masse wahrscheinlich nicht immer ungehindert in den klüftigen Gesteinskörper übertreten können. Es werden deshalb zeitweilige Verstopfungen für möglich gehalten werden, die so lange andauern, bis der Auftrieb der vielleicht sehr groß gewordenen Gasblasen das Gewicht des überlagernden Schlammes verdrängen kann. In diesem Fall besteht die Gefahr, daß solche immer rascher durch den Schlamm aufsteigenden umfangreichen Blasen aus Methan zum plötzlichen Auswurf von Teilen des Fäkalkörpers aus dem Höhleneingang Anlaß sein können. Mit Exhalation verschiedener Giftgase muß jedenfalls immer gerechnet werden.

Die Geschwindigkeit der Abbauvorgänge ist von Erosionsleistungen, Wasserdurchsatz und Bakterienaktivität abhängig, wobei die letztere wieder durch Abbauprodukte stärker beeinflußt werden kann. Diese komplexen Systeme sind demnach bezüglich der Geschwindigkeit des Abbaus kaum abzuschätzen. Besser würde dies empirisch gelingen, doch sind keine Parallelfälle ähnlicher Größenordnung bekannt. Es wird lediglich vermutet, daß erst nach Jahrzehnten, wahrscheinlicher aber erst nach mehreren Jahrhunderten ein Rückgang der Belastung des Karstwassers eintritt.

In chemischer Hinsicht ist das Maß der Verdünnung mit sauerstoffreichem Wasser und auch der biochemische Einbau von Abbaustoffen in Biomasse, bis zum Fisch, entscheidend. Der Schwarzwasser-Bach hats als gefällsreicher Hochgebirgsbach in aller Regel genügend Sauerstoff und wirkt zumindest über den Großteil des Jahres genügend verdünnend.

A FEASIBILITY STUDY OF THE PALAEOMAGNETISM OF STALAGMITE DEPOSITS

Alf Latham,
Department of Geology,
McMaster University, Hamilton, Ontario, Canada

The Earth's magnetic field has shown changes in the past of which those of longer period, (10^2 to 10^6 years), are of special interest to the study of palaeomagnetism. One of the changes, called secular variation, also seems to be variable with locality.

Just as it has been possible to study these changes by investigating the palaeomagnetism of sediments and lavas, so also it may be possible to use layered speleothem deposits for the same purpose. The principal advantage of the study may be in extending the dating range from the C-14 limit at about 50,000 years, to 300,000 years, by the U/Th disequilibrium method.

The feasibility of the study depends on whether (i) stalagmite carries a natural remanent magnetism (NRM) of sufficient intensity to be measured, (ii) the NRM, or a sufficient fraction of it, has been stable since it was deposited, (iii) enough samples can be taken from a given horizon to yield meaningful results statistically, (iv) the horizon can be reliably age dated, (v) the growth rate of the speleothem was sufficient to enable to magnetic field changes to be effectively time-resolved and (vi) any growth rate changes and hiatuses can be detected and allowed for.

Sampling and specimen preparation procedures

Two types of stalagmite deposits lend themselves to study: layered flowstones and stalagmites. In the case of flowstones the orientation of the sample is fixed with respect to the horizontal and to the present Earth's field by means of a perspex tripod carrying a clinometer and a compass (Suunto types). The points of contact of the three legs are marked on the block by a tungsten scriber, the block is labelled and then removed by hammer and chisel.

The perspex orientor cannot be used with stalagmites and so a second device of aluminium has been invented. This allows scriber marks to be made on opposite sides of the sample, which are oriented by Suunto or Brunton compass along the parallel edge of the device. It is usual to repeat the orientation two or three times up the length of the stalagmite. The horizontal is determined by means of a simple transparent U-tube carrying dyed water. While one side of the U tube is fixed, the other side is positioned further round the stalagmite at some point. The water level is adjusted by raising or lowering the second limb until the meniscus in the first limb comes back to its original mark. The level of the second meniscus is then scribed on the stalagmite. This is repeated two or three times round the deposit, and it is usual to repeat the whole procedure further up the stalagmite.

In both cases the position of the speleothem deposit is uniquely determined. In the laboratory the sample is cast in Plaster of Paris in a rectangular mould so that there is some single relationship between the orientation marks and the sides of the mould. The sample is then cut up by a rock saw into many cubic specimens in such a way that the cuts are parallel and perpendicular to the growth horizons. This ensures (i) the greatest time resolution between horizons and (ii) ease of correlation between different specimens of the same sample. The cubes have sides ¾" to 1" long.

The orientation marks are then transferred to each specimen and they are labelled ready for NRM measurement.

Measurement of Natural Remanent Magnetism

Primary analyses by atomic absorption spectroscopy of various stalagmite deposits from Canada,

West Indies and the U.S.A. showed that the iron content was generally low; values ranged from about 5 to 50 ppm typically. It is by no means certain that the brown or ochre colouring of stalagmite deposits is always indicative of the presence of iron.

In order to measure the low intensities of NRM use is being made of a cryogenic magnetometer (University of Toronto), and the lowest values reliably measured so far for ¾" specimens has been less than 10^{-7} oersted/gm. Each specimen is placed in a thoroughly cleaned alternating-field (a-f) demagnetized specimen holder, and both are then lowered into the pick up coils of the sensor. A strip recorder outputs the field of the specimen in that orientation and also any residual field of the specimen holder. If the specimen is turned through 180° then an average value may be found for this magnetic component and allowance made for the effect of the holder. The field of the holder is usually a factor of ten less than the field due to the specimen but it may vary slightly and so has to be monitored at each measurement. By further re-orientation the x, y and z components of the specimens field are measured. The procedure is then repeated for as many other specimens of that horizon as are available and the results are combined by the use of standard palaeomagnetic statistics (Fisher statistics).

The hard work is taken out of the mathematics by means of a computer program. The output contains (i) the mean vector direction for the field — given by the declination D and the inclination I with respect to geographic North and the horizontal respectively (ii) the circle of 95% confidence i.e. the angle about the mean within which 95% of the specimen directions lie and (iii) the precision significance factor for that number of specimens.

The significance factor and the chi-square tests indicate how good the groupings are about the mean value and largely determine the confidence that one can place in the NRM mean value for that time horizon.

Stability of the Magnetism

It is of great importance to know whether the magnetism of the deposit is that originally laid down. If some of the carriers of the magnetism are 'soft' then over a period of time their magnetism will change in order to align themselves with later (changed) Earth's magnetic fields.

This soft magnetism may be removed howevery by progressive a-f demagnetization which effectively randomizes these softer components. The procedure is to a-f demagnetize each specimen in successively higher fields and, at each stage measure the magnetism that remains. If the direction of the field vector changes then demagnetization is continued until the direction stabilizes. The assumption is then made (usually a safe one) that this final direction is the original (primary) direction of the field at the time of deposition; it is this value rather than the NRM direction (for no a-f demagnetization) which is adopted. For instance it is usual and desirable, to find that the significance and precision factors both improve upon a-f demagnetization of all the specimens of the same age.

The Nature of the Carriers of Magnetism

It is most likely that the magnetic grains are in the mode of a detrital remanent magnetism (DRM) or a chemical remanent magnetism (CRM) or a mixture of the two. In the former case, DRM, the magnetic particles become embedded on the surface of the deposit from suspension in the flowing liquid. Nucleation and grain magnetism have been acquired before deposition. Their subsequent orientation is influenced to some extent by the topography of the surface as well as by the ambient Earth's field. This especially affects the inclination of the more elongate grains as has been demonstrated from the studies of sedimentary deposits.

In the second case, CRM, the grains may form at the surface from a nucleation process. As the crystals grow and pass from single to multi-domain grains their magnetism will tend to align along the ambient field independently of the surface topography. By sampling horizons of varying topography and by comparing the inclinations of each specimen it may be possible to distinguish between the two types of carrier mode and to determine which of the two types is the majority carrier.

The significance of this is that when constructing master curves of the varying field directions with time, if the grains are CRM derived then we may have more confidence in the inclination values — thus producing two such curves instead of one. Otherwise a bedding dip correction has to be applied to the inclination values which introduces more uncertainty into the master curves.

The Dating Method and Growth Rates of Speleothems

The dating method used (described more fully elsewhere in these proceedings) is based on the Uranium/Thorium dsequilibrium method.

For palaeomagnetic study, two factors of great importance are (i) reliability of the dating method and (ii) size of the standard deviation in the age.

Each laboratory in quoting an age usually gives a standard deviation based only on counting statistics. It is only recently that inter laboratory calibrations have been made for this method and it was found that the standard deviation of the group mean was, in general, less than the mean counting deviation of any individual sample (Harman & Ku 1976). A Barbados coral of age 105×10^3 years had an interlaboratory deviation of 4×10^3 years.

It thus appears that although stalagmite growth rates may be such as to enable field changes of 1,000 years or less, to be resolved, nevertheless it may prove more difficult to fix the age of such changes. Growth rates of flowstone are typically 0.15 cm/10^3 years whereas fast growing stalagmites may attain growth rates of 1-5 cms/10^3 years (Harmon, *et.al.* 1975).

A kind of sampling compromise exists between the two types of deposit. Although flowstones grow

at a slow rate, they furnish many specimens per horizon. Stalagmites on the other hand, have a better time resolution but the fact that much of their thickness is taken up with radial growth prevents the acquisition of many specimens per horizon.

Growth rate changes and hiatuses often show up as changes in banding and layer topography. It may be sufficient to age date the layers occurring immediately above and below the suspected hiatus and interpolate other ages. The safest thing to do is age date every horizon or set of horizons after the palaeomagnetic work has been done — if time permits.

Discussion

The research proposes to study Earth's field variations of period 10^3 to 10^5 years as far back as the limit of the dating method at about s.10^5 years. The changes are known as Secular Variation (10^3 years), events/excursions (10^4 years) and reversals (10^5-10^6). By sampling different localities it may also be possible to produce inclination and declination master curves for different longitudes and latitudes and to compare them with each other. Such master curves may then be used to complement those obtained for sedimentary sequences and which have in turn already been used to date archeological cave sites (Creer & Kopper, 1970).

The study at the time of writing is in its infancy and so no results are presented here, other than to state that stalagmite deposits from the Canadian Rockies and Jamaica do have a measurable NRM and that horizon specimen directions are well grouped with high precision and low significance factors. Their magnetism appears to be stable and primary.

References

Creer, K.M. & Kopper, J.S. Palaeomagnetic dating of cave paintings in Tito Bustillo Cave, Astorias, Spain. *Science, 168*, 348-350.

Harmon, R.S. & Ku, R. November 1976 in an interlaboratory communication of the Geochronology Interlaboratory Comparison Project, Michigan State University, Department of Geology.

Harmon, R.S. *et.al.* 1975. Uranium Series Dating of Speleothems, *Bull. Nat. Speleol. Soc.*, 37, 2, 21-32.

RELATIONSHIP BETWEEN WORLD-WIDE KARSTIC DENUDATION (CORROSION) AND PRECIPITATION

Sandor Lang
H-1012 Budapest
Logodi U63, Hungary.

The major results about the relationship between the karstic denudation (corrosion) and precipitation are presented in fig. 1.

On this logarithmic graph, the mean values of karstic denudation (corrosion, Dc) in different countries of the world are represented by dots, forming a narrow band on both sides of the straight trend line.

The equation of the function of the trend can be expressed in the form:

$$Dc = 0.08\ R^{0.8},$$

where R= the mean annual precipitation of the karstic region.

The data for the figure were collected by the Hungarian specialist Dr. D. Balazs from many karstic regions of the world; and some of my own data have been added.

LA DOCUMENTATION SPELEOLOGIQUE EN FRANCE
SPEOLEOLOGICAL DOCUMENTATION IN FRANCE

R. Laurent
Commission du Fichier des Cavités Naturelles et
Artificielles. F.F.S., 130 rue St. Maur 75011
Paris, France

From an early date the results of explorations and of scientific research on French caves have been recorded in different documents: publications, documents and different lists of caves. As some of these documents are often difficult to trace, we have compiled a chronological bibliography of the most important scientific publications and other documents in which information about the underground world in France can be found.

1) *Les Publications:* Monsieur Gèze a déjà abordé la chronologie de celles-ci. Je pense qu'il n'est pas inutile de la rappeler. Aussi je me suis permis de reproduire le schéma illustrant l'évolution de nos publications nationales (Gèze, 1961). On se reportera à cet article pour connaitre la Société Spéléologique responsable de la publication et le nombre de fascicules parus.

S. LANG

Karstic denudation/ precipitation

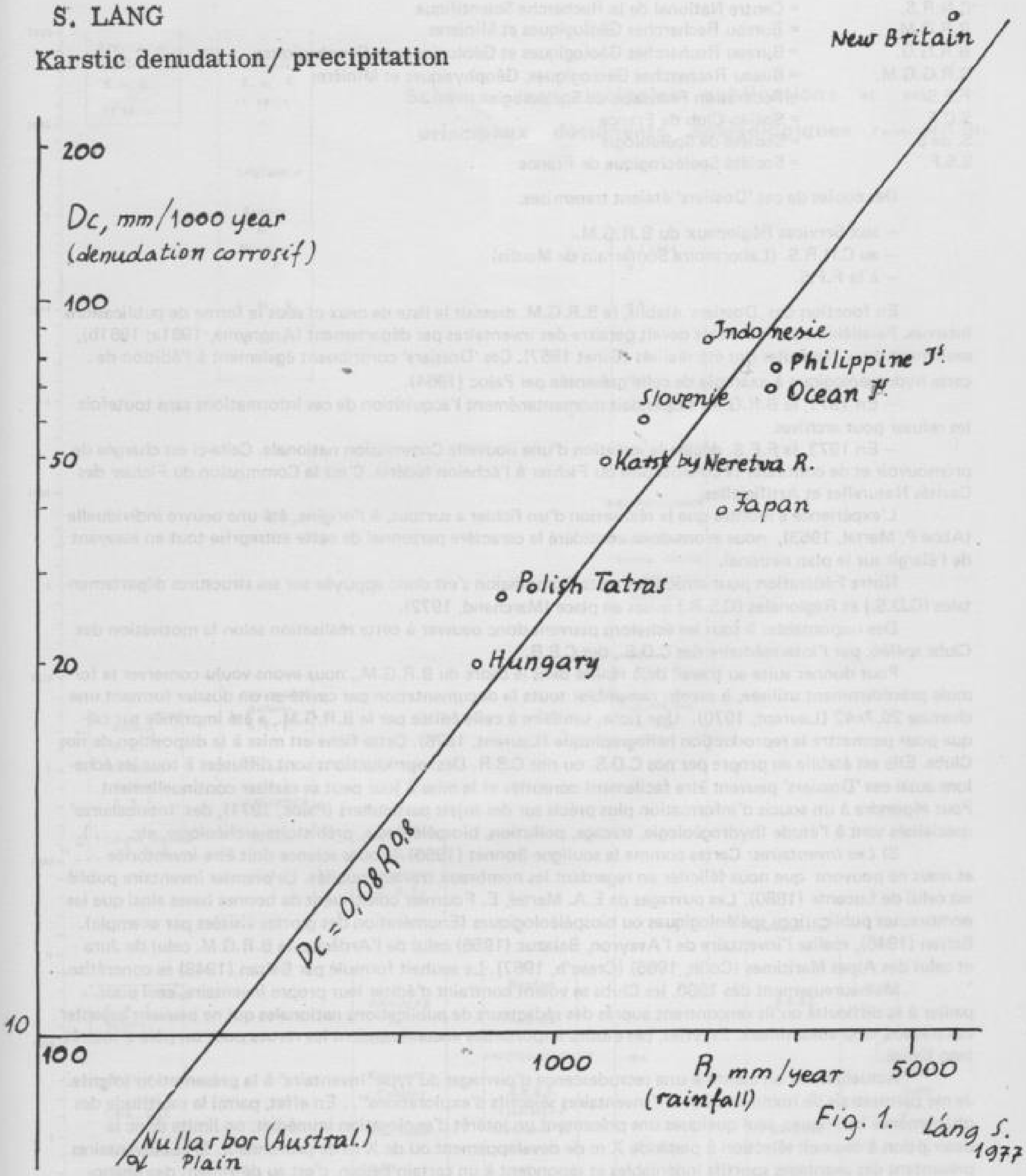


Fig. 1.

2) *La Documentation:* En L945, le B.R.G.G.(I) sous l'impulsion de Monsieur Gèze (Anonyme, 1946; B.R.G.G., 1951) mettait en place un système de fiches utilisées sur le plan national et archivées par ce service (Rouire, 1953). Ce principe était maintenu et amélioré par le B.R.G.M. (Rouire, 1961; B.R.G.M., 1969).

Des correspondants établissaient des 'Dossiers': soit avec des informations directes soit à l'aide de la bibliographie.

(1) voir liste des abréviations employées dans le texte et sur le schéma.

Liste des sigles cités dans le texte et sur le schéme

Arch. Zoo. Exp. Gén. = Archives Zoologique Expérimentale et Générale
C.A.F. = Club Alpin Francais
C.D.S. = Comité Départemental de Spéléologie: F.F.S.
C.S.R. = Comité Spéléologique Régional: F.F.S.
C.N.S. = Comité National de Spéléologie

C.N.R.S.	= Centre National de la Recherche Scientifique
B.R.G.M.	= Bureau Recherches Géologiques et Minieres
B.R.G.G.	= Bureau Recherches Géologiques et Géologiques et Géophysiques
B.R.G.G.M.	= Bueau Recherches Géologiques, Géophysiques et Minières
F.F.S.	= Fédération Francaise de Spéléologie
S.C.F.	= Spéléo-Club de France
S. de S.	= Société de Spéléologie
S.S.F.	= Société Spéléologique de France

Des copies de ces 'Dossiers' étaient transmises:

- aux Services Régionaux du B.R.G.M.
- au C.N.R.S. (Laboratoire Souterrain de Moulis)
- à la F.F.S.

En fonction des 'Dossiers' établis, le B.R.G.M. dressait la liste de ceux-ci sous la forme de publications internes. Parallèlement à ces listes devait paraitre des inventaires par département (Anonyme, 1961a; 1961b), seulement deux fascicules ont été réalisés (Ginet 1967). Ces 'Dossiers' contribuent également à l'édition de carte hydrogéologique à exemple de celle présentée par Paloc (1964).

— En 1971, le B.R.G.M. suspendait momentanément l'acquisition de ces informations sans toutefois les refuser pour archives.

— En 1973, la F.F.S. décide la création d'une nouvelle Commission nationale. Celle-ci est chargée de promouvoir et de continuer la constitution du Fichier à l'échelon fédéral. C'est la Commission du Fichier des Cavités Naturelles et Artificielles.

L'expérience a montré que la réalisation d'un fichier a surtout, à l'origine, été une oeuvre individuelle (Abbé P. Martel, 1953), nous avons donc considéré le caractére personnel de cette entreprise tout en essayant de l'élargir sur le plan national.

Notre Fédération pour structurer cette Commission s'est donc appuyée sur ses structures départementales (C.D.S.) et Régionales (C.S.R.) mises en place (Marchand, 1972).

Des responsables à tous les échelons peuvent donc oeuvrer à cette réalisation selon la motivation des Clubs spéléo, par l'intermédiaire des C.D.S., des C.S.R.

Pour donner suite au travail déjà réalisé dans le cadre du B.R.G.M., nous avons voulu conserver la formule précédemment utilisée, à savoir: rassembler toute la documentation par cavité en un dossier formant une chemise 29,7x42 (Laurent, 1970). Une fiche, similaire à celle éditée par le B.R.G.M., a été imprimée sur calque pour permettre la reproduction héliographique (Laurent, 1976). Cette fiche est mise à la disposition de nos Clubs. Elle est établie au propre par nos C.D.S. ou nos C.S.R. Des reproductions sont diffusées à tous les échelons aussi ces 'Dossiers' peuvent être facilement consultés et la mise à jour peut se réaliser continuellement. Pour répondre à un soucis d'information plus précis sur des sujets particuliers (Paloc, 1971), des 'Intercalaires' spécialisés sont à l'étude (hydrogéologie, tracage, pollution, biospéléologie, préhistoire-archéologie, etc. . . .).

3) *Les Inventaires:* Certes comme le souligne Bonnet (1966) "Toute science doit être inventoriée . . ." et nous ne pouvons que nous féliciter en regardant les nombreux travaux publiés. Le premier inventaire publié est celui de Lucante (1880). Les ouvrages de E.A. Martel, E. Fournier constituent de bonnes bases ainsi que les nombreuses publications spéléologiques ou biospéléologiques (Enumération des grottes visitées par exemple). Balsan (1946), réalise l'inventaire de l'Aveyron, Balazuc (1956) celui de l'Ardèche, le B.R.G.M. celui du Jura et celui des Alpes Maritimes (Colin, 1966) (Creac'h, 1967). Le souhait formulé par Balsan (1948) se concrétise.

Malheureusement dès 1960, les Clubs se voient contraint d'éditer leur propre inventaire, ceci pour pallier à la difficulté qu'ils rencontrent auprès des rédacteurs de publications nationales qui ne peuvent accepter ces travaux trop volumineux. En effet, ces études importantes encombreraient les revues pour un pôle d'intérêt trop limité.

Actuellement on assiste à une recrudescence d'ouvrages du type 'Inventaire' à la présentation soignée. Je me permettrais de nommer ceux-ci "Inventaires sélectifs d'explorations". . En effet, parmi la multitude des phénomènes karstiques, seul quelques uns présentent un intérêt d'exploration immédiat; on limite donc la description à ceux-ci: sélection à partir de X m de développement ou de X m de profondeur. Si ces inventaires présentent des avantages sportifs indéniables et répondent à un certain besoin, c'est au détriment des phénomènes karstiques environnant la cavité décrite.

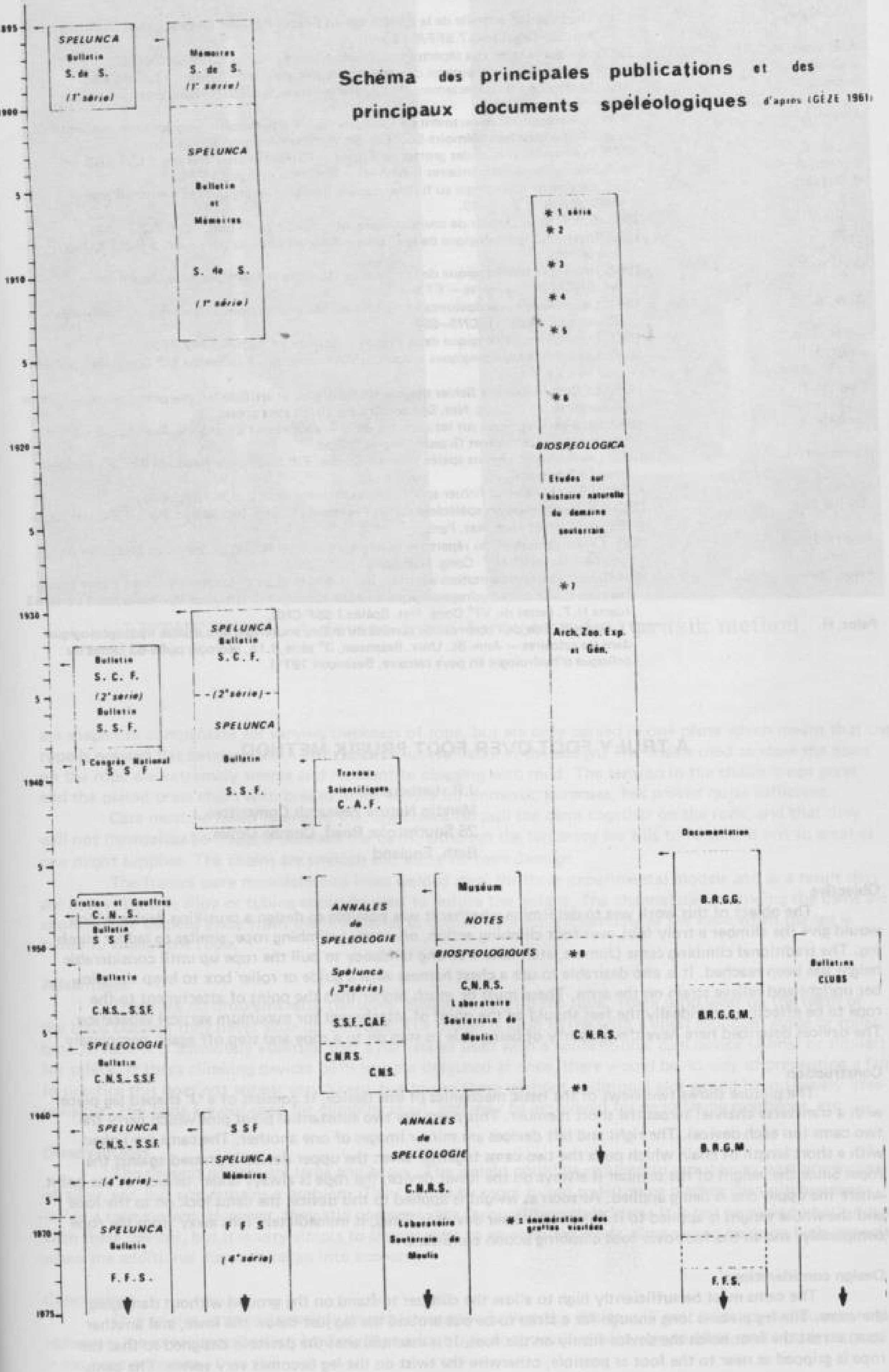
Conclusion: Les 'Inventaires' ou les 'Dossiers' de cavité convergent vers le même but: une meilleure connaissance de notre domaine karstique.

Certes les inventaires ont l'énorme avantage de regrouper sous peu de volume des renseignements sur un département, un massif, une région. Renseignements qui sont malheureusement vite périmés, seule la situation reste inchangée. L'importance du réseau, la nature des transits internes, les travaux réalisés sont seulement valables à une data donnée, celle de la publication.

Par contre un Fichier peut suivre au jour le jour toutes les informations sur tous les phénomènes karstiques quels qu'ils soient. Son contenu n'étant pas limitatif, il restera donc d'actualité selon la motivation des explorateurs pour communiquer leur information. Malheureusement, son maniement est lourd.

Notre Commission fédérale est jeune et nous avons bon espoir pour cette réalisation. Les spéléologues ressentent la nécessité de ce Fichier national. Un Fichier à jour qui débouchera sur des publications importantes ou des 'Inventaires'. Reste à trouver la formule d'une publication 'évolutive' qui permettrait d'ajouter des additifs au fur et à mesure de nos connaissances sur les réseaux, sans pour cela condamner la précédente édition.

Schéma des principales publications et des principaux documents spéléologiques d'après (GÈZE 1961)



Bibliographie

Anonyme, 1946. Organisation actuelle de la spéléologie en France III) — le Service spéléo du B.R.G.G. — Ann. Spéléo tl pp4-7 SFF/CAF.

Anonyme, 1961a: La publication des répertoires spéléologiques Spelunca f.3 pp56 CNS/SSF.

Anonyme, 1961b. Instructions aux auteurs d'inventaires spéléologiques — Spelunca f.4 pp53-56.

Balazuc, J. 1956. Spéléologie du département de l'Ardèche — Soc. Spéléo. Italiana, mémoire II ed. Como 158pp 62pl.

Balsan, L. 1946. Spéléologie du départment de l'Aveyron (essai d'inventaire géographique, descriptif et bibliographique) Mémoire Soc. Let. Sc. Arts de l'Aveyron t25 365pp.

Balsan, L. 1948. Pour un inventaire des grottes de France — Grottes et Gouffres no. 2 pp3 CNS.

Bonnet, A. 1966. Bienvenue aux inventaires (éditorial) — Spelunca F. 2 pp84 FFS.

B.R.G.G. 1951. Service de spéléologie au Bureau des Recherches Géologiques et Geophysiques — Bull. C.N.S. f. 2-3 pp40.

B.R.G.M. 1969. B.R.G.M. — Dossier de cavités naturelles — Spelunca f.I pp82-83 F.F.S.

Colin, J. 1966. Inventaire spéléologique de la France — I départment du Jura — éd. BRGM 307pp Icarte FFS.

Creac'h, Y. 1967. Inventaire spéléologique de la France — II) — départment des Alpes-Maritimes — éd. BRGM 349pp Icarte — FFS.

Geze, B. 1961. La renaissance de Spélunca et l'évolution des publications spéléologiques nationales — Spelunca f. I pp5-11, CNS—SSF.

Ginet, R. 1967. Inventaire spéléologique de la France — Spelunca f.3 pp248-249 FFS.

Laurent, R. 1970. Les fichiers spéléologiques — Spelunca Mémoires no. 7 (actes du IX° Cong. Nat. Spéléo. pp71-78 FFS.

Laurent, R. 1976. La Commission du fichier des cavités naturelles et artificielles, des phénomènes kartiques — (actes du XII° Cong. Nat. Spéléo. Grasses 1976) sous presse.

Lucante, A. 1880. Essai géographique sur les cavernes de la France et de l'Etranger — Bull. Soc. Et. Sc. d' Angers imp. Germain et Grassin, Angers 202pp.

Marchand, G. 1972. Les nouvelles régions spéléo sont en marche. F.F.S. Quoi de Neuf no. 6 pp2-3 (supplément à Spelunca).

Martel, P. Abbé, 1953. Un essai de fichier spéléologique régional Bull. C.N.S. f. 3 pp54.

Rouire, J. 1953. La documentation spéléologique en France — I° Cong. Int. Spéléo. Paris 1953 tIV pp91-96 éd. Muséum Hist. Nat. Paris.

Rouire, J. 1961. La réorganisation du répertoire spéléologique du B.R.G.M. — Spelunca Mémoires no. 1 pp91-92 (actes du III° Cong. Nat. Spéléo) SSF-CNS.

Paloc, H. 1964. Normes de représentation adoptées par le B.R.G.M. pour la représentation à titre expérimentale d'une carte hydrogéologique en zone karstique — Spelunca Mémoires no. 4 pp41-43 Icarte H.T. (actes du VI° Cong. Nat. Spéléo.) SSF-CNS.

Paloc, H. 1971. Contribution de l'observation directe du milieu souterrain aux études hydrogéologiques dans les calcaires — Ann: Sc. Univ. Besancon, 3° série, f.15, géologie pp59-63 (actes du colloque d'hydrologie en pays calcaire, Besancon 1971).

A TRULY FOOT OVER FOOT PRUSIK METHOD

J.R. Letheren
Mendip Nature Research Committee
25 Southstoke Road, Combe Down,
Bath, England

Objective

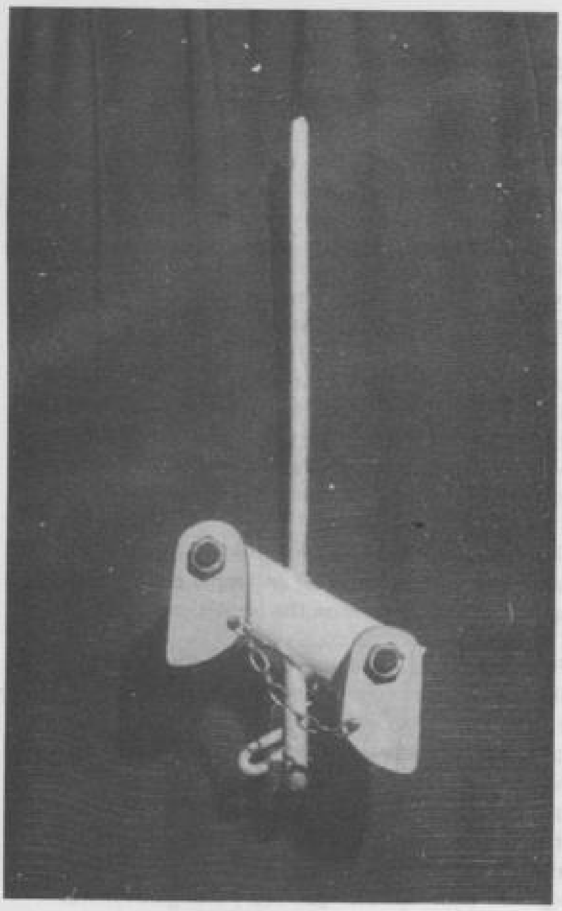
The object of this work was to determine whether it was possible to design a prusiking device which would give the climber a truly foot over foot climbing action, on normal climbing rope, similar to ladder climbing. The traditional climbing cams (Jumars, etc.) have a strong tendency to pull the rope up until considerable height has been reached. It is also desirable to use a chest harness with a guide or roller box to keep the climber upright and relieve strain on the arms. These must be much higher than the point of attachment to the rope to be effective, and ideally the feet should be the point of attachment for maximum vertical separation. The devices described here have the property of being able to step on to a rope and step off again, completely.

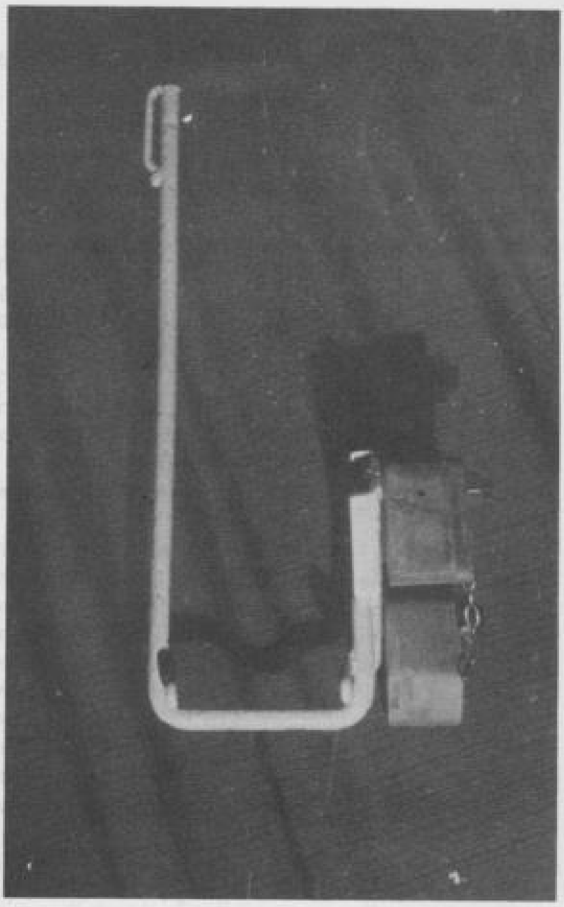
Construction

The picture shows two views of the basic mechanics of one device. It consists of a 'J' shaped leg piece with a transverse channel across the short member. This piece has two substantial pivot pins which carry the two cams (on each device). The right and left devices are mirror images of one another. The cams are linked with a short length of chain which pulls the two cams together when the upper device is pressed against the rope. Since the weight of the climber is always on the lower device, the rope is always under tension at the point where the upper one is being applied. As soon as weight is applied to this device, the cams lock on to the rope and the whole weight is applied to it. When the lower device is lifted, it immediately falls away from the rope completely, and so the foot over foot climbing action continues.

Design considerations

The cams must be sufficiently high to allow the climber to stand on the ground without damaging the cams. The leg piece is long enough for a strap to be put around the leg just below the knee, and another strap across the foot holds the device firmly on the foot. It is essential that the device is designed so that the rope is gripped as near to the foot as possible, otherwise the twist on the leg becomes very severe. The cams





LETHEREN A device for a foot over foot prusik method.

are shaped to compensate for varying thickness of rope, but are only curved in one plane which means that the rope is pressed flat between them. This appears unavoidable in the design. The chains used to close the cams on the rope are extremely simple and resistant to clogging with mud. The tension in the chains is not great and the plated brass chain with brazed links, as sold for domestic purposes, has proved quite sufficient.

Care must be taken to ensure that the chains do pull the cams together on the rope, and that they will not themselves be trapped between the cams, although the tendency for this to happen is not so great as one might suppose. The chains are smooth and cause no rope damage.

The frames were manufactured from welded steel for these experimental models and as a result they are heavy, though alloy or tubing could be used to reduce the weight. The channel pieces holding the cams are angled thirty degrees away from the horizontal to compensate for the bending at the knee when the leg is raised to engage the rope.

Advantages

There are no problems with the lower device pulling up the rope. There is no wear on the teeth of the cams because they never slide up the rope. The design is ideal to use with a chest mounted guide or roller box. In fact, it is absolutely essential that a harness be used with a conventional cam device (Jumar or similar) for safety. If these climbing devices both became detached at once, there would be no way of preventing a fall. In practice this does not appear very likely, but to use them without additional aids would be extremely irresponsible. The arms are not used for climbing at all, and may be employed for negotiating overhangs, etc.

Disadvantages

The present devices are large and heavy. The weight could be reduced to sensible proportions by use of alloy, etc. but size remains a problem. They would be more suited to entrance pitches than pitches deep inside a cave system. However, they still compare very favourably with ladders! It is not possible to back down with these devices, but it is very simple to change over to an abseiling mode. Cost would be quite high, especially when the additional Jumar is taken into account.

Conclusions

Due to size, cost and possibly weight, it is unlikely that this design will ever be produced commercially. However, the experiment set out to show that a foot over foot prusik device was possible, and in this respect it has been a success.

FERNS IN CAVE ENTRANCES

Oliver C. Lloyd
Withey House,
Withey Close West,
Bristol, England

Last winter my brother introduced me to the Shield Fern (*Polystichum aculeatum*) which looks attractive all through the winter, unlike the Male Fern *(Dryopteris filix-mas)* which it otherwise resembles but whose leaves die in the autumn. Another distinguishing feature is that in the Shield Fern there is a tiny prickle at the point of each leaflet.

When I am not actually caving I like to do "surface work", which may mean going around a caving area with a guide book, map and nosebag spotting cave entrances for future trips. While doing this at Easter I was struck by the fact that nearly all of the caves entrances in the Allotment Area of Yorkshire had the Shield Fern growing on their wet vertical faces. Back on Mendip I found the same fern growing in the entrance to Lamb Leer. Since then I have found it a general rule that, whatever other ferns may be there, the Shield Fern will be there as well.

In June I did some surface work in the Dismal Hill neighbourhood (N. Yorkshire) and found a fern that I had never seen before. This is the Bladder Fern *(Cystopteris fragilis)*, much smaller and more delicate. It derives its name from the bladder-like swelling of the young spore cases to be seen on the undersides of the leaves. I found it at Dismal Hill and Old Ing Caves and also at Calf Holes.

After that I was on the look out for the Bladder Fern and found it in Poulnagollum (Slieve Elva) and even in a spring high up on the Ailwee Mountain in Ireland. In Wales I found it at Ffynnon Ddu and Porth yr Ogof, where it is accompanied by that loveliest of ferns the Lady Fern *(Athyrium filix-femina)*. But I couldn't find it on Mendip. There was nothing in Cheddar but a good clump of Lady Fern in the First Feeder. Ebbor has plenty of Male Fern, Buckler Fern (*Dryopteris dilatata*), Shield Fern and of course the Hart's Tongue *(Phyllitis scolopendrium)*, which will grow anywhere shady, even in show caves by the lights. Also the Common Polypody *(Polypodium vulgare)* which likes to grow on rotting branches. It was absent from Easterwater, Swildon's, Longwood, Rhino Rift, Reed's Grotto, Tyning's Stream sink and from G.B. Cave, which sports some very well grown Lady Fern. Lastly I went to Tyning's Great Swallet, all overgrown with nettles. I got badly stung but it was worth it, for there in the cleft, where the sun never shines and cavers never go, was the Bladder Fern growing in great profusion.

Here is a check list of ferns which are commonly found in cave entrances in Britain:

Asplenium ruta-muraria	:	Wall Rue
Asplenium trachomenes	:	Common Spleenwort
Athyrium filix-femina	:	Lady Fern
Cystopteris fragilis	:	Bladder Fern
Dryopteris filix-mas	:	Male Fern
Phyllitis scolopendrium	:	Hart's Tongue
Polypodium vulgare	:	Polypody
Polystichum aculeatum	:	Shield Fern
Pteridium aquilinum	:	Bracken

PREMIERS ELEMENTS POUR UNE ETUDE PHYSICO – CHIMIQUE DES EAUX MASSIF DE LA CHARETALP (Suisse – Canton de Schwyss)

B. Loiseleur et H Salvayre
11, r. des Alouettes (village)
66140 Canet-en-Rousillon

En 1975 et 1976 le Groupe d'Etude du Karst du Centre Universitaire de Perpignan a participé aux travaux des opérations Glaneralpen II et III qui se sont déroulées dans le massif de la Charetalp au Sud – Est de Zurich, dans les bassins de la Muota affluent du lac de Luzern et de la Linth affluent du Rhin. L'altitude moyenne du massif est de 2100 m les écoulements souterrains reconnus par coloration se font vers l'Ouest vers la vallée de la Muota et la résurgence de l'Hinterseeberg.

La prospection résistivimétrique sur le terrain a été suivie d'une campagne d'analyses des eaux souterraines et superficielles. Les premiers résultats portent sur des périodes identiques, du I° au 15 Août qui succédérent à deux années climatologiques différentes une à fort enneigement: 1975, l'autre très séche 1976.

Mesures Resistivimetriques:

Les mesures ont été réalisées dans la vallée de la Linth du col de la Klaussen Pass 1948 m à la retenue de Oberen Hutten 1310, dans la vallée de la Muota du cirque de Milchbuelen 1400 m à la résurgence du Holloch. Dans les deux cas les mesures ont porté sur le lit de la rivière et les affluents des deux rives qui sont le plus souvent des résurgences. Sur le massif lui même quelques mesures furent effectuées dans les écoulements sou-

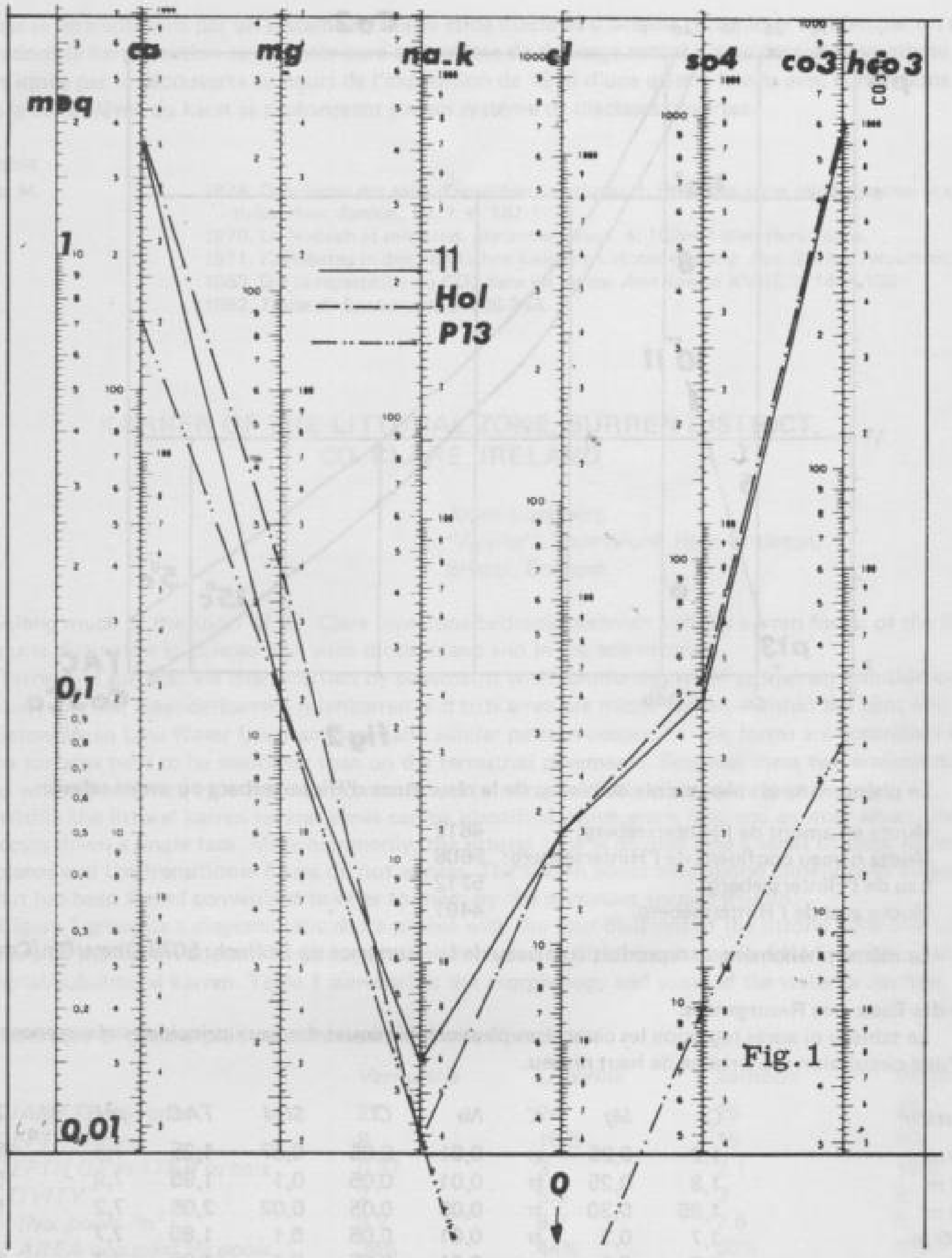


Fig. 1

terrains reconnus au cours des explorations. Les résultats peuvent être groupés en trois séries:

1° Les Eaux de la Surface Du Massif:

Neige Glace Souterraine:	R est compris entre 28860 et 15 288.
Eaux de la Couche Superficielle du karst	R Compris entre 12306 et 6944

2° Les Eaux des Resurgences dans la Vallee:

La Linth Résurg.	
Rive Droite:	R Compris entre 5400 et 5100
La Muota Résurg.	
Rive droite:	R compris entre 5169 et 5148

3° Les Eaux des Rivieres:

La Linth:	R Compris entre 4812 et 4817
La Muota:	R Compris entre 4812 et 4491

(R = Resistivité en ohms/Cm/Cm2 à 20°)

On notera la valeur caracteristique des eaux de drainage des massifs calcaires, comprise entre 5100 et 5700 qui se differencie quelque soit l'altitude ou la nature géologique des eaux superficielles.

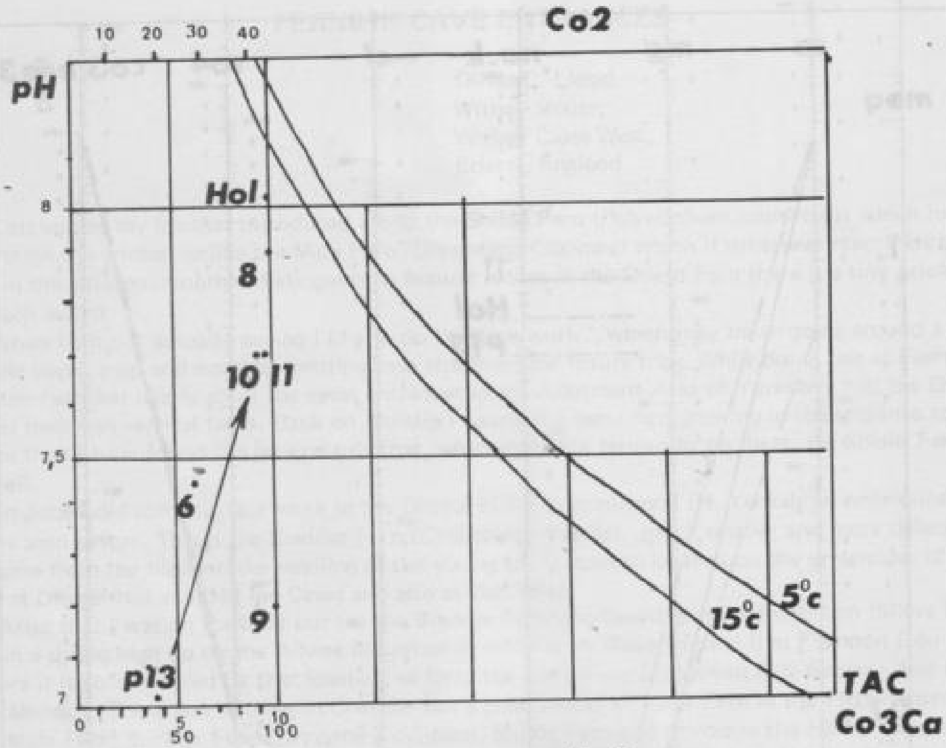


fig2

Le phénoméne est bien visible au niveau de la résurgence d'Hinterseeberg où avons relevé:

Muota en amont de l'Hinterseeberg:	4812
Muota niveau confluent de l'Hinterseeberg:	5608
Eau de l'Hinterseeberg:	5712
Muota aval de l'Hinterseeberg:	4491

Le même phénoméne se reproduit au niveau de la résurgence du Holloch: 5079 Ohms/Cm/Cm2à 20°

Chimie des Eaux Des Resurgences:

Le tableau ci aprés regroupe les caractéres physico chimiques des eaux principales résurgences du massif et d'une circulation souterraine de haut nivaeu.

Designation	*Ca*	*Mg*	*K*	*Na*	*Cl*	*SO4*	*TAC*	*pH*	*T°*
6 1400 m	1,2	0,25	tr	0,01	0,05	0,07	1,25	7,4	5°7
8 1360 m	1,8	0,25	tr	0,01	0,05	0,1	1,95	7,9	5°9
9 1330 m	1,85	0,30	tr	0,03	0,05	0,02	2,05	7,2	5°7
10 1200 m	1,7	0,3	tr	0,01	0,05	0,1	1,85	7,7	
11 780 m	1,8	0,1	tr	0,01	0,05	0,1	1,95	7,7	5°7
Holloch	1,8	0,2	tr	0,01	0,05	0,11	2	8,05	5°3
P 13	0,7	0,1	tr	0,01	0	0,02	0,8	7,05	5°3

(6: Resurg. Taschibach, 8: Resurg. Feldmoos, 9: Resurg. Hochweidquellen, 10 Résurg. Richliswaldach, 11: Résurg: Hinterseeberg. les valeurs sont exprimées en milliequivalents).

Le report de ces valeurs sur un diagramme logarithmique permet de situer ces eaux dans la famille des eaux Bicarbonatées Calciques trés faiblement minéralisées. (Fig. 1).

Sur les courbes d'équilibre de Tillmans elles se situent en dessous des courbes de saturation avec un pH de 7,05 à 7,7 pour les eaux issues du massif de la Charetalp. Il atteint 8,05 à la résurgence du Holloch située à une altitude plus basse que celle de l'Hinterseeberg. Les valeurs de T.A.C. se placent entre 5° et 10° Francais, soit une teneur de 50 à 100 mg de CO3Ca par litre.

On peut avoir une idée du sens de l'évolution chimique de l'eau dans le massif en comparant la composition chimique de l'eau du P 13 avec celle de l'Hinterseeberg (II Fig. 2) on constate une variation trés nette du pH de 7,05 à 7,7 sans élévation notable de la teneur en CO3 Ca.

Ces caractéres apparentent ces eaux aux écoulements d'une altitude bien supérieure dans les Pyrénées sans doute faut il voir là l'effet conjugué d'une plus haute latitude et d'un karst entiérement déboiseé.

Conclusion:

Les premiers résultats d'une campagne physico chimique sur les eaux souterraines du massif de la Charetalp (Suisse) sembleraient prouver que la dissolution chimique en profondeur serait modeste. Les circulations

souterraines se feraient donc par un systéme de failles et de diaclases d'origine tectonique ou bien par un réseau souterrain dont la karstification serait antérieure au systéme de drainage actuel. Cette dernière hypothése est en partie confirmée par la découverte au cours de l'expédition de 1976 d'une galerie fossile avec concretions massives dans la zone élévée du karst se prolongeant par un systéme de diaclases ouvertes.

Bibliographie

Bakalowicz, M. 1974. Géochimie des eaux d'aquiféres karstiques. I. Relations entre minéralisation et conductivité. *Ann. Speleo.*, 29, 2, p. 167-173.

Boegli, A. 1970. Le Holloch et son karst. *Stalactite,* suppl. 4: 109p+ I plan Hors Texte.

Boegli, A. 1971. Kalkabtrag in den nordlichen kalkalpen. *Actes 4° Cong. Nat. Speleo. Neuchatel,* 1970.

Roques, H. 1963. Sur la répartition du CO2 dans les karsts. *Ann Speleo* XVIII, 2, 1414-185.

Trombe, F. 1952. *Traite de Speleologie* p: 205-243.

KARREN OF THE LITTORAL ZONE, BURREN DISTRICT, CO. CLARE, IRELAND

Joyce Lundberg
"Apples", Scumbrum, High Littleton,
Bristol, England.

Along much of the coast of Co. Clare limestone bedrock outcrops and the karren forms of the littoral zone are quite distinctive in comparison with those inland and in the sub-littoral.

Terrestrial surfaces are characterised by pavements with solutionally enlarged joints. Solution cups (kamenitzas), runnels, meanderkarren, rillenkarren and tritkarren are minor features within the clint and grike pattern. Below Mean Low Water Level an essentially similar pattern occurs; i.e. the forms are controlled by jointing but the surfaces tend to be smoother than on the terrestrial pavements. Between these two environments lies a band where kamenitza-type features dominate and jointing has little control on form.

Within the littoral karren several zones can be identified which grade into one another where the sequence occurs down a single face. More commonly, the littoral zone is divided into a series of steps relating to bedding planes and the transitional forms do not appear. The karren zones correspond closely with biological zones and it has been found convenient to refer to them by the dominant species therein.

Figure 1 presents a diagrammatic shore profile with the four divisions of the littoral zone and accurate cross-sections of the karren above. The joint pattern is included to illustrate the basic difference between littoral and terrestrial/sub-littoral karren. Table 1 summarises the morphology and some of the water properties.

Table 1: Summary of geomorphic measurements and water properties.

Zone	*Verrucaria*	*Littorina*	*Barnacle*	*Mussel*
Average DIAMETER in cms.	27	24	25	43
Average DEPTH in cms.	8	16.5	15	40
Average DEPTH OF WATER in cms.	0.37	3	2.1	15.5
*CONNECTIVITY**	2	5.5	3	6
DENSITY (No. pools /m^2).	6.2	8.7	7.5	5
% TOTAL AREA occupied by pools.	36%	44%	50%	80%
pH.	8.5	8.2	8	7.1
$CaCO_3$ ppm.	1500	1360	1100	1005
% $CaCO_3$ SATURATION	97%	100%	101%	99%

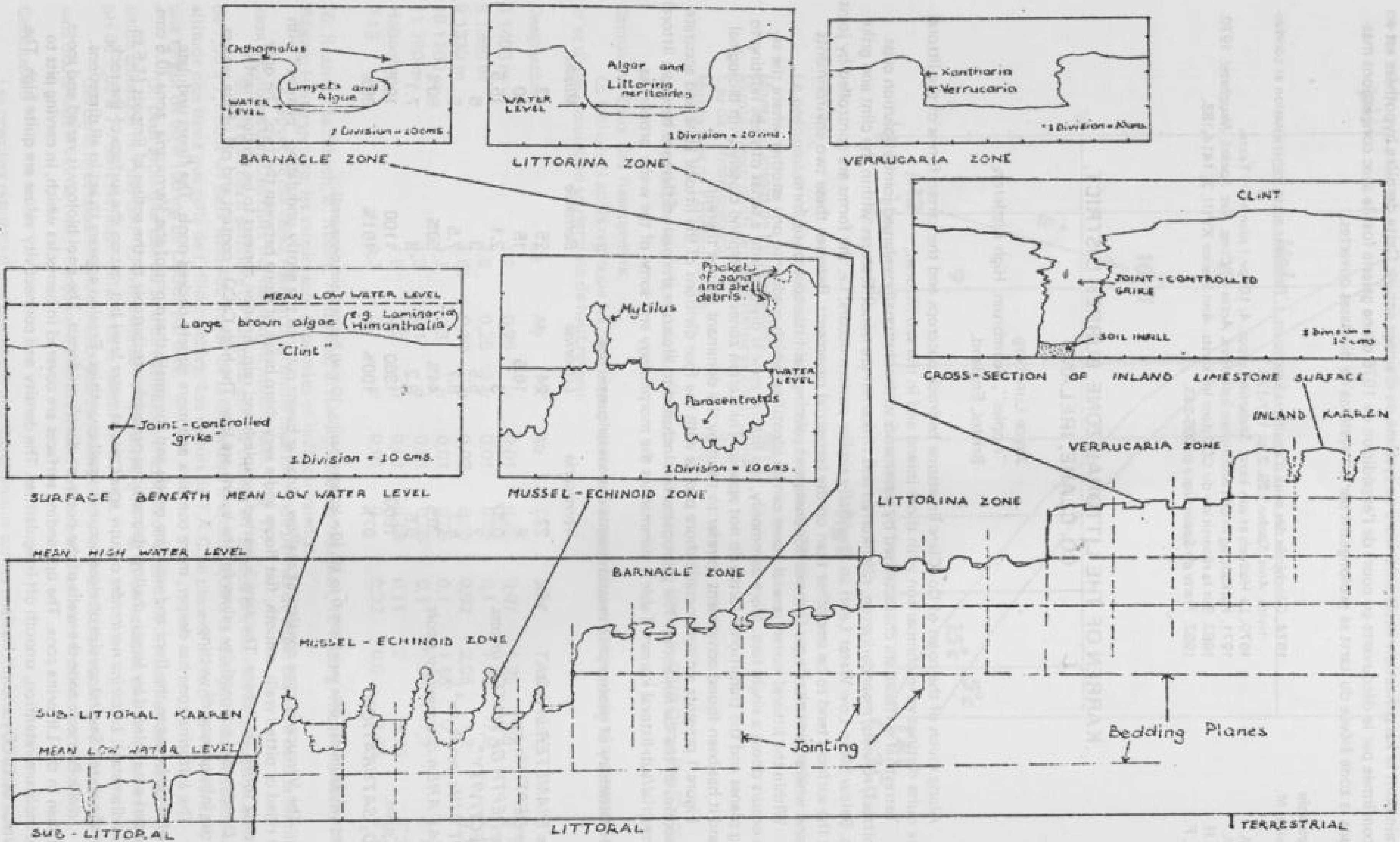
* Connectivity estimated on a scale from 0 to 10. (0 = isolated basins, 10 = all basins interconnected).

The *Verrucaria* zone consists of shallow, circular basins cut into the gently undulating "plateau" with vertical rilled or pitted walls, smooth, flat floors and a very sharp break of slope between the two. The only obvious life forms are lichens. The zone is wetted by splash and rain. Erosion appears to be predominantly lateral. Density and connectivity values for the basins are low. The high $CaCO_3$ content and pH of the waters reflect the infrequency of wetting.

The *Littorina* zone has deeper, more complex and more closely-packed pools. The floors undulate, breaks of slope between the floor and walls are gentle and the small, sharp pits of the *Verrucaria* zone (0.5 cms. in diameter) are replaced by larger, shallow depressions probably attributable to the action of limpets (1.5 to 2 cms. in diameter). *Littorina neritoides* occupy small pits at water level but rest on the surface of the rock beneath the water. Several species of algae occur in small quantities. Erosion appears to act in all directions.

In the Barnacle zone the walls of the pools are deeply undercut. The pool biology is varied and more prolific than in the Littorina zone. The upstanding surfaces are covered in barnacles which, in carving pits to increase moisture retention, smooth off irregularities. The density and connectivity values are quite high. The same is true of $CaCO_3$ and pH levels.

As soon as the pools become deep enough for Echinoids to become established the morphology changes dramatically. The pools of the Mussel/Echinoid zone are large, deep and highly connected. The low



DIAGRAMMATIC SHORE PROFILE ILLUSTRATING ZONATION OF KARREN, EFFECTS OF JOINTING AND TYPICAL SEPARATION OF ZONES BY CLIFFS.
ABOVE: ACCURATE CROSS-SECTIONS OF SAMPLE FROM EACH ZONE SHOWING DOMINANT SPECIES (All at the same scale)

Figure 1.

density value is a reflection of the size rather than packing index. The surfaces below water are occupied by *Parancentrotus lividus* all to the exclusion of all other species. Each one of these carves a hemispherical cup. 2.5 to 5 cms. in diameter in which it rests. The surfaces above water are colonised by mussels. Beneath these, pockets of sand and shell debris are often hidden. From the size of the pools, the small areas of rock remaining above water and the frequency of secondary pool formation within a primary pool, it would appear that erosion is reasonably rapid in this zone.

Modifications to this basic pattern are common. With increasing slope angle the forms become streamlined, their depths are limited and eventually meanderkarren forms take over. With increasing energy level of the environment the forms become deeper, more jagged and connectivity is increased. Both freshwater flows and abrasion by beach material have a smoothening effect on all surfaces. Effects of lithology are minor. The effect of time will be to transform a zone into the zone seaward of it as the total surface is lowered but the sea level remains constant; e.g. after several stages of pool formation in the Barnacle zone, the water level will be high enough for echinoids and mussels to colonise and the pool morphology will begin to change.

A few accounts of littoral karren appear in the literature but most of these refer to tropical coasts, e.g. Ginsburg (1953). Emery (1946) describes marine solution basins in a mediterranean climate. Guilcher (1953) compares the karren of four coastlines – the British Isles, Morocco, Provence and Hawaii. From these examples it appears that the karren of temperate coastlines is distinctive from that of other climates.

The short account of littoral karren from the Burren District by Williams (1971) is of direct relevance to the present study. He presents two cases. The first is of a semi-exposed shore which he divides into four zones; 1. Black lichen pans, 2. Calcareous and green algae pans, 3. Barnacle anvils and 4. Algae flats. The second is a very exposed shore where the "Algae flats" zone is replaced by: 4. Mussel pinnacles and 5. Echinoid pits. The only differences between this classification and that presented above by the author are in zones 4 and 5 and in the treatment of shores according to exposure. The author considers (i) that these "Echinoid pits" are simply a final stage of the Mussel/Echinoid zone, and (ii) that the dip and height of bedding planes is of greater significance to karren development than is exposure. Williams' diagram of the semi-exposed shore show beds dipping gently coastwards whereas those of the very exposed shore dip steeply seawards. His account is brief and does not attempt any explanation for the origin of the karren.

When an explanation for the formation of these features is sought a basic difficulty emerges. Seawater is normally supersaturated with $CaCO_3$ yet solution is probably the only process capable of producing such delicate forms. For this to occur sea-water must, at some stage, become aggressive to $CaCO_3$. Emery (1946) appreciated this problem and suggested that aggressivity may be increased at night by the release of CO_2 during plant respiration. Since the samples taken during the day showed low aggressivity and high pH it was decided to examine samples taken during the night. Any further biotic activity was halted by the immediate killing of all microscopic organisms. The results from the 39 samples are presented below.

	% $CaCO_3$ Saturation		*pH*	
	Day	*Night*	*Day*	*Night*
Verrucaria zone	96.29	61.34	8.2	8.2
Littorina zone	103.3	62.84	8.35	7.2
Barnacle zone	81.6	46.4	8.0	6.3
Mussel zone	95.1	55.9	6.25	5.9

The average percentage saturation for all the day-time samples was 100.05%, with a standard deviation of 6.2, and for the night-time samples 56.6% (s.d. 6.5); i.e. the water in the rock pools became aggressive after nightfall. The pH became lower, significantly so in most cases. In order that the increase in aggressivity and dissolution of Calcium Carbonate may be effective in terms of karren formation, photosynthesis and the re-precipitation of $CaCO_3$ must be prevented. Alternatively the $CaCO_3$-enriched waters must be removed. The latter is achieved by the tidal cycle. Maximum removal of $CaCO_3$ will occur when low tide coincides with darkness. Many algae are seasonal: it is probable that the greatest erosive effect occurs in winter when the algal biomass increases. Microscopic algae are of equal significance to macroscopic algae.

The formation of littoral karren is dependent on the isolation of small bodies of water harbouring various flora and fauna. The zonation is produced by a combination of the frequency of wetting and replacement of the water, and of the species present. The *Verrucaria* zone is more affected by rain than by seawater. Evaporation and reprecipitation of $CaCO_3$ give the smooth floor surface and prevent vertical erosion. Microscopic algae become more significant in the *Littorina* zone. The action of barnacles contributes to the smooth appearance of the upstanding rock in the third zone, and boring by limpets assists the deep undercutting of the walls. In the Mussel/Echinoderm zone the activities of boring animals are more pronounced and the effects of animal and algal respiration combine to give the highest erosion rate of the four zones. Beneath low water level the increase in aggressivity at night has little effect because it is not concentrated in a small volume.

References

Emery, K.O. — 1946. Marine Solution Basins, *J. Geol.* 54, 4., pp.209-228.

Ginsburg, R.N. — 1953. Intertidal Erosion on the Florida Keys, *Bull. Mar. Sci. Gulf and Carib.* pp.55-69.

Williams, P.W. — 1971. Excursion Guide for Fieldwork, *Commission on Karst Erosion, International Speleological Union.*

AN ANALYSIS OF THE FORM OF RILLENKARREN FROM THE TOWER KARST OF CHILLAGOE, NORTH QUEENSLAND, AUSTRALIA

Joyce Lundberg
"Apples", Scrumbrum, High Littleton,
Bristol. U.K.

Chillagoe lies about 320 kms. to the N.W. of Cairns, North Queensland (17° 10'S, 144° 30'E) and has a seasonally-humid tropical climate. Most of the 774 mms. of rain falls with high intensity between November and April. The limestones of the Chillagoe Formation, Upper Silurian to Lower Devonian in age, are in general hard, compact, dark grey in colour and fossiliferous. Small and large karren features cover most of the exposed rock surfaces. Only rillenkarren are treated here.

J. LUNDBERG Karren at Chillagoe

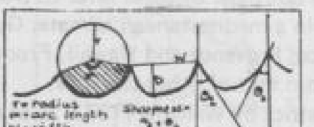
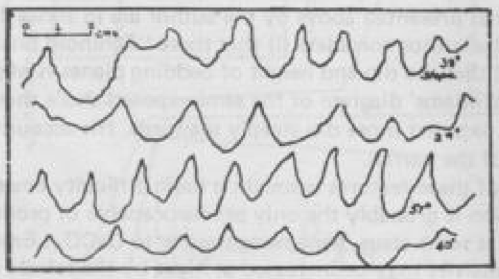
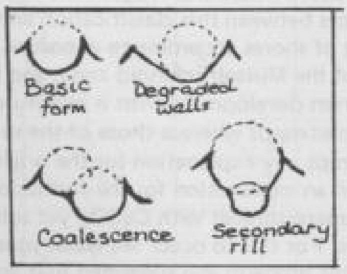


Figure 1: Measurements from rill cross-sections.

Figure 2 (below): Some samples of rill cross-sections

Figure 3 (below right): Variations on the basic semicircular form.





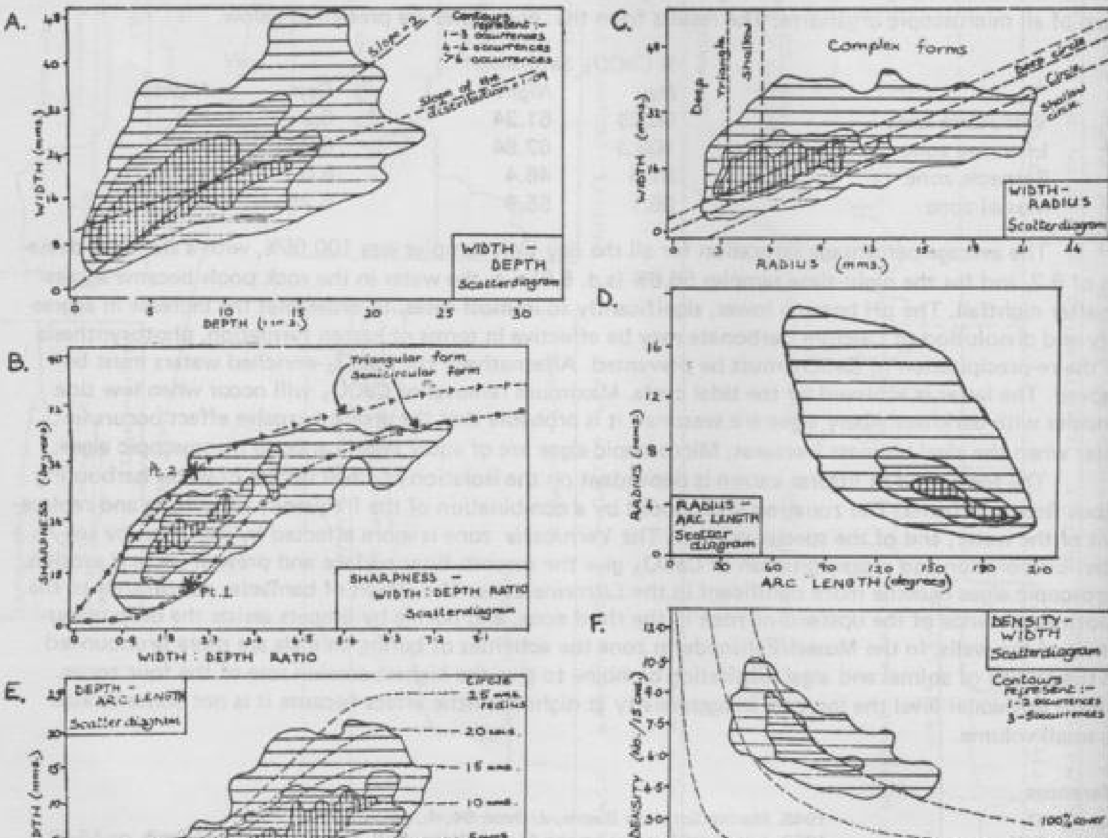


Figure 4 : Scatter diagrams of selected variable pairs.

The idea of recording the cross-sections of groups of rills with the "Carpenter's Profile Gauge" was conceived by D. Dunkerly (Pers. Comm. 1975). This device consists of numerous parallel rods 1mm. in diameter held together in a plane but free to move up and down in relation to one another. When pressed against a feature, the gauge conforms to that shape which can then be recorded by tracing directly onto paper. For this analysis, cross-sections of 1174 rills were taken (midway between the top and bottom of the rill) and their slope inclinations were recorded. Each rill cross-section was then measured accurately to obtain values for (i) Width, (ii) Depth (iii) Angles of the left- and right-hand walls with the vertical, (iv) Radius of a fitted circle, (v) Length of arc of contact of that circle with the rill, and (vi) Density expressed as the number of rills in 15cms. of cross-section (Fig. 1).

Basic descriptive statistics are presented in Table 1. Width and Depth values convey the magnitude of the rills; the width: depth ratio gives a general indication of form. The angles of the left- and right-hand walls with the vertical were averaged to give a "Sharpness" index: Sharpness combined with the Width: Depth ratio describe the walls of the rills. (A ratio of 2 and a sharpness value of c.30° indicates an inverted triangular cross-section while a ratio of 2 and a sharpness value of c.10° indicates a semicircular form). Measures iv and v help to assess the degree of conformance of the rill to a semicircular form and isolate simple forms from complex ones. It has been found that, in most cases, some part of the section will conform to the circumference of a circle. If the semicircle is taken as the basic form, complexities occur when the sides of the rill are degraded (i.e. width will be high but arc length low), when several rills have coalesced and now form a single drainage channel (high width value but normal arc length) and when the rill has become overdeepened or secondary rill formation has taken place (small radius, high arc length and large depth). Figure 2 shows some of the rill cross-sections and Figure 3 shows some of the variations diagrammatically. The final measure, that of density, must be viewed in relation to the average width of the rills in that 15 cms. of section to obtain a "cover value". A low density and a high average width indicates a high cover value but a low density and a low average width indicates a low cover value. The information in Table 1 can be fully appreciated only in comparison with similar information from other areas and climates.

TABLE 1. Descriptive Statistics

	Mean	*Std. Dev.*	*Range*	*Skewness*	*Kurtosis*
Width (mms)	19.47	7.33	62	1.06	2.45
Depth (mms)	8.39	4.36	31	0.99	1.35
Sharpness (degrees)	35.49	13.07	72	0.17	-0.33
Radius (mms)	7.3	3.84	28	1.49	3.03
Arc Length (degrees)	145.07	30.13	187	-0.18	-0.27
Slope Inclination (degrees)	53.34	18.43	81	-0.65	-0.34
Density (No./15 cms)	6.95	1.45	7.9	0.1	-0.09

TABLE 2. Pearson Correlation Co-efficients

	Width	*Depth*	*Sharp*	*Radius*	*Arc. L.*	*Density*	*Slope*
Width	1	0.626	-0.135	0.571	-0.127	-0.545	0.189
Depth		1	-0.634	0.064	0.472	-0.282	0.026
Sharp			1	0.218	-0.661		
Radius				1	-0.534	-0.438	0.240
Arc L.					1	0.279	-0.158
Density						1	-0.233
Slope							1

The Pearson Correlation Co-efficient matrix (Table 2) and the scatter diagrams of selected variable combinations (Figure 4A-F) further elucidate the forms of the rills. The scatter diagrams are contoured according to the density of occurrences at each point. In order to help in the evaluation of these diagrams the positions of simple geometric shapes have been plotted where appropriate.

Figure 4A shows the width: depth relationship. Semicircles and rectangles, of W:D ratio 2, will have a W:D correlation of 1.0 and a slope of 2 on the scatter diagram. The correlation of 0.626 and the slope of 1.09 indicate that these rills correspond reasonably closely to a constant geometric form but the shallower rills tend to be relatively wide and the deeper rills narrow. This trend is confirmed by the negative sharpness:depth correlation: i.e. the form appears to change with size. On the curves in Figure 4B which show circles and inverted triangles of varying depths, points 1 and 2 mark the semicircle and a triangle of the same proportion. Shallow forms fall to the right of these points and deep forms (V or U shapes) to the left. The centre of the rill distribution falls between the two curves in the deep to medium range and veers over the circle curve in the shallow range. A picture of rill development emerges where a circle becomes incised until the width of the rill is the diameter of the circle. Coalescense of rills in early stages of development could account for the shallower V shapes and secondary rill formation for the deeper ones. The proportion of V-shaped rills is rather high. This may be a reflection of the high intensity rain since intensity is probably of greater significance to rill formation than total rainfall. It would be of interest to compare this population with one from an area of low intensity rainfall.

The radius:arc length scatter diagram isolates the V-shaped rills in the region of highest density because these tend to have low scatter along the arc length axis, i.e. arc length is always maximum – 150° to 190°. The radius value which correlates with this range is 3 to 6 mm. The width:radius scatter diagram shows the highest density in the radius range 3 to 10.5 mm: i.e. it appears that secondary rill formation involves smaller circles.

Figure 4C, with:radius scatter diagram, isolates forms which are neither circular nor triangular in cross-section. Only very shallow triangular forms will have a radius of greater than 5mm. Therefore, complex forms lie in the area to the right of the shallow triangles and above the deep circles. As may be expected, a reasonable proportion of the population is neither circular nor triangular.

Figure 4E, depth:arc length scatter diagram, gives as estimate of stage of development or maturity. The dashed lines show the positions of circles of selected radii as they deepen through time until the maximum arc length is reached. This rill population is fairly mature. Rills from a region of less intense rainfall may appear further towards the origin on this diagram.

Figure 4F examines rill density showing that most of the surface is covered, i.e. these rills do not develop isolated from one another.

It is of interest that none of the variables correlate with slope inclination. It appears that the angle of receipt of rain is irrelevant in this area.

This method of form analysis initially requires a great deal of work but, if the data is recorded on computer cards or tape, the subsequent analyses can be produced with from standard statistical programmes. It allows comparison between karren of different areas, lithologies, climatic regimes, etc. From such comparisons estimates of controls on rill formation can be made and models developed.

REMARQUES SUR LA COMPOSITION DES POPULATIONS CAVERNICOLES DE STENASELLUS VIREI DOLLFUS (CRUSTACEA ISOPODA ASELLOTA)

REMARKS ON THE COMPOSITION OF CAVERNICOLOUS POPULATIONS OF STENASELLUS VIREI (CRUSTACEA ISOPODA ASELLOTA)

Guy Magniez
Laboratoire de Biologie Animale et Générale,
Université de Dijon, 6, Bd. Gabriel,
21000 Dijon, France.

The stenasellids are anophthalmous Asellota from underground waters (phreatic karstic waters and thermal springs) of Southern Europe and North-tropical regions: Africa, Asia and Mexico. Seven genera and about 38 species are known. The lifespan of the Pyrenean species studied is very long: some 15 years, and the reproductive female intermolt lasts 12-18 months. Thus the minimum laying rhythm is biennial but, according to temperature and availability of food, the interval between successive reproductions from a single female can reach 5 years.

Therefore, the size of Stenasellid populations is very uniform over a period contrary to epigean Asellid populations which are entirely renewed each year. Moreover, the percentage of reproductive females during a single year cannot be more than 50% in the best conditions. This percentage decreases to 20% or less in some biotopes with poor temperature and food conditions.

La Famille des Stenasellidae:

Les *Stenasellidae* Dudich, 1924 représentent une famille archaique d'Aselloides, tous anophtalmes, qu'il ne faut pas confondre avec les *Asellidae*. Tous vivent dans les eaux souterraines continentales: eaux karstiques, nappes phréatiques et sources thermales. La première forme connue, *Stenasellus virei* Dollfus, 1897, a été découverte en 1896 par Armand Viré, dans la rivière souterraine de Padirac (France). Actuellement, ce groupe comprend 7 genres (Magniez, 1974a, Cvetkov, 1975): *Stenasellus* Dollfus, 1897, *car.emend.* (14 espèces en Europe méridionale, 4 en Afrique orientale et 2 en Asie), *Balkanostenasellus* Cvetkov, 1975 (2 espèces des Balkans), *Johannella* Monod, 1924 (1 espèce d'Algérie), *Magniezia* Lanza, 1966 (4 espèces d'Afrique occidentale); *Metastenasellus* Magnieg, 1966 (4 espèces de la région congolaise), *Parastenasellus* Magniez, 1966 (1 espèce d'Afrique occidentale). Le peuplement américain récemment découvert comprend déjà 4 espèces de la région mexicaine (Argano, 1973) et deux autres en cours d'étude, mais l'homogénéité du genre *Mexistenasellus* Cole et Minckley, 1972 parait douteuse.

L'espèce polytypique *Stenasellus virei*, composée de 5 sous-espèces dissociées (Magniez, 1968), est largement répandue dans les eaux souterraines du Sud-Ouest de la France et du Nord de l'Espagne. Quelques 118 stations ont déjà été décrites (Magniez, 1974b, 1975b). La sous-espèce des grottes pyrénéennes: *St. virei hussoni* a été étudiée au moyen d'élevages de longue durée (1960-74) et a fait l'objet d'une série d'observations biologiques (Magniez, 1975a, 1976a).

Allongement du Cycle Vital Des Stenaselles Cavernicoles

Les élevages et les observations de populations naturelles ont permis de noter l'existence d'un cycle vital très dilaté chez ces Stênaselles:

A. *Durée des mues:* Alors que cette durée ne dépasse pas 24 h chez les Asellides épigés, elle atteint environ 2 semaines chez les Sténaselles (13-14 jours chez les ♂ adultes, 8-16 jours chez les ♀ adultes).

B. *Duree des intermues et longevite:* Les intermues sont 10 à 20 fois plus longues que celles d'*Asellus aquaticus* , dans les mêmes conditions. Les intermues des Sténaselles adultes ♂ et ♀ atteignent 9-12 mois, ce

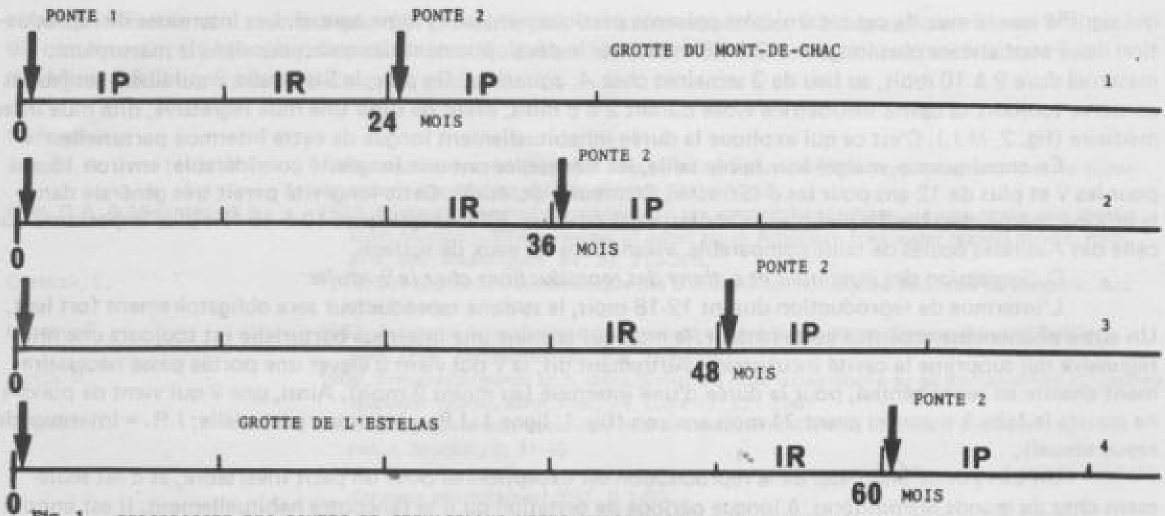


Fig. 1. PERIODICITE DES PONTES DE STENASELLUS VIREI HUSSONI SELON LES STATIONS

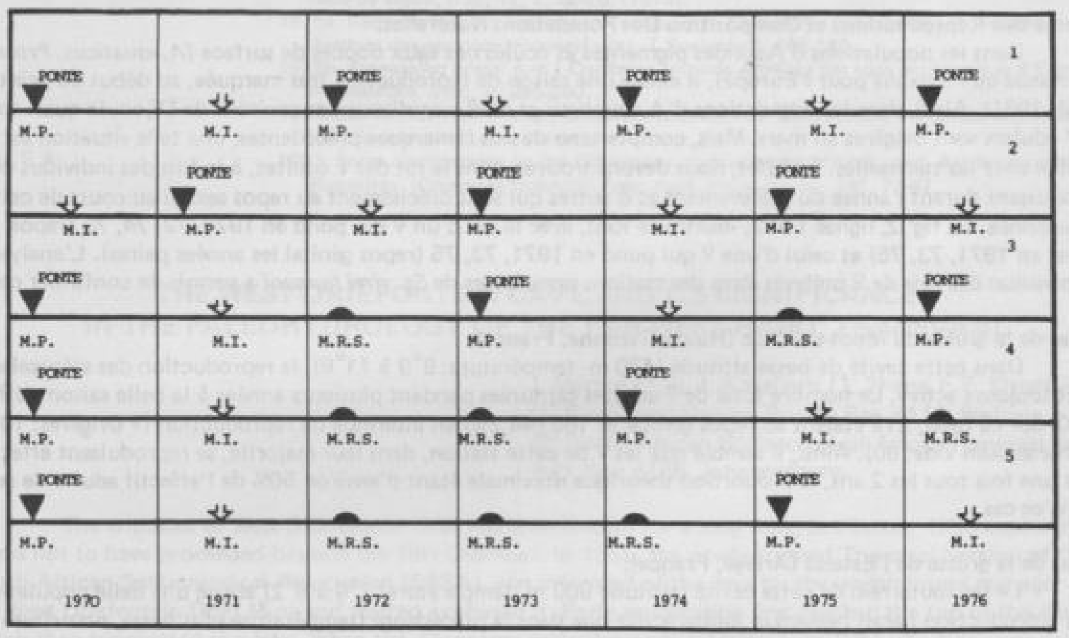


Fig. 2. ETAT GENITAL DES FEMELLES ADULTES DANS UNE POPULATION CAVERNICOLE DE STENASELLUS VIREI HUSSONI

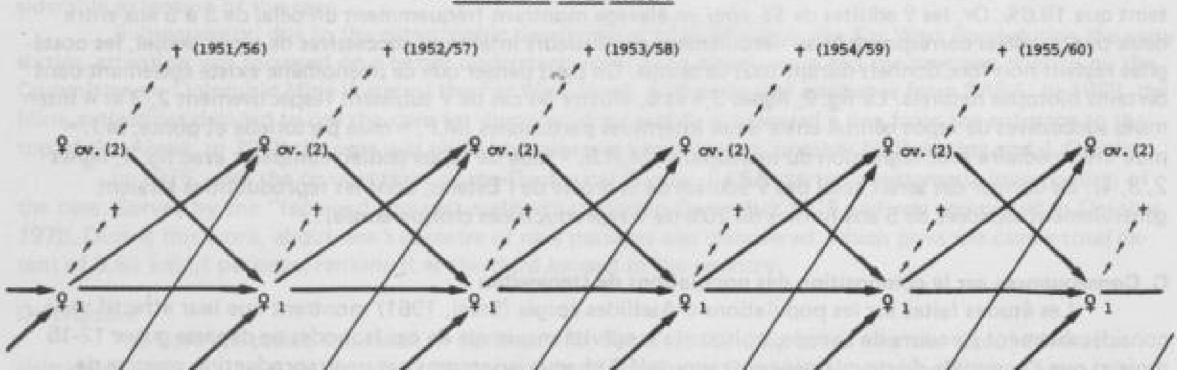


Fig. 3. RENOUVELLEMENT DU LOT DES FEMELLES ADULTES DANS UNE POPULATION CAVERNICOLE DE STENASELLUS VIREI HUSSONI

qui signifie que la mue de ces cavernicoles présente pratiquement un rythme annuel. Les intermues de reproduction des ♀ sont encore plus longues (12 à 18 mois), car le développement des embryons dans le marsupium maternel dure 9 à 10 mois, au lieu de 3 semaines chez *A. aquaticus.* De plus, le Sténaselle ♀ qui libère ses jeunes conserve toujours sa cavité incubatrice vidée durant 2 à 8 mois, avant de subir une mue régressive, dite mue intermédiaire (fig. 2, M.I.). C'est ce qui explique la durée inhabituellement longue de cette intermue parturielle.

En conséquence, malgré leur faible taille, les sténaselles ont une longévité considérable: environ 15 ans pour les ♀ et plus de 12 ans pour les ♂ (*St. virei, St. breuili, St. buili*). Cette longévité parait très générale dans le groupe, même chez des formes d'eaux souterraines chaudes. Elle est quelques 10 à 15 fois plus importante que celle des Asellides oculés de taille comparable, vivant dans les eaux de surface.

C. *Succession des intermues et rythme des reproductions chez la ♀ adulte:*

L'intermue de reproduction durant 12-18 mois, le rythme reproducteur sera obligatoirement fort lent. Un autre phénomène accentue cette lenteur: la mue qui termine une intermue parturielle est toujours une mue régressive qui supprime la cavité incubatrice. Autrement dit, la ♀ qui vient d'élever une portée passe nécessairement ensuite au repos génital, pour la durée d'une intermue (au moins 9 mois). Ainsi, une ♀ qui vient de pondre ne pourra le faire à nouveau avant 24 mois environ (fig. 1, ligne 1: I.P. = intermue parturielle; I.R. = intermue de repos sexuel).

Un tel rythme bisannuel de la reproduction est exceptionnel pour un petit Invertébré, et c'est seulement chez de grands Mammifères, à longue période de gestation qu'il se rencontre habituellement. Il est imposé aux Sténaselles par le rythme quasi annuel de leurs mues.

Rythme des Reproductions et Composition Des Populations Naturelles:

Dans les populations d'Asellides pigmentés et oculés des eaux douces de surface *(A.aquaticus, Proasellus meridianus* ou *P.coxalis* pour l'Europe), il existe une saison de reproduction très marquée, au début du printemps (Steel, 1961). Ainsi, dans les populations d'*A.aquaticus* et de *P.meridianus* des environs de Dijon, la quasi-totalité des ♀ adultes sont ovigères en mars. Mais, compte-tenu de nos remarques précédentes, une telle situation est impossible chez les sténaselles. En effet, nous devons trouver, dans le lot des ♀ adultes, à la fois des individus qui se reproduisent durant l'année du prélèvement et d'autres qui sont précisément au repos sexuel au cours de cette même année. La fig' 2, lignes 1 et 2, illustre ce font, avec le cas d'un ♀ qui pond en 1970, 72, 74, 76 (repos génital en 1971, 73, 75) et celui d'une ♀ qui pond en 1971, 73, 75 (repos génital les années paires). L'analyse de la composition des lots de ♀ prélevés dans des stations populeuses de *St. virei hussoni* a permis de confirmer ces faits.

A. Cas de la grotte du Mont-de-Chac (Haute-Garonne, France):

Dans cette cavité de basse altitude (430 m, température: 9°9 à 11°8), la reproduction des sténaselles parait toujours active. Le nombre total de ♀ adultes capturées pendant plusieurs années à la belle saison s'élève à 380. Sur ce total, 212 étaient au repos génital et 168 (44,2%) en intermue de reproduction (♀ ovigères: 108; ♀ à marsupium vide: 60). Ainsi, il semble que les ♀ de cette station, dans leur majorité, se reproduisent effectivement une fois tous les 2 ans, la proportion théorique maximale étant d'environ 50% de l'effectif adulte de sexe ♀ dans ce cas.

B. Cas de la grotte de l'Estelas (Ariège, France):

Le lac souterrain de cette cavité (altitude 900 m, temperature: 7°9 à 8°2) abrite une belle population où la reproduction parait beaucoup moins active que dans la précédente (température plus basse, nourriture moins abondante). 441 ♀ adultes ont été capturées, dont 356 au repos génital et 85 seulement en intermue de reproduction (♀ ovigères: 16; ♀ à marsupium vide: 69). Ainsi, la proportion des ♀ en intermue parturielle n'atteint que 19.6%. Or, les ♀ adultes de *St. virei* en élevage montrent fréquemment un délai de 3 à 5 ans entre deux pontes, délai correspondant au déroulement de plusieurs intermues successives de repos sexuel, les oostégites restant non-fonctionnels durant tout ce temps. On peut penser que ce phénomène existe également dans certains biotopes naturels. La fig. 2, lignes 3,4 et 5, illustre les cas de ♀ subissant respectivement 2, 3 et 4 intermues successives de repos génital entre deux intermues parturielles (M.P. = mue parturielle et ponte; M.I. = mue intermédiaire avec régression du marsupium; M.R.S. = mue de repos sexuel; comparer avec fig. 1, lignes 2, 3, 4). Le dernier cas serait celui des ♀ adultes de la grotte de l'Estelas, dont les reproductions seraient généralement espacées de 5 ans (moins de 20% de ♀ reproductrices chaque année).

C. Conséquences sur la composition des populations de stenaselles:

Les études faites sur les populations d'Asellides épigés (Steel, 1961) montrent que leur effectif varie considérablement au cours de l'année, puisque la longévité maximale de ces Isopodes ne dépasse guère 12-15 mois et que l'ensemble du peuplement est renouvelé à chaque printemps par une reproduction massive de tous les adultes ayant hiverné. Les populations naturelles de Sténaselles souterrains montrent, au contraire, une grande stabilité au cours de l'année et des années successives. En effet, ils vivent quelques 15 ans et les naissances de chaque automne ne renouvellent qu'une fraction réduite du peuplement qui se compose d'une quinzaine de générations annuelles. Les prélèvements de nombreux adultes dans les populations cavernicoles à effectif limité (Magniez, 1973) se traduisent durant plusieurs années par un déséquilibre numérique des différentes catégories d'individus, marqué par un accroissement de la représentation relative des classes jeunes, normalement réduites par l'effet de la concurrence vitale intraspécifique qui règne dans le milieu.

La phase adulte des sténaselles ♀ durant au moins 7-8 ans, la fig. 3 nous montre comment se renouvellent les ♀ de la population: par exemple, les ♀ immatures ($♀_o$) nées en 1964 (JUV. 1964) donnent en 1970-71 à la fois des $♀^1$ (♀ adultes, au repos génital, possédant des oostégites non-fonctionnels) et des ♀ ov. (♀ ovigères

acquérant directement un marsupium et pondant, puis devenant ensuite des ♀ à marsupium vide ou ♀²), tandis que meurent (†) les plus vieux individus (♀ nées en 1953-58). Les flèches continues matérialisent les différentes variations possibles du cycle génital ♀.

References

Argano, R. 1973. *Mexistenasellus magniezi* n.sp., a blind aquatic isopod from Veracruz, Mexico (Crustacea). *Accad. Naz. Lincei, Roma,* 171, 97-103.

Cole, G.A. & Minckley, W.L. 1972. Stenasellid isopod Crustaceans in the western hemisphere — a new genus and species from Mexico — With a review of other north American freshwater isopod genera. *Proc. Biol. Soc. Washington,* 84, 39, 313-326.

Cvetkov, L. 1975. Sur la position systematique des *Stenasellinae* (Crustacea Asellota) de Bulgarie. *Act. Zool. Bulgar.,* 1,9-22.

Husson, R. 1957. A propos de la biologie du Crustacé troglobie aquatique *Stenasellus virei* Dollfus. *Ann. Univ. Saraviensis, Sc.,* 6,4, 259-269.

Lanza, B. 1966. *Stenasellus pardii* sp.n. della Somalia e note sistematiche su gli *Stenasellinae* (Crustacea Isopoda). *Monit. Zool. Ital.,* 74, (*Suppl.),* 221-256.

Magniez, G. 1973. Les populations naturelles de *Stenasellus virei* Dollfus (Crustacé Asellote troglobie). *Int. J. Speleol.,* 5, 31-48.

1974a. Données faunistiques et écologiques sur les *Stenasellidae* (Crustacea Isopoda Asellota *des eaux souterraines) Ibid.,* 6,1-80.

1974b. Observations sur *Stenasellus virei* dans ses biotopes naturels. *Ibid.,* 6, 115-171.

1975b. Les stations de *Stenasellus virei* Dollfus (suite). *Sous le Plancher, Organe du Speleo-Club de Dijon, N.S.,* 12, 2, 22-26, (1973).

1976a. Remarques sur la biologie et l'écologie de *Stenasellus virei Dollfus* (Crustacea Isopoda Asellota *des eaux souterraines). Int. J. Speleol.,* 8, 135-140.

1976b. *Stenasellus bragai* n.sp., *Crustacea Isopoda Asellota* des eaux souterraines d'Espagne méridionale. *Ibid.,* 8, 285-290.

1977. *Stenasellus escolai* n.sp., Crustacea Isopoda Asellota des eaux souterraines d'Espagne méridionale. *Ibid.,* sous presse).

Steel, E.A. 1961. Some observations on the life history of *Asellus aquaticus* L. and *Asellus meridianus* Racovitza. (Crustacea Isopoda). *Proc. zool. Soc. London,* 137, 71-87.

THE WEST DRIEFONTEIN CAVE AND ITS SIGNIFICANCE IN THE PALEOHYDROLOGY OF THE FAR WEST RAND, TRANSVAAL

J. Martini (1,2), I. Kavalieris (1, 2) and F.F. Stuart (2)
(1) Geological Survey, Private Bag X112, Pretoria.
(2) South African Spelaeological Assoc. Transvaal Section, P.O. Box 6166, Johannesburg.

The entrance of West Driefontein Cave has been known for a long time, but before 1955 exploration seems not to have proceeded beyond the Rift Chamber. In 1955, the newly-formed Transvaal Section of the South African Spelaeological Association (SASA), was informed of the cave by the underground manager of the West Driefontein Gold Mine and started exploring it. Early exploration first reached the top of the Abyss, which then terminated in a lake. When the Abyss was again descended during June 1961, the floor was dried, cracked mud. Progress through the previous sump eventually interconnected with Texas-Deep Range, a considerable extension of the cave.

Subsequently, due to the catastrophic development of sinkholes in the Far West Rand during the early sixties, attention was focussed on a better understanding of karst phenomena and the cave was studied by the Committee on Dolomitic Mine Water of the Far West Rand, with technical assistance from SASA. In 1963, the Mine authorities decided to use the cave for dumping slime and first surveyed a line from the entrance to the top of the Abyss. In 1968 the cave was visited by overseas karst experts, notably M. Sweeting and J. Quinlan.

In 1975, with the co-operation of the Geological Survey, SASA started a systematic investigation of the cave. Survey by the "tape and compass method" started in December 1975 and was completed in October 1976. During this work, about one kilometre of new passages was discovered, which gives the cave a total extent of 5.65 km of passages, ranking it as the third longest in the country.

Description

The Cave is situated southeast of Carletonville, Far West Rand. It opens near the top of a hill at an altitude of 1618 m. It has developed in the upper part of the Eccles Formation, which consists of a very cherty dolomite with a few bands of chert-free dolomite not thicker than 3-4 m.

From the two entrances, the cave descends mostly vertically through a complex of inter-connecting gravity dislocation cavities. This zone of collapse leads to two large chambers, about 90 - 100 m below surface, the Workshop and the Dining Room, from which several phreatic mazes extend. From the Dining Room a long passage leads to the Cloverleaf: a large but very flat discoid chamber, developed from the dissolution of one of the chert-free horizons mentioned previously. The Cloverleaf is directly connected to a collapse cavity: the Texas and Deep Range Chambers, with combined dimensions 150 x 80 x 40 m high. From Texas, Cloverleaf and Workshop, 3 pitches lead to a lower elongated chamber called the Abyss, which was occupied by a large lake at -140m marking the water table before dewatering by pumping from the mine. From the Dining Room, a major sub-vertical crack, the Great Chasm, extends to the deepest point of the cave at - 183m. It is estimated

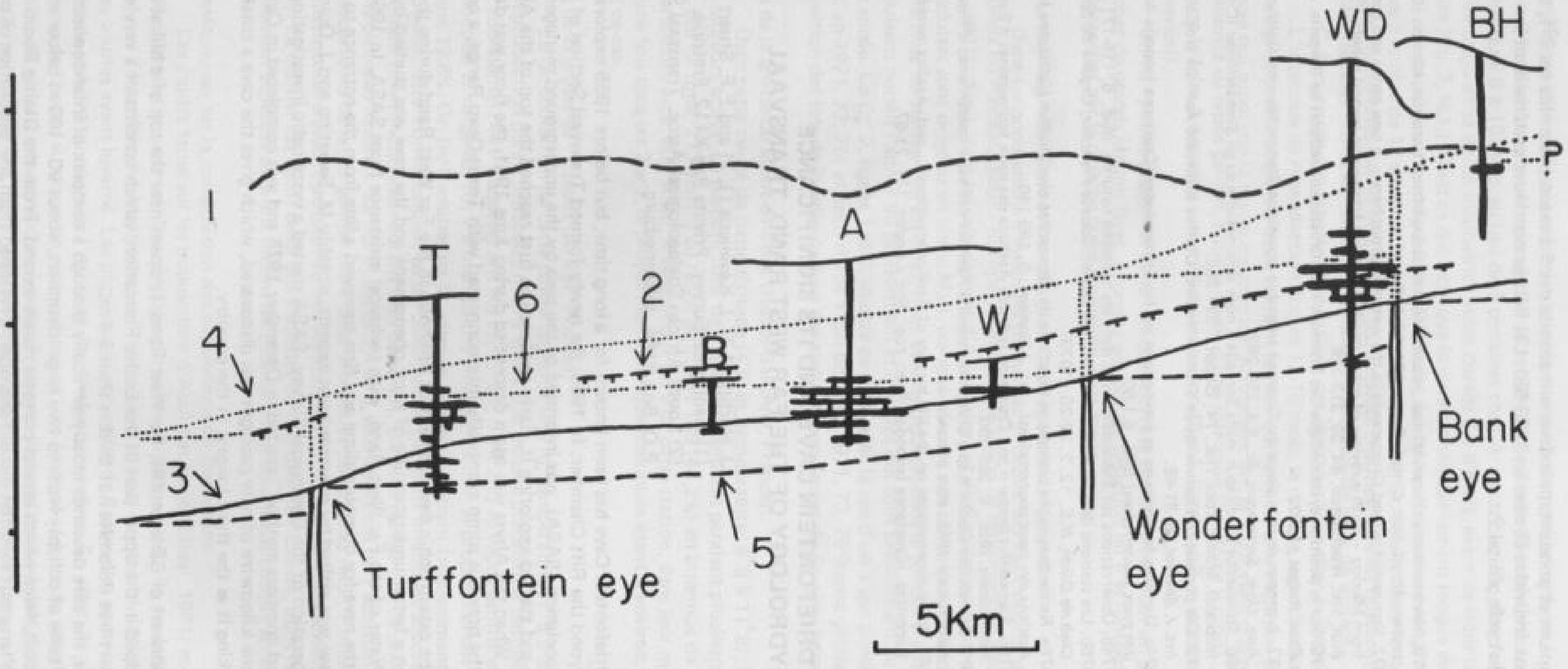


Fig. 1. Profile along the Wonderfonteinspruit Valley.

1. African Surface
2. Terrace Surface
3. Present-day thalweg.
4. Paleo water-table.

T. Turffontein Cave
B. Bobbejaan Cave.
A. Apocalypse Pothole.
W. Wonderfontein Cave.
W.D. West Driefontein Cave
B.H. Blowing Hole Cave

that about two-thirds of the cave is composed of dissolution passages and that one-third is due to collapse. From the entrances to about – 80 m, no solution passages are observed. They developed between –80 and –115 m, but are essentially concentrated close to 100 m, a value which therefore may be taken as the main cave level.

Gypsum is very abundant in many places, on the floor of the cave as a layer of a very light material up to more than one metre thick. It has been called "candy floss" by SASA members. The candy floss consists of minute gypsum needles and is particularly abundant in the Cloverleaf. According to J. Quinlan, it represents an ultimate product of bat guano decomposition, an opinion supported by the authors. In a paper dealing especially with the mineralogy of the Transvaal caves, to be published elsewhere, this idea will be discussed more fully. Strange, black stalactites, stalagmites and flowstones are presently forming in various places in the cave (see map). Some draperies reach nearly 2 m, as for instance in the Abyss. They consist essentially of a soft black manganiferous material producing no X-ray diffraction pattern and therefore may be considered to be "manganomelane". They also contain minor amounts of other minerals: evansite, apatite, crandallite. Carbonate-apatite speleothems, including attractive reddish translucent stalactites have been observed in two places.

An interesting feature is the remnant of a paleokarst channel clearly exposed in the Cloverleaf (fig. 1). The filling of this narrow channel (0.3 m in width) consists of laminated shale which can be followed in the ceiling of the flat Cloverleaf chamber for 70 m. Only the bottom of the paleochannel is visible, the top being concealed in the ceiling rock. Nevertheless, it is possible to observe, that in cross section the shale body is elongated vertically. In addition the channel exhibits a simple, slightly meandering pattern (see map). It seems to represent a vadose type channel originated by the erosive action of a small stream. Such a pattern is very rare in the present day karst of the Transvaal. The age of this feature is certainly older than Karoo. In thin section the clay minerals show an advanced stage of recrystallization, presumably as a result of the low-grade regional metamorphism that affected all the Transvaal Super-group. This recrystallisation is responsible for a certain silky lustre. The paleokarst is therefore very probably related to a break, represented by the disconformity separating the Malmani Subgroup and the Pretoria Group. Comparable karst features ranking among the oldest in the world (about 2,200 million years) have been described elsewhere (J. Martini 1976).

Evolution of the Cave

The development of the cave is complex and involves several phases:

1. Formation of a phreatic network of passages at the average depth of – 100 m below surface. This could have happened when the watertable was stationary about –80 m.
2. At an advanced stage in the development of solution passages, or when the water-table was lowered, a major pyramid of collapse developed below the present entrances (see map and horizontal sections). In fact the subsequent opening of the cave is due to this collapse. It seems that this structure was initiated in the vicinity of the –100 m level by the collapse of flat chambers similar to the Cloverleaf. That the collapse does not extend below this level is shown by the presence of unshattered dolomite in Orange Grove and in Bones passage.
3. The water-table was lowered to its recent position of –140m. There is no direct evidence of solution passages generated during this period of lowered water-table, except for the Abyss chamber. However, the indirect effect of dissolution is well exhibited in the form of 4 main collapse zones: Great Chasm, Orange Grove, Abyss and Texas-Deep Range. Collapse of the Great Chasm block obviously started at a minimum depth of 43 m below the water-table. This depth, though in the range for cavity formation, is certainly greater than the optimum cave development. In the geologic context of the Far West Rand the possibility of a much deeper water-table in the past seems to be excluded.
4. After gold mining started in the fifties, human activity introduced some important modifications. In 1958 the water-table was lowered to a great depth by pumping. Tremors generated by rock bursts after stopping of ore are apparently responsible for recent collapses of the ceiling. A major collapse occurred between 1973 and 1975 in the western part of Texas, and in the southern ceiling of the Abyss chamber.

General Evolution of the Far West Rand Karst

The West Driefontein Cave, when considered together with other large cave systems on the Far West Rand, is of special interest for the understanding of karst evolution in general.

This evolution could be as follows:

1. An hypothetic older karst period may be linked to the African Surface peneplanation (King 1963) the age of which is not known in this area but is assumed to be Tertiary (Du Toit, 1951). This surface is mainly developed immediately to the north of the area considered as a slightly undulating dolomite plateau at an average altitude of 1550-1570 m. This value is however less than the true elevation of the African peneplain. This is evident if one considers the diamondiferous gravel trails resting on this plateau. They represent old river beds which have lost their thalweg profile as they are observed to run up and down hill. A certain thickness of dolomite must have therefore been irregularly dissolved and the peneplain may in fact have been close to 1600 m. As it is likely that the water-table was not deep below the latter elevation, and if it is assumed that the main cave development occurred immediately below the water-table, it is clear that a great part of the phreatic network must have disappeared. In fact, on the Far West Rand, all the large cave systems are too low in altitude to be related to the African surface. This is contary to what is generally accepted by previous authors. (Brink, et. al. 1965).

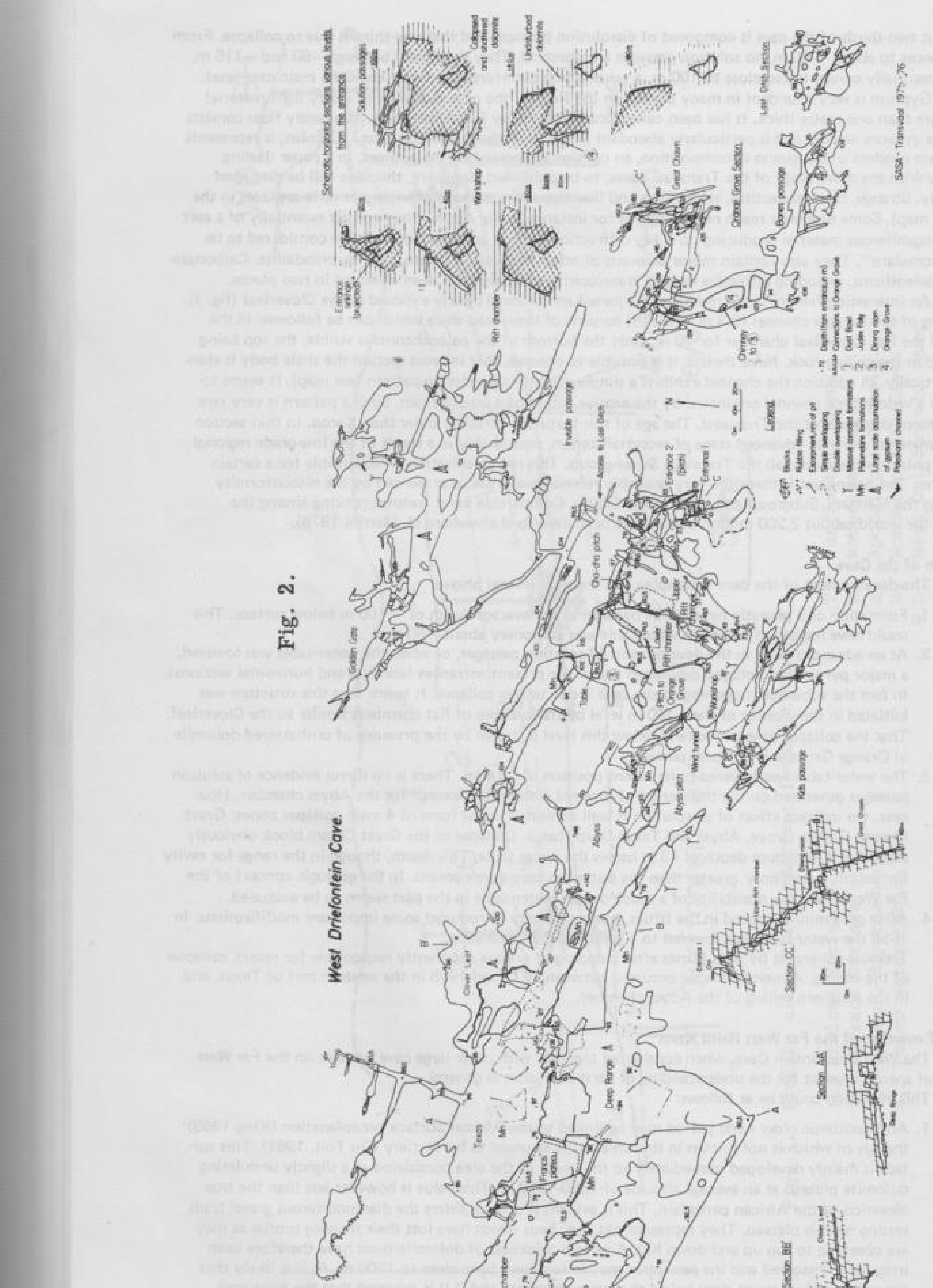


Fig. 2. West Driefontein Cave.

2. After the incision of the African Surface by the Post-African erosion Cycle, it seems that no significant caves developed until the river incision reached a position a few ten metres above the present thalweg (see fig. 2). It is presumed that the surface karst morphology was similar to the present, that is, poorly developed (J. Martini et. al. 1976).
In the Turffontein compartment, the phreatic cave networks are developed at a fairly constant level and indicate therefore the position of the former water-table. By extrapolation it is possible to know the approximate elevation of the paleo-eye. It could have been 40 or 50 m higher, depending on whether the maximum cave development or the highest part of the phreatic network is considered. West Driefontein Cave is situated in the Oberholzer compartment, having discharged its water at the Wonderfontein eye, and its paleophreatic level is about 50 m above the caves of the Turffontein compartment.

Similarly, it is possible to assess the elevation of the paleo-eye of Wonderfontein above the present eye; 45 m in this case. The position of the paleo-eye of the Bank compartment can be inferred very approximately as the only deep cave in this compartment, the Blowing Hole, exhibits only a very poor development of phreatic passages. As it seems reasonable to assume that these caves developed simultaneously the contemporaneous thalweg may be reconstructed (see fig. 2).

If one assumes, that when the caves formed, the thalweg was stationary, a correlatable surface morphology should be detectable. The only erosion surface which can be detected and which would not be too controversial, is a 10 to 20 m terrace (see fig. 2) above the Wonderfontein Spruit. There seems to be a relationship between the terrace and the paleo-eye of Turffontein, however, the paleo-eye of Wonderfontein seems to have been higher than the terrace. Therefore, although it is evident that the major caves have developed at step-like levels, controlled by the height of the paleo-eyes of each compartment, the reason why they formed only when the thalweg was lowered to a specific position at a certain time is not clear.

Nevertheless, this example of the Far West Rand demonstrates that cave development is not necessarily related to well-peneplaned surfaces which can be traced over long distances at relatively constant altitude, as has been advocated by some authors (Marker et. al. 1969).

Acknowledgements

We would like to thank the management of West Driefontein Gold Mind who allowed us to study the cave, gave us access to their information and provided us with facilities. Mr. J.R. Vegter of the Geological Survey edited the manuscript critically.

References

Brink, A.B.A. & Partridge, T.C. 1965. Transvaal Karst: some consideration of development and morphology, with special reference to sinkholes and subsidences on the Far West Rand. *South African Geogr. J.* 47, 11-34.

Du Toit, A.L. 1951. *The Diamondiferous Gravels of Lichtenburg.* Geol. Surv. South Africa, Mem, 44, 35 p.

King, L.C. 1963. *South African Scenery,* 3rd ed. (revised) Oliver Boyd Edinburgh & London, 308 p.

Marker, M.E. & Moon B.P. 1969. Cave Levels and Erosion Surfaces in the Transvaal, South Africa. *S.A. Geogr. J.* 51, 106-113.

Martini, J. 1976. The Fluorite Deposits in the Dolomite Series of the Marico District, Transvaal, South Africa. *Economic Geology,* 71, 625-635.

Martini, J. & Kavalieris, I. 1976. The Karst of the Transvaal. *Int. J. Speleol.* 8.

APERCU SUR LES "SPELEO-SECOURS" NATIONAUX, EN BELGIQUE ET DANS LE MONDE

A de Martynoff
Ave Ovan Goldstroven 45
B-1180 Brussels
Belgium

Il y a 25 ans:

En France: le 16 Aout 1952, — Marcel Loubens mourait après une agonie de 36 heures, au fond de la grotte "Pierre-Saint-Martin".

En Suisse: le même jour, le professeur Boglie, pénétrait dans le "Holl-Loch" et ne ressortait que 10 jours plus tard, sain et sauf grace à son sang-froid, avec ses 3 coéquipiers, sauvés d'une violente crue subite qui les a bloqués.

En Belgique: la Radio et les journaux nous apprenaient ces accidents quasi simultanés, nous troublaient profondement et nous faisaient réfléchir: si des accidents pareils survenaient encore — ce qui est fort probable, que fallait il faire? — Comment pouvoir organiser les équipes existantes pour que le S.O.S. les touche le plus rapidement possible pour intervenir éfficacement? — A quel organisme officiel demander de l'aide ? ? ?

C'est pourquoi, le 19 octobre de la même année, lors d'une Réunion Nationale des clubs spéléologie belges; la question fut pasée: Puisque la Spéléologie prend un essor considérable, ne serait-il pas bon d'organiser une équipe *nationale*, prête jour et nuit à intervenir si un accident survenait? La réponse fut positive.

C'est ainsi que l'idée dun organisme national de secours spéléologique permanent est née et que j'ai

eu l'honneur d'être chargé de resoudre ce problème difficile.

Etions nous les premiers en Belgique à se pencher sur ce problème et d'en chercher la solution? Sincèrement je ne le crois pas, par exemple: nos amis britanniques qui avaient déja des équipes de sauvetage depuis 1937, si je ne me trompe, mais dispersées, — et que nos collègues francais traumatisés par l'accident tragique survenu à Marcel Loubens étudiaient aussi les possibilités de sauvetage organisé.

Si nous avons réussi à créer le premier "Spéléo-Secours" national, nous avons eu — si l'on peut dire, la chance de vivre dans un petit pays où les distances et les accès des grottes ne posaient aucune difficulté. Néanmoins, malgré ces avantages, tout était à étudier et à créer. Il faut se placer dans l'atmosphère de l'époque pour comprendre les obstacles qu'il fallait vaincre. Quand nous avons pris la décision d'organiser un "Spéléo-Secours" Valable, nous n'avions aucun exemple que nous pouvions prendre comme base. Les contacts entre nos collègues étrangers étaient presque inexistant. En plus nous passions pour des fantaisistes, — la spéléologie sportive étant fort peu éstimée tant par les "scientifiques" que par les organismes publiques. Nous étions, comme le signalait Pierre Minvielle dans son livre "La Conquete Souterraine", — " . . . les fous d'aventure et de rêves" ! De ce fait nos démarches auprès des organisations officielles et des Ministères s'avéraient décevantes: — on nous renvoyait d'une adresse à l'autre comme une balle de Ping-Pong. Or, que fallait-il obtenir en premier lieu, ayant déja un groupe de spéléologues chevronnés et de bonne volonté? Tout d'abord une centrale téléphonique fonctionnant jour et nuit, qui accepterait de lancer les appels aux responsables de l'équipe de secours, selon une liste préparée d'avance.

En belgique nous avons pu être agréés par la Croix Rouge qui a mis à notre disposition sa Centrale téléphonique des appels aux ambulances.

Ceci, enfin obtenu, que fallait-il faire?

1 — Trier parmi les spéléologues du pays et d'écarter ceux qui venaient à nous par curiosité ou par gloriole;

2 — Rechercher parmi les civières existantes celle qui convenait le mieux à nos grottes étroites et amasser (our créer) le materiel nécessaire.

3 — Former les spéléologues-secouristes, tous volontaires et bénévoles, en leur faisant passer les concours théoriques et pratiques et les obligeants à participer sous peine de renvois, aux entrainements qui se faisaient tous les 2 ou 3 mois, chaque fois dans une grotte différente. Ceci pour habituer nos compagnons à toutes les difficultés qu'on pouvait rencontrer chez nous.

4 — De repartir les équipiers, domiciliés dans différents endroits du pays, en trois puis quatre "G.P.I." (Groupes Première Intervention), choisir leurs chefs responsables et déterminer leurs rayons d'action.

5 — De préparer un règlement.

C'est ainsi que petit à petit s'est créé le premier Spéléo-Secours national.

10 Ans Apres:

Dix ans ont passés et notre organisation a pris sa forme définitive. Plusieurs incidents et malheureusement des accidents, ont rodés nos équipes, nous ont fait connaître. En plus de la Croix Rouge, notre première alliée, la Protection Civile a accepté de nous seconder par leur imposant materiel, et le Ministère de l'Intérieur a donné les instructions pour que les appels de secours nous soient transmis par le poste téléphonique No. 900 (numéro d'appel unique en Belgique pour tous les accidents tels que les incendies, innondations, accidents de route . . .)

Libérés des sourcis d'organisations, nous nous sommes demandés: — mais qu'est-ce qui passe ailleurs? — Ne pouvons nous pas apprendre du nouveau et aussi de montrer à nos confrères des autres pays ce que nous avons réalisé? C'est ainsi que j'ai pris le risque de concevoir le projet d'une Réunion Internationale sur le sauvetage.

Le temps ne me permet pas de vous donner les détails de ce premier Symposium. Je vous signalerais rapidement que grâce à la collaboration éfficace d'Alain Leroy, d'André Slagmolen de Dimitry de Martynoff et d'autre confrères, nous avons eu le plaisir et la joie d'accueillir 7 pays (France, Grande Bretagne, Liban, Luxembourg, Italie, Roumanie et la Suisse), représentés par plus de 40 participants — non compris la Belgique.

Si je vous parle, de cette réunion, c'est qu'a cette occasion, un des participant, — a cette époque, Secrétaire Général de notre UIS, — le professeur Albert Anavy a suggéré de créer une Commission Internationale de Secours dépendante de notre Union. C'est donc grace à lui que nous nous retrouvons ici ensemble.

Et Maintenant

où en sommes nous?

Je ne vous cache pas que c'est avec plaisir que je cesse de parler de la Belgique, — chose que je devais faire si je voulais vous narrer le processus historique des Spéléo-Secours Nationaux, — car heureusement bien d'autres pays ont actuellement d'excellentes organisations de secours spéléologique et elle n'est plus seule, un exemple à suivre.

17 pays sur 30 ont voulu me signaler qu'ils ont ou sont en train de créer les "Spéléo-Secours" nationaux. Il faut les féliciter, car comme j'ai signalé au début de mon exposé, si nous avons réussi assez rapidement, nous devions beaucoup à la petitesse de la Belgique. Prenons comme exemples l'Australie, l'URSS et la Nouvelle Zelande: pour le deux premiers — ce sont des immences distances qui gènent le déroulement rapide des secours, pour l'autre — les distances sont peut-être moindres — mais ce sont les brousses qu'il faut traverser.

Dans d'autres pays, comme en Suisse, une structure politique (24 Etats fédérés) peut rendre difficile

une rapide uniformisation d'un Spéléo-Secours, et aussi les montagnes qui créent les grandes difficultés d'organisation de sauvetages, obligeant à des transports difficiles et pénibles du materiel.

Actuellement, sur la base des données en possession de notre Commission, les pays qui possèdent un Spéléo-Secours national, sont les suivants:

a) *Les Speleo-Secours bien organises:*

Autriche
Belgique
Bulgarie
France
Grande Bretagne
Hongrie
Italie
Pologne
Yougoslavie

b) *Spéléo-Secours organises:*

Afrique du Sud
Australie
Nouvelle Zelande
Suisse
U.R.S.S.

c) *Les Spéléo-Secours en voie d'organisation:*

Canada
Etats Unis D'Amerique
Grece

Je signale immédiatement que cette subdivision est très aléatoire. La Commission ne recoit pas toujours des renseignements souhaités. Prenons comme exemple la Nouvelle Zélande: les indications sur son organisation des équipes de sauvetage, dates de 1971! De l'U.R.S.S. nous n'avons eu que des renseignements fragmentaires datant de 1973; or nous avons recu des brochures sur l'organisation des écoles spéléologique de première valeur. Et l'Espagne qui ne se trouve pas sur notre liste? Il serait pourtant surprenant qu'elle ne possède pas un Spéléo-Secours national.

Nous avons voulu d'éditer une brochure sur les Spéléo-Secours et nous vous avons adressé une demande de renseignements, en espérant de pouvoir les reproduire. Les réponses — nous n'avons recu que 3 documents C'est peu. . .

Nous vous demandons, dans l'intérêt de tous, votre collaboration continuelle, — des renseignements et des conseils sont toujours les bienvenus, pour nous permettre d'être et de continuer d' être, toujours éfficaces.

TOURISME SPELEOLOGIQUE EN BELGIQUE

Alexis de Martynoff
45 Av Ovan Goldstnoven,
Brussels, Belgium.

Je voudrais vous signaler l'immense avantage que nous avons et aussi pour ceux qui voudront visiter notre petit pays, — c'est la grande facilité d'accès de nos grottes. Elles se trouvent aux bords des excellentes routes dans, ou à coté des villes et villages et se nichent dans une région fortement vallonnée, boisée et belle. La Belgique n'a qu'une superficie de 30.510 km^2, la frontière francaise n'est distante par l'autostrade, de la frontière allemande, que de 200 km. environ et que du bord de la mer du Nord au Grand Duché de Luxembourg, il n'y a que c. 300 km. Ainsi vous pourriez le voir en peu de temps — à moins que vos arrêts ne se prolongent.

Le Commissariat Général au Tourisme de Belgique, qui tout en laissant une entière liberté aux initiatives privées, souhaitait depuis longtemps que les dirigeants et propriétaires des grottes aménagées s'entendent pour harmoniser leurs activités. La crainte que le plus fort prenne sa part de lion, a longtemps empêché la réalisation de ce voeu. C'est tout récemment seulement que 9 d'entre eux, les plus importants il faut le dire, qui exploitent 10 grottes et un musée du monde souterrain, se sont heureusement décidés de créer une "ASSOCIATION BELGE DES GROTTES ET CAVERNES A INTERET TOURISTIQUE ET EDUCATIF" (en abrégé A.G.E.C.I.T.), afin de pouvoir se réunir et de collaborer ensemble pour coordonner leur activité, leur propagande, les moyens d'action et d'étudier les aménagements.

Pour alimenter la caisse de l'association, une participation financière est versée par les associés, proportionnellement au nombre annuel des visiteurs.

Je citerais, par ordre alphabétique, les grottes et les cavernes qui font partie de ce groupement:

— Comblain au Pont (province de Liège) — abîme et grottes
— Floreffe (province de Namur) — grottes
— Goyet (province de Namur) — grottes préhistoriques
— Han (province de Namur) — grottes, navigation souterraine
— Merveilleuse (province de Namur) — grottes
— Mille et une nuit (prov. de Luxembourg) — grottes
— Neptune (prov. de Namur) — grottes, navigation souterraine
— Pont D'Arcole (prov. de Namur) — grottes
— Remouchamps (prov. de Liège) — grottes, navigation souterraine
— Rochefort (prov. de Namur) — grottes abîme.
ainsi que le musée "DU MONDE SOUTERRAIN" de Han.

Signalons également que le rôle du Commissariat Général au Tourisme, ne se confine pas seulement à promouvoir. Il lutte pour la défense de l'environnement, tâche combien difficile en Belgique, — aide à l'installation des "syndicats d'initiative", publie; imprime et distribue les affiches, dépliants, programmes des manifestations, subside les activités valables dans le domaine du tourisme, etc.

Mais la Belgique spéléologique n'est pas que celà. Elle contient aussi dans sa petite superficie karstique de C. 130 km. de long sur c. 50 km de large, très rarement dénudée, environ 2.000 grottes, aménagées ou non, cavités et abris sous roche, dont les plus importante ont été topographiés. Nous ne trouverons pas des abîmes profonds et des galeries immenses. Mais pour l'exploration des grottes non amenagées, les 3 fédérations spéléologiques belges ne demanderont pas mieux que de vous faciliter la visite.

Disons aussi, que les musées belges possèdent de très belles collections géologiques, minéralogiques, biologiques, des fouilles préhistoriques, etc. (comme par exemple, — les célèbres iguanodons de Bernissart).

Mais quel avantage retire la population belge du mouvement touristique?

Pour le connaître le Commissariat Général au Tourisme a fait une étude sur l'évolution de deux entités touristiques belges, dont une nous intéresse particulèrement, car sa seule activité est l'exploitation commerciale d'une grotte aménagée; il s'agit de la commune de Han-Sur-Lesse.

Cette étude a permis de comparer cette localité touristique à ses 3 voisines qui se trouvent à quelques kilomètres seulement, dans des sites similaires et ne possédant aucun établissement industriel.

Il a été constaté que:

1° — la population de Han, malgré le faible taux de natalité en Belgique wallonne, a augmenté de 200,9% en 134 années, tandis que les trois autres villages ont augmenté de 106,6%, 119,5% et de 123,8%.

2° — le produit intérieur brut par habitant (en F. belges): pour Han-sur-Lesse 42.000 — et pour les autres localités: 36.000, — 36.200, — et 37.200 Fb.

3° — l'indice de la population active en 1961 (1947) = 100%) pour Han 114%; pour les autres 52%, 76%, et 98%.

4° — la proportion de voirtues privées qui était en 1966 de 10/77 habitants dans la province, était de 10/47 à Han; celle des téléviseurs était de 10/86 dans la province, contre 10/46 à Han.

Il resort clairemont de ses comparisons dit Mr A. Haulot, dans son importante étude "TOURISME ET ENVIRONNEMENT" — la recherche d'un équilibre —", que le mouvement touristique, seule industrie de la commune "a apporté à Han-sur-Lesse un regain de prospérité que" autres communes rurales n'ont pas trouvé dans leurs "activités traditionnelles".

Quelques mots encore sur le sujet qui nous préoccupe tous: la protection de nos sites et cavernes.

En Belgique le problème est complexe et difficile à résoudre. La petite superficie et la surpopulation ne permettent pas de créer des grandes reserves naturel les ni des importants parcs nationaux. Les carrières rongent les falaises le long de la Meuse et creusent le sol de l'Ardennes. Déjà quelques petites grottes et sites préhistoriques ont disparus, dont la grotte " Aux Chandelles" qui était très joliment concrétionée. Actuellement les Grottes de Hotton "Mille et une Nuits" de Ramioul et de Rosée, pour ne citer que les plus belles sont menacées par l'avancement des travaux des carrières. Malgré les efforts du Commissariat Général au Tourisme les dirigeants de ces carrières refusent d'abandonner l'exploitation en arguant leurs droits de propriétaires du sol et la menace de la mise au chômage du nombreux personnel.

Un autre danger c'est le vandalisme de certains que je ne voudrais pas appeler des "spéléologues" qui profitant des facilités des accès, massacrent des concrétions et les emportent soit pour les garder commedes souvenirs, soit pour les vendre.

Les Fédérations Spéléologiques essaient de règlementer les accès de certaines cavités et ont créé une Commission Nationale de Protection des Sites Spéléologiques (Interfédérale).

Ces efforts ne sont pas toujours couronnés de succès mais sont dignes d'éloges.

Mais il faut avouer que la vraie sauvegarde de nos "trous" est surtout due aux dirigeants de nos grottes et cavernes aménagées qui tout en accordant parcimonieusement l'accès et les travaux de recherches sur leurs terrains aux spéléologues surveillent efficacement leurs sites.

Certes, ce ne sont plus les sites sauvages et exaltants que nous avons pu voir jadis à la lumière de nos lampes frontales mais au moins leur intégrité est sauvegardée.

Bibliographie Sommaire:

Atlas Des Grottes de Belgique: vol. No. 1,2 et 3. Edit: Institut Royal des Sciences Naturelles de Belgique. vol No. 4 et 5 Edit. Setek, route des Canons, 20 B — 5000 Namur.

C.G.T. (Commissariat Général au Tourisme) — Le Tourisme belge. Rapports annuels. Edit. C.G.T. 1000 Bruxelles.
Conseil de L'Europe: Charte européenne des sols. Strasbourg, 1972.
Conseil de L'Europe: Charte européenne de l'eau. Strasbourg, 1968.
de Martynoff Al. Les Grottes touristiquees Belgique. Edit. Actes du IV° C.I.S. Ljubljana 1971.
de Martynoff Al. Le Karst belge. Edit. C.G.T. 1971.
de Martynoff Anne et Lambert F. La Belgique souterraine. Guide Vokaer. Bruxelles B-1180. 1977.
Equerre (Group I') Le tourisme, facteur de dévelopement économique et social: — Le cas de Han-sur-Lesse, Belgique, Liège 1967.
Haulot Ar. Tourisme et environnement — la recherche d'un équilibre. Edit. Marabout "Monde Moderne" B-4800 Verviers (Belgique) 1974.

A NATIONAL CAVE RECORDING SYSTEM

Peter G. Matthews
66 Frogmore Crescent
Park Orchards,
Victoria 3114, Australia

Background

Recognising that speleology, amateur as well as scientific, depended on reliable and accessible cave information, the Australian Speleological Federation (ASF) resolved in 1964 to publish an ordered summary of all then known caves in Australia and Papua New Guinea. On the understanding that no detailed locations would be published and that circulation would be restricted to bona fide cavers and researchers, societies and individuals right across the country co-operated: information was extracted from society newsletters, bottom drawers, cartons under beds, and from cranial recesses, so that in 1968 ASF was able to publish *Speleo Handbook* with information on about 1700 caves. It was a notable success, and your own organisation probably has an 'exchange' copy.

But probably the most significant result was a widespread awakening to how little we knew about our caves and to the importance of systematic record keeping. So in 1970 ASF set out to design a system to make it easy for cavers to record their observations on trips and for this data to be collated in a uniform manner throughout Australia. The system is now starting to operate and at present we have data on over 4000 caves and over 1200 maps.

The design of the system has been aided by discussions with many people from Australia, Europe and the USA, and their assistance is gratefully acknowledged. The development cost has been aided by a grant from the Australian Heritage Commission. The continuing operation of the system is made possible by the unstinting co-operation of societies and cavers throughout Australia.

Description

The system caters for the following basic needs:

1. Unique identification of caves and cave maps.
2. Gathering raw data.
3. Summarizing the data.
4. Making it accessible.
5. Updating.

Identification

Every cave is identified by a number, unique nationally but allocated by the local society. (Of course many caves get named as well, but names are inadequate for unique identification). The number is discreetly marked at the cave entrance, usually on a small metal plate or plug. Clear physical identification is essential for accurate collation of data from multiple sources. Fortunately it has been Australian practice since the 1950s to number caves.

Example: 3B-10	3	B	10
	State postcode	State-agreed area code	10th cave in area

Usually abbreviated to B-10 locally.

Gathering Three field forms have been designed for cavers:

Cave Report
Sketch Sheet
Trip Report

They are issued as pads in a returnable kit at meetings or store. The forms are very easy to fill in and prompt the caver (1) to record observations and (2) what he could write about. The idea is to remove as many obstacles as possible from recording observations. The emphasis is on the Cave Report, which forces one cave per sheet, to permit immediate filing under cave number with no processing needed.

Summarizing Three summary forms have been designed for society record keepers:

Cave Summary
Area Summary
Map Summary

Each Cave Summary deals with one cave and contains predominantly lists of coded choices under various headings as listed in Table 1. It is designed for direct punching into a computer. The form is A3 folded to A4 size to make a folder in which Cave Reports and other documents, including those not catered for on the summary, can be filed.

In addition to the society copy of a summary, there is also a national copy. This is normally held by a State coordinator if one exists, and may summarise results from more than society. This is the copy used to update the national register.

TABLE 1. List of available subject headings under which cave data can at present be stored in data base. Most headings have a numbered set of preselected answers from which to choose.

1.	Ident. No.	18.	Latitude (to 5')	35.	Most compreh. map
2.	What, if not cave	19.	Longitude (5')	36.	How entre.marked
3.	Name(s)	20.	Topo sheet name	37.	Air temp range
4.	Cave type	21.	Grid ref to 10km	38.	Humidity range
5.	Rock type	22.	Nearest locality	39.	Moisture level
6.	Cross references	23.	Entrance elev.	40.	Discoverer
7.	Qty of entrances	24.	Hazards	41.	Date discovered
8.	UIS entr. type	25.	Difficulties	42.	Extension disc.
9.	Devel/descr. keys	26.	Degree explored	43.	Contents
10.	Decoration	27.	Prospects	44.	Species found
11.	Length	28.	Owner type	45.	Importances
12.	Length accuracy	29.	Cave use	46.	Comments
13.	Vertical range	30.	Surface use	47.	Bibliography
14.	Vert. accuracy	31.	Damage	48.	Data by, date
15.	Max chamber size	32.	Cave protection	49.	Items above not to be printed.
16.	Pitch lengths	33.	Controller		
17.	Average slope	34.	Percent mapped		

Making Accessible The data is made accessible beyond the society which gathered it by two methods:

1. By publishing it nationally as the *Australian Karst Index*.
2. By storing the cave data in a computer data base with national (and international) accessibility.

The published index contains basically the following:

1. Integrated area and cave summaries similar in presentation to those in the original *Speleo Handbook*. Locations are given only to the nearest 10 Km grid square.
2. Map summaries.
3. Related bibliography.

The cave data base is with an international time-sharing company, which makes it personnel-independent and enables it to be accessed by ASF-authorized users from any dial-up terminal, or Telex machine. It is therefore within the reach of cavers as well as institutions. It is now very easy for example, to do the following:

1. Cheaply and quickly select all caves having any required combination of attributes. This can aid conservation planning, national park management, or selection of likely caves for further study in some particular science.
2. Obtain pre-publication information on any particular cave(s).
3. Obtain statistics on the quantity and type of data coming in to help plan future development of the recording system.
4. Tabulate which caves are lacking in what kimd of data to readily indicate where future effort should lie.

Updating At update time the national copies of all summary forms are recalled from the States. By a special marking method it is very easy to see what items have been changed since last time, and only these need to be punched.

To remain useful the published karst index must also be regularly updated. It was to make this possible year after year that the computer was introduced: it cuts the volunteer man-hours needed down to a

continuously sustainable level, as follows: The karst index is phototypeset, i.e. the text is stored on magnetic tape and typeset photo-optically, which means that only the changes have to be considered each time. However, whereas the area and map summaries and bibliography are updated by running the editing tape containing these changes against the previous taped version, the tape for cave data is produced anew each time directly by the data base computer. It converts the stored code numbers into a series of readable English statements for each cave, and outputs them to the typesetting tape. Proper typeface is used to enable considerable size reduction while still retaining legibility.

Conclusion

The provision of comprehensive basic data about caves is obviously of immediate use for normal caving pursuits. But it goes further than that: it is one very definite way the amateur caver can contribute to the advancement of scientific speleology. The scientist with foresight will respond by making the effort to train cavers in basic observation related to his particular science.

Like any such system, a cave recording system must confront the realities of human behaviour. Forms are used to prompt cavers to write, and the forms themselves prompt what to write about. Societies need to maintain an atmosphere that recording is the "with it" thing to do. The system should not become unworkable when society record keepers don't keep up to the job. In general, detailed cave locations should not leave the local society; they are then still in control of the situation and can more easily co-operate. A spirit of mutual co-operation is most important.

The programmes have been designed to be readily usable by other organisations. For example it is very easy to change the predetermined choices and/or spoken language used in typesetting the cave data. It is intended to publish an operating manual for the complete system.

In view of the growing interest in cave data bases in several countries, and the new ease and economy of international access to data bases, it would appear opportune for UIS to investigate and recommend whether and to what extent national or other cave data bases should be compatible to facilitate international searches and analyses.

HYDROGEOLOGY OF THE KARSTS OF THE U.S.S.R.

G.A. Maximovich
Director of All-Union Karstology and Speleology
Institute, Perm University U.S.S.R.

Here with a short description of the USSR carbonate karst waters is provided [1,2].

In the USSR limestone, dolomite and marble karst aquifers waters are widespread. Chalk fracture-karst aquifers also play a role in the platform sedimentary cover.

Karst aquifers are found throughout the geological record from PreCambrian to Neogene. In artesian and hydrogeological folded regions of the USSR they are distributed in the following way.

Pre-Cambrian aquifers of the metamorphosed carbonate series are known to be in the hydrogeological folded areas of the Sayano-Eniseysky, Baikalsky, Uralsky, Tyan-Shansky, Altaisky, Khingano-Bureinsky and Karpatsky regions. They are of less importance in the Ukrainian folded region and practically of no importance in the Baltiysky region.

Paleozoic karst waters, especially Devonian and Carboniferous, predominate in the USSR.

Mezozoic karst aquifers are less extensive. In the East-European artesian region they occur in the chalk. In the Caspian-Chernomorsky and Aralo-Caspian regions Jurassic and Cretaceous deposits are aquifers. Jurassic and Cretaceous carbonate deposits of the Karpatsky, Krimsky, Kopetdagsky, Yuzhno-Tadjiksky folded regions and the Fergansky median artesian basin also contain karst waters.

In the USSR, Triassic carbonate deposits are restricted, their karst waters are only known to be in the Kavkazsky and Pamirsky folded regions.

Paleogene carbonate aquifers occur in the Dagestansky artesian basin, Kavkazsky and Yuzhno-Tadjiksky folded regions and Fergansky artesian basin.

Neogene limestones of low thickness, and weakly karstified, contain small amounts of water in the Caspian-Chernomorsky, Aralo-Caspian artesian regions and Kerchensko-Tamansky and Kopetdagsky folded regions.

Thus, in the USSR predominant karst waters occur in Paleozoic deposits. Waters of the Neogene and Triassic deposits are of least importance.

The artesian karst basins of the USSR belong to three belts: arctic, boreal and mediterranean. The Pechorsky and Khatangsky artesian regions belong to the arctic circumpolar belt. The boreal belt of artesian basins is presented by the East-European and East-Siberian artesian regions. The Caspian-Chernomorsky and Aralo-Caspian artesian regions belong to the mediterranean belt of artesian basins.

Each belt has certain common features.

The arctic belt in the USSR is presented by two open artesian regions, Pechorsky and Khatangsky which are poorly researched hydrogeologically, especially the latter. They are in a frozen zone. Cryogenesis creates unique conditions. In the Khatangsky region under the frozen zone there is a zone of saline waters in liquid phase at sub-zero temperatures.

The boreal belt artesian basins are characterized by large extent and substantial amounts of low temperature fresh waters. The temperature increases with depth; geologically saline waters and brines may be hot.

The mediterranean belt is characterized by numerous artesian basins which are smaller than those in the boreal belt. The thickness and extent of the fresh water zone in arid provinces is also smaller. Closed basins with widely-spread Mesozoic and Cenozoic water-bearing horizons predominate here. Cenozoic carbonate deposits are thin. In the near-surface water-bearing horizons temperature is higher than in the boreal belt.

Non-artesian karst basins and platform or folded sedimentary regions are not investigated well yet. In the recharge area on the periphery of the platform, monoclinal karst basins are widespread, and anticlinal basins are also widespread. The Ufimskoye plateau karst basin with an area of about 10,000 square kilometres is an example of the latter type. Monoclinal basins are widely spread in the margins of the East-European artesian region. The Silurian plateau basin is one of them.

There are numerous karst basins in the folded regions. In the Ukrainian folded region there is the Saksagansky basin with an area of 9 square kilometres. In the Urals (in the Tagilsko-Magnitogorskaya karst province) there are the Petropavlovsky and Kisilsky karst basins, and in the East-Ural province there are the Alapaevskie karst basins and others. In the Aldan folded region there are the Yukhtinsko-Illimakhsky and Ginimsky basins. In the Vostochno-Sayansky folded region, karst basins are known to occur in cores of synclines. In the northern part of the Enisei massif (in the Cambrian and Proterozoic carbonate series) karst basins are also found in synclinal structures.

In the Central-Kazakhstan folded region there are numerous karst basins confined to brachy-anticlines.

In the Dauria folded region area the Ust-Borzinsky karst basin is 6,5 square kilometres in extent. Karst basins occur in the Krimsky, Bolshekavkazsky and other hydrogeological folded regions. In the Caucasus, karst and stratal-karst waters occur in the carbonate series of Mineralny Vody, Sochinsky and other artesian basins.

Karst basins, artesian slopes and artesian basins of the USSR are regions of spring-run-off concentration. Giant and vauclusian type springs of more than 1 cubic metre per second flow are known to occur there.

References

Maximovich, G.A. Fundamentals of karstology, v.2, ch. 2. Regional Karst Hydrogeology, p. 92-171, Perm, 1969.

Maximovich, G.A. Subterranean Carbonate Karst Waters in the Artesian and Hydrogeological Folded Regions of the USSR. Karst in Carbonate Rocks. Transactions of the Moscow Society of Naturalists, vol. 47, p. 29-35, Moscow, 1972.

MAN'S UTILIZATION OF CAVES THROUGHOUT THE AGES

G.A. Maximovich
Director of All-Union Karstology and
Speleology Institute, Perm University,
U.S.S.R.

Karst and other natural caves, as well as man-made ones, have been used since the Paleolithic, and, probably, even earlier. In the 20th century man still finds various applications for underground cavities [1.4].

Cave tourism. The most important application of the caves is equipping them for visitors. In the eastern hemisphere over 400 caves are visited by more than 15 million tourists a year.

For people's comfort railways have been built in five caves; four are equipped with lifts and two with funiculars.

Cave, particularly karst tunnels and bridges, are used as ways of communication. Automobile roads are built through some of them.

The second application of natural (and in many cases man-made caves), but of no less importance, is *speleotherapy*. Karst caves, salt and other cavities are equipped like hospitals[3].

Museums and various underground laboratories, dancing and concert halls have been made in caves. In some countries caves are used for organisation of New Year, Christmas and wedding parties.

Cave temples of different religions are especially numerous in Asia. Burials were made in caves in the past. Experiments "beyond time" have been conducted in underground cavities.

Mushrooms are grown in the caves of Europe and Cuba. In the caves of Europe cheese is made. Underground gardening and vegetable-growing are however seldom feasible. Caves are used for food and wine storage. Enclosures for cattle have been made in caves since ancient times.

People hunted in some caves in the Stone Age, a practice still followed in tropical countries.

Restaurants and dining-rooms exist in caves all over the world. Caves are used for small factories and storehouses.

Long ago caves served as dwelling places and even now they are often used for this purpose.

Cave waters are used for water supply, energy generation and as water-ways for tourists e.g. in the sea grottos of Fingals Cave in Scotland, the Isle of Capri, Malta and Yugoslavia. In many caves of the USSR and other countries, underground rivers and lakes are used for boating.

Useful minerals. Onyx marble, optical calcite and gypsum are produced in the caves of the Soviet Union and other countries. Phosphorites, guano, and birds' nests should be mentioned among organic products.

Earlier both in the USSR and USA, saltpetre, gypsum (for white ritual paint) borax for curing eyes, and stalactites (for arrow-heads) were produced in caves[2].

Cave ice has been used for refrigerators, producing fresh water and skating.

In different historical ages underground cavities and their deposits have been used in different ways. (Figure 1).

Research and exploitation of underground cavities are the modern trends. It is important that these trends lead to conservation.

References

Maximovich, I.G.A. 1972. Scientific and practical significance of the caves. Peshchery, v.12-13, p. 118-129, Perm.

Maximovich, G.A. 1975. Useful minerals and matters of the caves. Hydrogeology and Karstology, v.6, p.140-149, Perm.

Maximovich, G.A. & Khoroshavin, N.G. 1972. The types of natural and artificial caves, used for medical purposes/speleotherapy/ Peshchery, v.12-13, p. 129-146, Perm.

Delloca, S. 1962. Note di speleologia economica. Utilizzazioni della grotte. Rassegna speleologica italiana Anno XIV, N I, p. 76-109.

THE CONSERVATION AND MANAGEMENT OF CAVES IN TASMANIA, AUSTRALIA

G.J. Middleton
National Parks and Wildlife Service of Tasmania,
P.O. Bos 210, Sandy Bay, Tas. 7005, Australia

Tasmania, an island of 68,330 sq.km., is the smallest state of Australia, comprising less than 1% of the nation's area. However, Tasmania's caves include some of the finest and most challenging in the country. In proportion to its size Tasmania has the greatest extent of karst and cave development of any State (Jennings, 1975); it has Australia's longest cave (Exit, at 17 km) and its deepest (Khazad-Dum, at 322 m) and boasts 13 of the 15 deepest caves in Australia (Ellis, 1975).

In Tasmania there are probably about 600 karst caves recorded, with the greatest number being in Ordovician limestone, located in the central north (Mole Creek, Gunns Plains), west (Bubs Hill, Gordon & Franklin Rivers), south (Junee-Florentine) and far south (Ida Bay, Precipitous Bluff). Some caves are found in Precambrian dolomite (Mt Ronald Cross, Mt Anne) and Permian limestone (Maria Is., Grey), with one in Tertiary calcareous aeolianite on Flinders Island (Ranga).

Administration

Although other States reserved land for conservation purposes earlier, Tasmania had the first specific legislation – the Scenery Preservation Act of 1915. In 1971 that Act was replaced by the National Parks and Wildlife Act and the National Parks and Wildlife Service constituted thereby as a department of the Tasmanian Government now has primary responsibility for the conservation of natural and scenic areas, including caves.

The first reserves for caves as such were created under the Crown Lands Act of 1890, over caves on Sassafras Creek and Wet Cave in the Mole Creek area (6.11.1894). A number of caves were included in the Mount Field National Park, one of the first group of areas reserved under the Scenery Preservation Act (29.8. 1916). A small reserve (gazetted 3.7.17) under the Mines Act purports to protect Mystery Creek Cave at Ida Bay, though its real value is doubtful (Kiernan 1974).

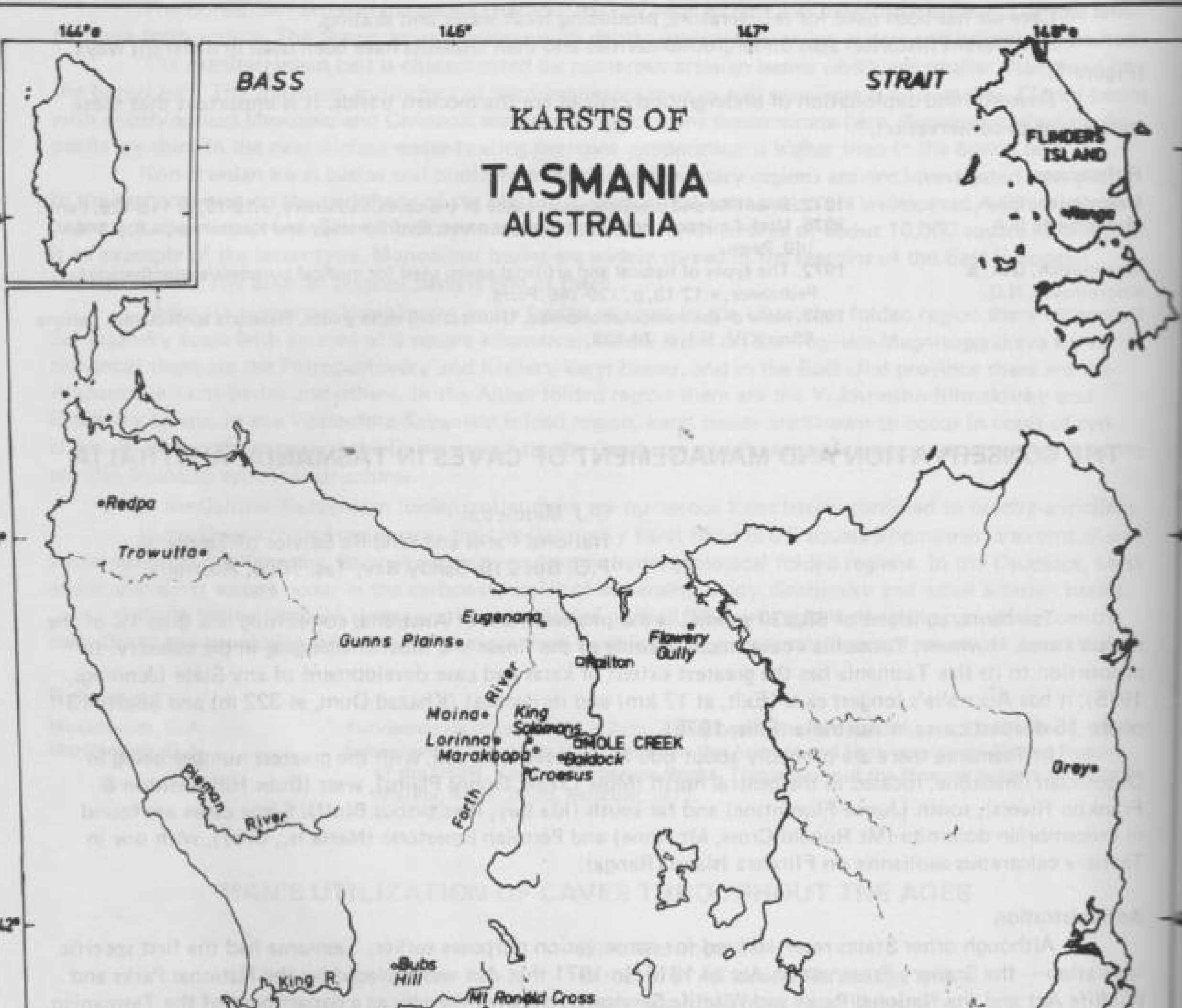
Apart from Mount Field National Park (Junee-Florentine area), caves were reserved under the Scenery Preservation Act at Gunns Plains (19.2.18), Hastings (24.6.19) and Mole Creek (16.8.39). These reserves became State Reserves under the National Parks and Wildlife Act and to them have been added Croesus Cave at Mole Creek (12.7.72), Junee Cave (8.9.76), Trowutta Caves (20.10.76) and the caves at Precipitous Bluff (17.11.76 and 1.12.76).

The National Parks and Wildlife Act of 1971 gives State Reserves full protection from mining and the issue of forestry and other development rights. State Reserves can only be revoked if Parliament passes a resolution to that effect; this is rare. Reserves under the Crown Lands Act and Mining Act do not have this security of tenure, nor do they have effective regulations. The National Parks and Reserves Regulations 1971 provide for the day to day management of State Reserves. All wildlife (including invertebrates) is protected and no plants, Aboriginal relics, sand, gravel, rocks and minerals can be interfered with. Formations in caves in reserves are specifically protected. Unauthorised access to caves can be prohibited.

Threats to Caves

Major threats arise from mining, forestry, hydro-electric development, agriculture, vandalism and pollution.

Limestone is mined in apparently non-cavernous areas at Railton and Mole Creek in the north and in a cavernous area of Ida Bay in the south. At Ida Bay a quarry reaches to within a few hundred metres of Exit Cave; a State Reserve is proposed to protect it. Current demand for limestone appears to be being satisfied from existing quarries. However a legal battle has been waged since 1971 over an application for an Exploration Licence at Precipitous Bluff (Environmental Law Reform Group 1971; Kiernan 1973). The Bluff was included in the Southwest National Park in November 1976, protecting it from mining, but the legal battle continues as conservationists seek to establish their right to object to applications under the Mining Act of 1920.



Small scale quarrying has destroyed small but not unimportant caves at Eugenana and Flowery Gully. What remains of the Devonian cave fill at Eugenana (Harris & Kiernan 1971) is to be protected by a State Reserve. Plans for the diversion of Mystery Creek at Ida Bay from its swallet into a quarry in 1972 were dropped after objections from conservationists (Kiernan 1972).

Forestry practice in Tasmania's eucalypt forests results in clear felling, then burning, of large coupes,

followed by regeneration. Where this is done on limestone the results may be very harmful through rapid erosion of thin soils and siltation of caves. Forestry operations can also damage caves directly, as in the case of road construction over Owl Pot in the Florentine Valley, and indirectly, where new roads provide access to caves formerly protected by their remoteness.

The legal protection of Exit Cave by creation of a State Reserve is currently being prevented because of the reluctance of the holder of a timber concession to surrender even a few hundred hectares, despite the recommendations of a Government sponsored investigation (Richards & Ollier 1976).

Virtually all of Tasmania's electricity is derived from hydro-power and the Hydro-electric Commission is by far the largest State authority. Three cave areas have actually been inundated (Lorinna, Moina and Scotts Peak — Harris & Kiernan 1971) and current plans for damming the Gordon, Franklin and King Rivers would flood large areas of limestone, destroy the State's last major wild river and further reduce one of the world's few remaining temperate wilderness areas. A number of significant caves have recently been discovered in the area and its potential is believed high. Proposals for inclusion of the area in the Southwest National Park are strongly opposed by the HEC but are currently under investigation by a Government appointed committee.

Agriculture does not pose a major threat to caves in Tasmania but at Gunns Plains clearing of forest has resulted in excessive silt loads in the cave's stream and agriculture will cause continuing pollution. Mole Creek, the area of most significant cave development in the State, is also a rich pastoral district and many caves are on private land. Apart from raising the likelihood of pollution by pesticides, fertilisers and animal wastes, this situation increases the probability of excessive siltation, deliberate or accidental closure of entrances and problems of access. At the same time it leaves the caves without legal protection and leaves the limestone available for mining. Mole Creek probably raises the greatest problems for future conservation and management of karst in Tasmania.

Some readily accessible caves at Mole Creek have suffered from vandalism but this appears not to be the problem in Tasmania which it is elsewhere, perhaps because of the low population, the remoteness of many caves and their generally cold, wet conditions. Fears have been expressed for Croesus and Kubla Khan Caves at Mole Creek and Exit Cave in relation to forced or unauthorised entry and vandalism.

Cavers themselves cause some damage to the caves they enter by accidents, carelessness and sometimes by deliberate modification. This is largely a matter for education, for adequate controls on access and for the setting of high standards by speleological societies. Tasmania will have to consider tighter controls on access to reserved caves as use increases.

Protective Measures

The most satisfactory long term protection for caves in Tasmania is afforded by their proclamation as State Reserves. Current proposals for reservation cover Exit Cave, Kubla Khan Cave and caves at Mount Anne and Cracroft River; all are held up because of forestry rights. In the case of the Gordon and Franklin Rivers hydro-electric interests are preventing reservation. Other forms of reservation exist but have various drawbacks. For example, while inclusion of caves in State Forests prevents alienation, it does not provide protection from mining, vandalism or forestry operations and it provides no mechanism for management of the caves.

At Mole Creek, because of the large proportion of private ownership, it may be necessary for the Service to seek to enter into joint management arrangements with owners in order to obtain some legal protection for the caves.

Reservation under the Crown Lands Act has been shown only to be a temporary measure, some such reserves having been revoked and sold in the past (Kiernan 1974). Likewise the proclamation of a "Forest Park" within State Forest can be varied very easily and may have little long term value.

Even statutory protection is not enough — laws and regulations need to be backed up by full-time staff, preferably stationed on site. In Tasmania this has so far only been possible at the developed tourist caves. Thus, while tourist development may be seen to be in some respects detrimental to particular caves, it can be very beneficial when linked with the protection and management of other caves in the area.

Use of Caves

Apart from tourists the greatest users of caves are cavers or speleologists. In Tasmania the public has unrestricted access to most caves. The National Parks and Wildlife Service has the power to restrict access to caves in State Reserves but in the past this has only been exercised in relation to tourist caves. It may be necessary in the future to implement a system of zoning such at that suggested by Hamilton-Smith (1977) which provides for use (or non-use) of caves to be varied, depending on the particular qualities of each cave. This is intended to ensure the best use over the longest time of our irreplaceable cave resources.

References

Ellis, R. 1975. Australia's Deepest Caves — by States. *J. Syd. speleol. Soc., 19*, (2): 36-40.

Environmental Law Reform Group. 1973. *The National Estate and the Public Interest: Precipitous Bluff, Environmental Rights and Mining.* E.L.R.G.: Hobart 46pp.

Hamilton-Smith, E. 1977. An Introduction to the Management of Caves and Karst Areas. *J. Syd. speleol. Soc. 21*, (1): 3-15.

Harris, S. & Kiernan, K. 1971. Cave Conservation and Tasmania. *Southern Caver, 3*(2): 13-25.

Jennings, J.N. 1975. How Well Off is Australia for Caves and Karst? A Brief Geomorphic Estimate. *Proc. 10th Biennial Conf. A.S.F.* A.S.F.: Sydney p. 86.

Kiernan, K. 1 — 1972. Mystery Creek Diversion Threat. *Southern Caver*, 4(2): 23.
Kiernan, K. — 1973. The P.B. Affair. *Aust. Speleol. Fedn. Nl.*, 59; 12-13.
Kiernan, K. — 1974. A Critical Examination of Tasmania's Cave Reserves. *Southern Caver*, *6*(2): 3-25.
Richards, A.M. & Ollier, C.D. — 1976. *Investigation and Report of the Ecological Protection of Exit Cave near Ida Bay in Tasmania.* Report to National Parks & Wildlife Service. 72pp.

KARST OF THE CAVES BRANCH, BELIZE

Tom E. Miller
Department of Geography, McMaster University,
Hamilton, Ontario, Canada

Approximately 200 km^2 are drained by the resurgence of the Caves Branch River of northern Belize (Central America). Roughly half is derived from non-carbonate rocks on the northern face of the Maya Mountains, the rest from a mature kegelkarst (cockpits) located immediately to the north.

The kegelkarst has developed on a hard, crystalline Cretaceous limestone platform of 80-300 m elevation. Traces of a Paleo-drainage are visible that can in some cases be correlated with older phases of cavern development. The kegelkarst is completely dissected by cockpits varying from 50-100 m in relief. Much of the drainage exists through swallets located near the cockpit bottoms. Average relief decreases with elevation, and the lowest-lying cockpits show alluviation and lateral corrosion effects in preferential trends of doline orientation. Marked differences in doline density and relief in adjoining areas may be due to lithalogic variation.

The kegelkarst is underlain by extensive cavern systems of up to 20 km in length, mostly active vadose trunk channels. Four principal types of caverns are present, the oldest being isolated phreatic caves of relatively high elevation, appearing to represent at least two phases of development. Massive speleothem deposits occur in these caves. The vadose trunk caves are large (≈30m width), and show evidence of at least three major erosional and depositional phases. Swallet caves draining the cockpits are narrow, short and primarily vertical. Cliff-foot caves presumably developed by lateral corrosion, and isolated vertical joint enlargements form the remainder.

During the dry season, the bed of the Caves Branch is frequently empty, but the wet season brings discharge of up to $45m^3$/sec.

Measured hardness (calcium and magnesium) is less than 15 ppm before the river enters the karst area. As comparatively little bedrock is exposed to solution, the increase in hardness to 150 ppm at final resurgence is nearly all due to contributions from the vadose cavern systems.

With one possible exception, known vadose trunks carry allogenic water primarily derived from the highlands. Discharge and hardness is extremely variable due to individual factors: ≈$10m^3$/sec is the highest cavern discharge recorded, while total hardness of up to 145 ppm has been measured. In contrast to the river, these subsurface streams flow year-round with base flow less than $.5m^3$/sec. Dry season calcium hardness valves are little above atmospheric saturation expectations — 60 ppm. There is an abrupt rise in solution values with wet season discharge that is not related to any 'flushing' effect. A positive correlation has been established between total hardness and discharge, but it is not yet known whether this is related to increased biogenic activity.

Numerous small tributaries are common along the length of the vadose trunks, presumably originating from doline swallets. Their hardnesses are characteristically higher (150-230 ppm) and also seem to show an increase with the wet season.

Dissection of the limestone may have begun as early as the extreme end of the Cretaceous. The Caves Branch managed through discharge volume and alluviation to cut and maintain a course to the low-lying plains north of the karst, while initially a fluvial landscape developed on the limestone karstification eventually pirated all surface streams, and kegelkarst dissection began. Eventual establishment of a near-base-level cavern system pirated the Caves Branch River underground, leaving a large, alluviated polje in the centre of the karst area. Further piracies have continued to move the swallet of the Caves Branch farther upstream, and closer to the highland source. A gross estimate for denudation of the area would be in the vicinity of 40-70 mm/1,000 years at present.

METHODS OF DETERMINATION OF LAMINAR FLOWS EFFECTS ON CAVE DEVELOPMENT PROCESSES

C. Minganti — R. Braggio — A. Zucchiatti
Via S. Ugo, 6/12 bis, 16135 Genova,
Italy

The existence of cave development processes involving dynamic characteristics of flow was deduced from morphologic analysis of the Monte Cucco Cave (Umbria). The argument is that saturated water is able to dissolve $CaCO_3$ [1,2]. We can suppose that laminar flow operates on equilibria existing between the solid phase ($CaCO_3$, limestone) and the liquid (saturated water) enhancing solubilization of $CaCO_3$. If we consider a system

made by limestone and still water, the reaction is represented in figure 1 for the solid phase and interface only. Therefore we can write equations (1) and (2) where:

v_{sol} = solubilization velocity; v_{ins} = insertion velocity.

The equilibrium state is shown in equation (3):

If water is moving in a laminar fashion, our system is that of figure 1, i.e. it is possible to see an interface as a separation between solid phase and flow. In this case we can write equation (4):

where v_p is the velocity of the reaction between interface and flow.

The $[Ca^{2+}]$ for the relationships (1) and (2) is determined by the solubility product. In the case of equation (4) we have $[CaCO_{3(f)}]$ as a function of the flow [3,4,5,6]. Therefore a situation of equilibrium is impossible and we have steady state because of the continuous removal of $CaCO_{3(f)}$ by the flow. In this case we can write equation (5)

1. Laminar Flows — a flow is laminar when the velocity is everywhere a function of the considered points only, i.e. it doesn't change locally. Therefore the velocity gradient in a direction will be constant in time [7,8,9]. In this case only we can use equation (5).

A real fluid of density e, of dynamic viscosity u and of static viscosity μ = u.e follows the Navier-Stokes law that, in cylindrical coordinates, is shown in equation 6a, 6b and 6c.

Equations 6a, 6b and 6c concern a fluid placed between two infinite and coaxial cylinders of radii r_1 and r_2, $r_2 > r_1$, moving around their axis with angular velocities w_1 and w_2 respectively. Because of symmetry around z-axis (figure 2) we can write equation (7). Therefore equations 6a, 6b and 6c can be rewritten as equations (8a) and (8b). Integrating we obtain equation (9)

Therefore in any plane normal to cylinders' axis the flow is laminar with velocity given by equation (9) and is independent of fluid's characteristics, provided that they do not depend on r. If r_1 and $r_2 \neq 0$, $w_1 = 0$, and $w_1 \neq 0$, equation (9) must be expressed as in equation (10) (as in fig. 3).

2. Experimental — The foregoing statements suggest the following method for testing equation (5). A cylinder made of Carrara marble (diameter 40.0 mm, height 200.0 mm) is coaxial with a tank (diameter 138.7 mm, h 190.0 mm). This last rotates on its own axis with an angular velocity that may change with continuity between 28 rad/sec and 8 rad/sec. The velocity is measured with a photoelectric cell connected to a digital clock (fig. 4). There are two differences between the technical procedure and equation (10). The first is that fluid and cylinders are finite. On this account the surface of the fluid becomes a rotation surface whose intersection with a plane drawn through the cylinder's axis is as shown in equation (11).

Figure 4 shows the shape of this surface. However the flow is laminar as proved by experiments with dyes.

The second difference is that there are fluid layers between the end of marble cylinder and the bottom of the tank. In this case the condition of equation (12) is not verified. Nevertheless it is possible to avoid this fact.

Increasing w_2 the distance between the point P (fig. 4) and the bottom of the tank decreases, therefore we have to calculate the area of $CaCO_3$ in contact with the fluid at various velocities. Provided that the greatest quantity V of fluid we can utilize at w_2 = 28 rad/sec is 1500 ml, we can find:

$h(P) - h_0 = f(w_2)$ with: $f(w_2 = 0) = 0$

at V = const. = 1500 ml. We can then transform equation (11) into (13).

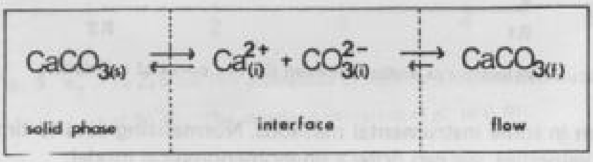


Fig. 1. The $CaCO_3$ flow system. An interface separates the two phases.

The value of A depends on r_1 and r_2 only. Therefore A is a constant characteristic of the instrument. Plotting Δh v/s w_2^2 we obtain a straight line with slope A. Fig. 5 shows the experimental results.

We can write the following equation (14) for the straight line of fig. 5: where σ is a constant which modifies A value in the real case. We need the introduction of σ because of the wettability of the two cylinders. The wettability changes the number of forces on water. The σ value depends on the material used for the two cylinders and it is independent of w_2. The A value is: $A = 5.41\ 10^{-3}$ cm sec^2. The σ value, for two plexiglass cylinders with $r_1 = 1.99$ and $r_2 = 6.94$, is: $\sigma = 1.78$.

3. Materials and Methods — Table 1 shows some chemical physic constants for $CaCO_3$. The apparatus shown in fig. 4 is placed in a flux of azote at constant temperature to avoid absorption of CO_2 in water. Because of equation (4), the $[CaCO_{3(f)}]$, apart from constants, may be considered as a measure of the dissolution by flow. Therefore different values of $[CaCO_{3(f)}]$ are expected for different velocities and for different times. By analysis of samples taken at different w_2 it is possible to quantify that phenomenon. Table 2 shows

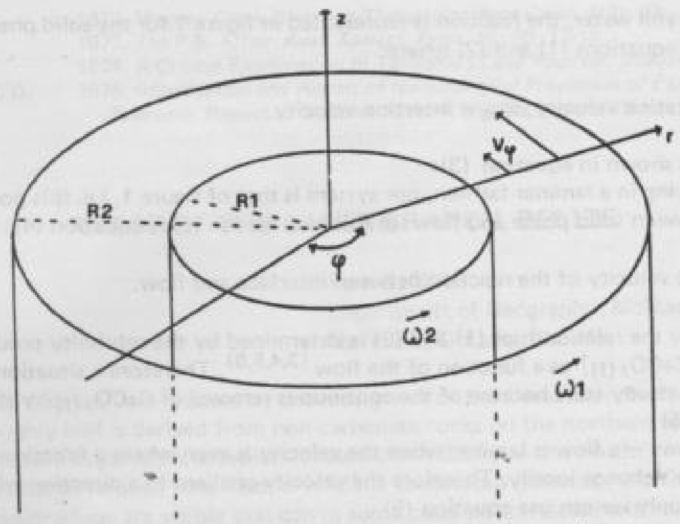


Fig. 2. The symmetry conditions for the Navier-Stokes equation with cylindrical coordinates.

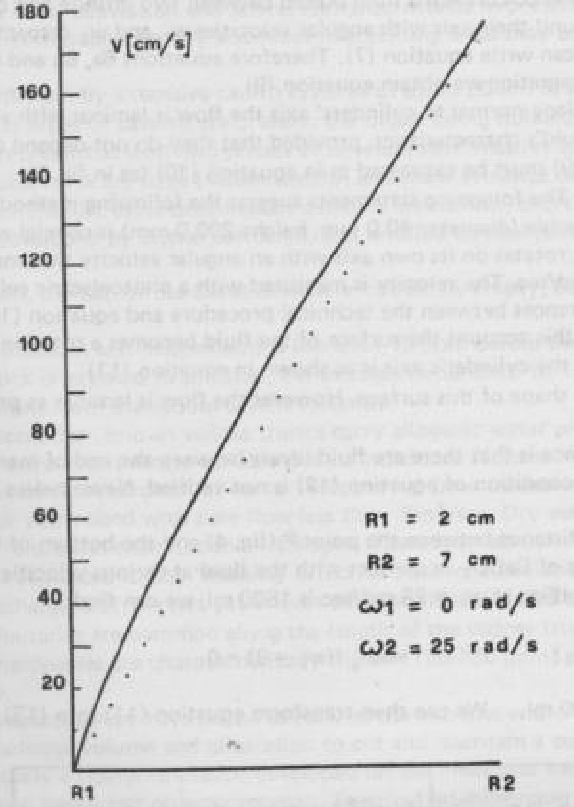


Fig. 3. Velocity v/s radius between the two co-axial cylinders.

the detection limits of calcium in some instrumental methods. Normalizing data to time and to surface in contact with the fluid at various velocities, we can draw a phenomenological model.

TABLE 1. Chemical Physics Constants for $CaCO_3$

	Calcite	*Aragonite*	*Ref.*
Hardness (Moh's scale)	3	3.5-4.0	10
Solubility in water at 25°C in grams per 100 cc	0.0014	0.00153	10
Solubility product of $CaCO_3$ at 25°C : 0.536 LO^{-8}			11
Pauling's crystal radius for Ca^{2+}ion $\frac{r}{A}$ = 0.99			12
Hydration entalpy of Ca^{2+}ion : 593.41 Kcal/grammoion			13
Carbonic acid	pK_1 = 6.37		
	pK_2 = 10.25		

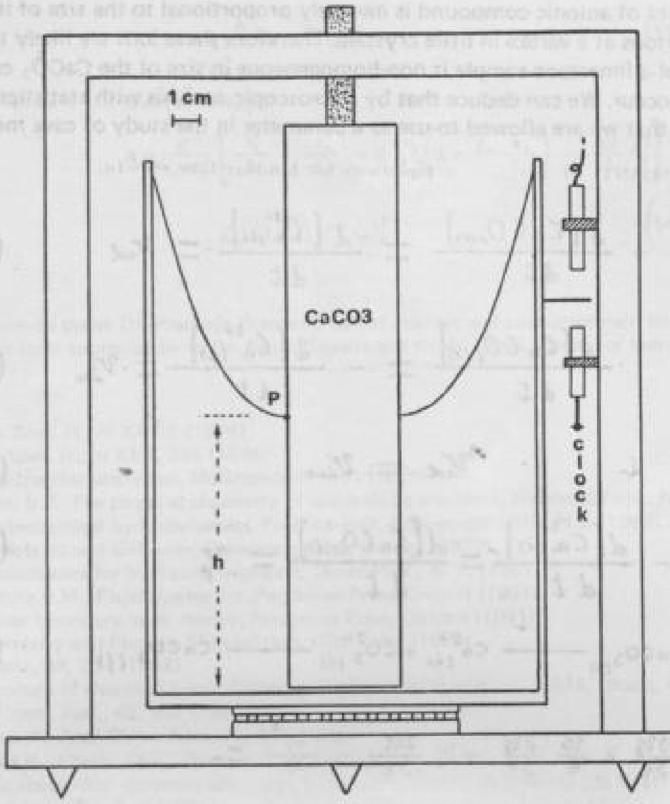


Fig. 4. Experimental apparatus showing fluid surface shape.

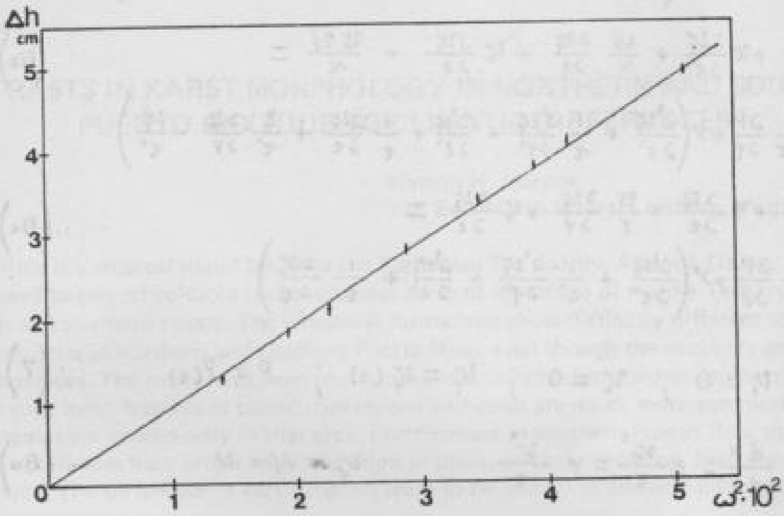


Fig. 5. w_2^2 v/s Δh for two plexiglass cylinders with distilled water at 25°C. The standard deviation of σ is 0.04.

TABLE 2. Detection limits of Calcium in Some Instrumental Methods

Method	*Detection limit*	*Remarks*	*Ref.*
polarographic	$10^{-3} - 10^{-4}$ M	streaming Hg electrode	14,15
atomic absorption	0.002 ppm/1%ABS	analytical wave length 422.7 nm, suggested resolution 13A	
atomic absorption	0.01 ppm	1% ABS = 0.1	16,17
atomic fluorescence	0.02 ppm	Xe (450 watts)	
flame emission	0.01 ppm		18

Dissolution velocity of anionic compound is inversely proportional to the size of its crystals. It is indeed very probable to find ions at a vertex in little crystals. Therefore these ions are likely to hydrate. We can state that the surface of a limestone sample is non-homogeneous in size of the $CaCO_3$ crystals. Therefore a selective dissolution will occur. We can deduce that by microscopic analysis with statistics it is possible to quantify the phenomenon that we are allowed to use as a parameter in the study of cave morphology.

C. MINGANTI et al Equations for laminar flow effects.

$$-\frac{d[CaCO_{3(s)}]}{dt} = \frac{d[Ca^{2+}_{(i)}]}{dt} = v_{sol} \qquad (1)$$

$$\frac{d[CaCO_{3(f)}]}{dt} = -\frac{d[Ca^{2+}_{(i)}]}{dt} = v_{ins} \qquad (2)$$

$$v_{sol} = v_{ins} \qquad (3)$$

$$-\frac{d[Ca^{2+}_{(i)}]}{dt} = \frac{d[CaCO_{3(f)}]}{dt} = v_p \qquad (4)$$

$$CaCO_{3(s)} \longrightarrow Ca^{2+}_{(i)} + CO^{2-}_{3(i)} \longrightarrow CaCO_{3(f)} \qquad (5)$$

$$\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} + \frac{v_\varphi}{r}\frac{\partial v_r}{\partial \varphi} + v_z\frac{\partial v_r}{\partial z} - \frac{v_\varphi^2}{r} = \qquad (6a)$$
$$= -\frac{1}{\rho}\frac{\partial P}{\partial r} + \nu\left(\frac{\partial^2 v_r}{\partial r^2} + \frac{1}{\rho^2}\frac{\partial^2 v_r}{\partial \varphi^2} + \frac{\partial^2 v_r}{\partial z^2} + \frac{1}{r}\frac{\partial v_r}{\partial r} - \frac{2}{r^2}\frac{\partial v_\varphi}{\partial \varphi} - \frac{v_r}{r^2}\right)$$

$$\frac{\partial v_\varphi}{\partial t} + v_r\frac{\partial v_\varphi}{\partial r} + \frac{v_\varphi}{r}\frac{\partial v_\varphi}{\partial \varphi} + v_z\frac{\partial v_\varphi}{\partial z} + \frac{v_r v_\varphi}{r} = \qquad (6b)$$
$$= -\frac{1}{\rho r}\frac{\partial P}{\partial \varphi} + \nu\left(\frac{\partial^2 v_\varphi}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 v_\varphi}{\partial \varphi^2} + \frac{\partial^2 v_\varphi}{\partial z^2} + \frac{1}{r}\frac{\partial v_\varphi}{\partial r} + \frac{2}{r^2}\frac{\partial v_r}{\partial \varphi} - \frac{v_\varphi}{r^2}\right)$$

$$\frac{\partial v_z}{\partial t} + v_r\frac{\partial v_z}{\partial r} + \frac{v_\varphi}{r}\frac{\partial v_z}{\partial \varphi} + v_z\frac{\partial v_z}{\partial z} = \qquad (6c)$$
$$= -\frac{1}{\rho}\frac{\partial P}{\partial z} + \nu\left(\frac{\partial^2 v_z}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 v_z}{\partial \varphi^2} + \frac{\partial^2 v_z}{\partial z^2} + \frac{1}{r}\frac{\partial v_z}{\partial r}\right)$$

$$v_z = 0 \;;\quad v_r = 0 \;;\quad v_\varphi = v_\varphi(r) \;;\quad P = P(r) \qquad (7)$$

$$\frac{dP}{dr} = \rho\frac{v_\varphi^2}{r} = \rho\frac{v^2}{r} \qquad v_\varphi \overset{def}{=} v \qquad (8a)$$

$$\frac{d^2 v}{dr^2} + \frac{1}{r}\frac{dv}{dr} - \frac{v}{r^2} = 0 \qquad (8b)$$

$$v_{(r)} = \frac{\omega_2 r_2^2 - \omega_1 r_1^2}{r_2^2 - r_1^2}\cdot r + \frac{(\omega_1 - \omega_2)\, r_1^2 r_2^2}{r_2^2 - r_1^2}\cdot\frac{1}{r} \qquad (9)$$

$$v_{(r)} = \frac{\omega_2 r_2^2}{r_2^2 - r_1^2}\cdot r - \frac{\omega_2 r_1^2 r_2^2}{r_2^2 - r_1^2}\cdot\frac{1}{r} \qquad (10)$$

$$y_{(r)} = \omega_2^2 K r^2 - 4\,\omega_2^2 K r_1^2 \ln\frac{r}{r_1} - \omega_2^2 K \frac{r_1^4}{r^2} \qquad (11)$$

where : $K = \frac{1}{2g}\left(\frac{r_2^4}{r_2^2 - r_1^2}\right)$

$$v_{(r)} = 0 \quad \text{if} \quad 0 < r < r_1 \qquad (12)$$

$$\Delta h = A\,\omega_i^2 \qquad (13)$$

where :

$$\Delta h = |h_P - h_0|$$

$$A = \frac{K}{r_2 - r_1}\left[\frac{r_2^3}{3} + \frac{r_1^4}{r_2} + 4 r_1^2 r_2\left(1 + \ln\frac{r_2}{r_1}\right) - \frac{16}{3} r_1^3\right]$$

$$\Delta h = A\,\sigma\,\omega_i^2 \qquad (14)$$

Acknowledgement

The authors wish to thank Dr. Pasquale Ottonello whose interest and encouragement have made this work possible. They also wish to express their appreciation to Dr. Bruno Segalla and to Mr. Ugo Lantero for their technical assistance.

References

1. Salvatori F., Rass. Spel. It., m XI-2,5 (1974)
2. Cigna A.A., Rass. Spel. It., m XI-1, 245 (1974)
3. Treybal R.E. Mass transfer operation, McGrow-Hill, N.Y. (1955)
4. Harned H.S. Owen, B.B. The physical chemistry of electrolytic solutions, Reinhold Publ., N.Y. (1958).
5. Levich V.G., Physiochemical hydrodynamics, Prentice-Hall, Englewood Cliffs, N.J. (1962).
6. Flynn C.P. Point defects and diffusion, Clarendon Press, Oxford (1972).
7. Rouse H., Fluid mechanics for hydraulic engineers, Dover Publ., N.Y. (1961).
8. Landau L.D. Lifshitz E.M., Fluid mechanics, Pergamon Press, Oxford (1961).
9. Meksin, D., Laminar boundary layer theory, Pergamon Press, Oxford (1961).
10. Handbook of Chemistry and Physics, 55th edition, CRC Press (1975).
11. Troilius, Tek. Tidskr, 88, 211 (1958).
12. Pauling, L., The nature of chemical bond, Cornell Univ.Press, IIIth edition, p. 514, Ithaca, N.Y. (1960).
13. Rossinsky D.R., Chem. Rev., 65, 467 (1965).
14. Proszt J., Gyorbiro K., Anal Chim. Acta, 15, 585 (1956)
15. Proszt J., Gyorbiro K., Chem. Anal., Warsaw, 1, 21 (1956).
16. Robinson, Atomic absorption spectroscopy, chap. 5, part. III, Marcel Dekker Inc., N.Y. (1966).
17. Slatin, Bio-Medical Lab. Dir., 1, 8 (1966).
18. Herrman, Alkemade, Flame photometry, Interscience Publ. John Wiley and Sons, Inc., N.Y. (1963).
19. Rialdi G., Minganti, C., Relata Technica, 10, Edizioni I.T.I., Genova (1976).

CONTRASTS IN KARST MORPHOLOGY IN NORTHERN AND SOUTHERN PUERTO RICO DUE TO CLIMATIC DIFFERENCES

Watson H. Monroe
126 East North Street, Leesburg, Virginia, U.S.A.

Puerto Rico is a tropical island between the Caribbean Sea and the Atlantic Ocean. A central mountain range composed largely of volcanic rocks separates areas of limestone of middle Tertiary age cropping out near the northern and southern coasts. The limestone formations show distinctly different solution and reprecipitation characteristics in northern and southern Puerto Rico, even though the rocks are petrographically similar in both provinces. The rocks have been much more structurally disturbed in southern than in northern Puerto Rico, but such karst features as closed depressions and caves are much more common in the northern province, and mogotes are known only in that area. Furthermore in southern Puerto Rico soft, powdery caliche is abundant, whereas hard crusts and induration in place, or case hardening, have been seen in the northern humid area. The difference in karstification seem to be related to climatic differences.

Climate

Puerto Rico has a warm, generally pleasant climate dominated by the easterly trade winds and by fairly regular rainfall throughout the year, but characterised by sudden showers. The nearly constant easterly direction of the trade winds has had a noticeable effect on the topography (Monroe, 1976, p. 45), especially in the shape of the mogotes.

The principal difference in climatic conditions between northern and southern Puerto Rico is in the rainfall and evaporation. The winds and the high mountains of central Puerto Rico combine to produce an orographic distribution of rainfall as shown by Figure 1. The annual rainfall ranges from about 860 mm in the very dry southwestern part of the island to more than 4,000 mm in the mountains of the northeastern part. In the northern karst belt the range is from about 1,300 to 2,500 mm. The rate of evaporation is very high. In San Juan the long-term average annual rate of evaporation is 2,072 mm, whereas the annual precipitation is only 1,631 mm. In southwestern Puerto Rico in the lee of the Cordillera Central the rainfall is less than 1,000 mm, and the evaporation rate is more than 2,000 mm. This results in a semi-arid or steppe climate.

Northern Puerto Rico

The limestone formations in the humid northern karst belt of Puerto Rico have been carved into a great variety of karst forms, including mogotes, cone karst, river and coastal ramparts, closed depressions, caves, zanjones, and relatively rare karren (Monroe, 1976).

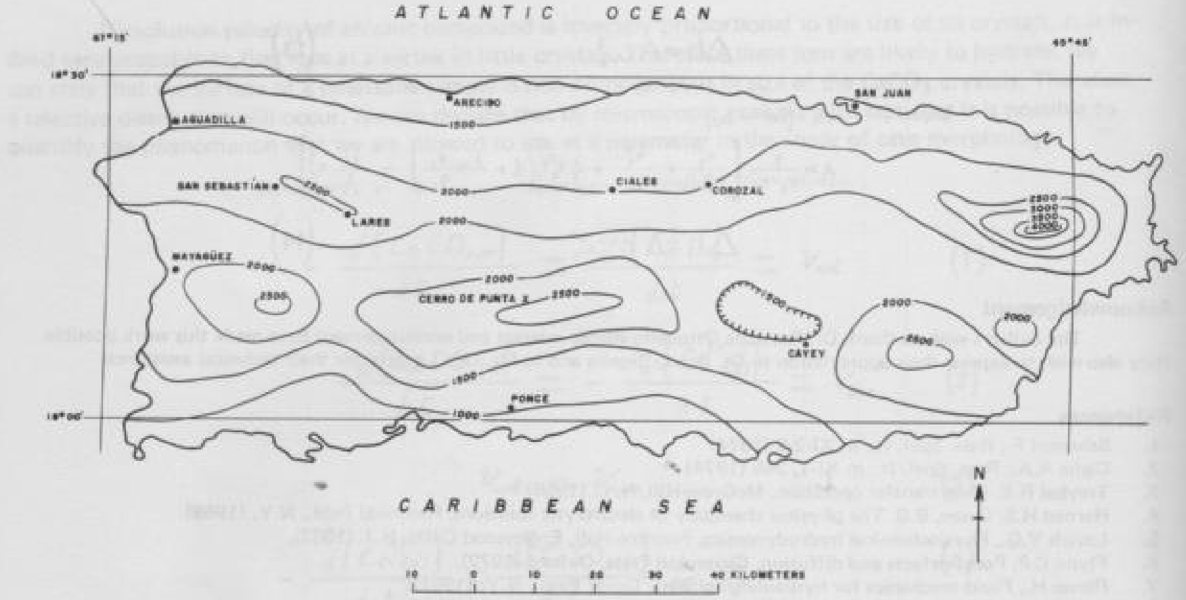


Fig. 1 Annual rainfall in Puerto Rico in millimetres. Data from U. S. National Weather Service.

Fig 2 Aerial view from the north of Tres Pueblos sink, 140m wide and 120m deep on the east side to rio Camuy, seen entering the sink on the south side

The mogotes are steep-sided hills from a few metres to 50 m high that rise out of plains covered by sandy clay. This cover is underlain by limestone similar in composition to the limestone in the mogotes, which are residual hills left by solution of the underlying limestone (Monroe, 1969; Miotke, 1973). Many of the mogotes are asymmetric, having a steeper slope on the western or southwestern side in the lee of the trade winds.

Cone karst is well developed especially near the southern edge of the northern karst belt and consists of conical hills surrounded by more or less star-shaped depressions. It is very similar to the cockpit karst of Jamaica.

Ramparts consisting of ridges of indurated limestone are common at the tops of canyons of several rivers and at many places along the Atlantic Coast. The tops of the ramparts are at about the same altitude as the tops of nearby mogotes (Monroe, 1969).

Closed depressions range in depth from shallow cup-like dolines, only a few metres deep, to large collapse features, more than a hundred metres deep (fig. 2). These latter depressions are mainly related to underground rivers, which flow through large caves.

Northern Puerto Rico contains dozens of caves that range in size from small rock shelters to large river caves, several kilometres long, containing canyon-like rooms more than 30 m high. The best known cave system, which is about 15 to 20 km southwest of Arecibo, is the Rio Camuy Caves and the tributary Angeles-Humo Cave (Gurnee, Russell and Jeanne, 1974; McKinney and Miller, 1972). These caves are by far the largest and longest in Puerto Rico, but several other large river caves have been only superficially explored (Monroe, 1976, p. 59-66).

Zanjones, which have not been reported elsewhere, are series of long, parallel trenches that are probably systems of joints that have been enlarged by solution (Monroe, 1976, p. 48-50).

Minor karst features include several kinds of karren, cliff-foot caves, and natural arches.

In summary, northern Puerto Rico presents a wealth of features typical of tropical karst morphology and several phenemena not reported elsewhere.

Southern Puerto Rico

The middle Tertiary limestone formations in southern Puerto Rico are generally covered and in many places concealed by an ubiquitous cover of caliche, which is friable chalk-like material of secondary origin. The thickness of the caliche is commonly of the order of a metre, but in some places the thickness is greater than 3 m. On a low hill on the coast about 20 km west of Ponce, most of the caliche was scraped away to be used in building a causeway. In 1970 all that remained of the deposit was a pillar 3.7 m high. At the top of the pillar was a bed of compact chalky limestone, banded in white and light brown, 27 cm thick, underlain by 1.5 m of indurated rubbly chalky limestone and soft banded chalk containing a few pieces of hard limestone. This bed rests on 2 m of soft rubbly chalk. All the chalk is banded in a lenticular fashion. A thin section cut from the top bed in the pillar shows that the rock is very ferruginous micrite containing a few scattered quartz grains. A chemical analysis of the top bed shows 95 percent calcium carbonate, 1.1 percent silica, and less than one percent each of alumina, ferric oxide, and magnesia.

The origin of the caliche is related to the arid climate of southern Puerto Rico. It has probably formed first by slight solution of the limestone during infrequent rains. The bicarbonate water is drawn to the surface by capillary attraction, and over a period of centuries this process has produced a thick capping of soft chalk. Occasional rains follows by sunshine have produced the cap of indurated limestone at the surface of the caliche, just as pure bedrock is indurated in northern Puerto Rico (Monroe, 1976, p. 17).

The more usual karst features of southern Puerto Rico include a few small caves, 3 closed depressions, abundant karren on exposed limestone surfaces, and one river cave, El Convento (Beck, 1974).

Conclusions

The island of Puerto Rico is an excellent place to investigate karst phenomena under varying climatic conditions. The karstified rocks are similar in both northern and southern Puerto Rico, but faults and joints are much more common in southern Puerto Rico, where karst features are relatively rare, whereas in northern Puerto Rico the karst morphology is much more fully developed, even though faults and joints are relatively scarce. The greater abundance of rainfall in northern Puerto Rico compared to southern Puerto Rico appears to be the determining factor.

References

Beck, B.F. 1974. Geology and hydrology of the El Convento Cave-Spring System, southwestern Puerto Rico: *Inter. Jour. Speleology*, v.6, p. 93-107.

Gurnee, Russell and Jeanne 1974. *Discovery at the Rio Camuy*, 183p., Crown Publishers, Inc., New York.

McKinney, F.E. & Miller, Forest 1972. The Cueva Humo-Cueva de los Angeles System: *Speleotype*, v.7, no.2, p.21-22.

Monroe, W.H. 1976. *The karst landforms of Puerto Rico:* U.S. Geol. Survey Prof. Paper 899, 69 p. map.

Monroe, W.H. 1969. Evidence of subterranean sheet solution under weathered detrital cover in Puerto Rico, *in* Problems of the karst denudation-Internat. Speleol. Cong. 5th, Stuttgart, 1969, Supp: Československ Akad. Věd Geog. Ustav Brno Studia Geog. 5, p. 111-121.

Miotke, F.D. 1973. The subsidence of the surfaces between mogotes in Puerto Rico east of Arecibo (translated from German by W.H. Monroe): *Caves and Karst*, v.15, no.1, p. 1-12.

DEUX KARSTS DU GYPSE REMARQUABLES DES ALPES OCCIDENTALES

par J. Nicod
E.R.A. 282 du C.N.R.S., Institut de Geographie d'Aix,
29 rue Robert Schuman — 13621 Aix. France.

A tentative synthesis (J. Nicod 1976) is based on recent research in the domain of the sedimentation of evaporits and on the examination of their properties (solubility and plasticity). In the Alps, the Triassic gypsum karsts are very numerous; many funnel-shaped doline fields, and small blind valleys with swallow holes, generally developed at the contact

between gypsum and crystalline rocks or flysch. Gypsum karst show spectacular forms, particularly in Beaufortin and near the Mont-Cenis pass. In high altitudes, the depressions are exceptionally recent and still evolutive; they have appeared since the last stages of late glacial deglaciation.

Dans une tentative de synthèse (J. Nicod 1976) nous avons montré la grande extension des karsts du gypse dans les bassins sédimentaires, et étudié leurs rapports avec les conditions de sédimentation des évaporites, sur lesquelles il y a maintenant de très nombreux travaux.

Dans les Alpes les karsts du gypse sont liés aux évaporites due Trias; cargneules et dolomies sont généralement associées au gypse.

1°) — Conditions generales

En raison des mouvements tectoniques tangentiels intenses qui ont présidé à l'orogénie alpine, les affleurements de gypse ne constituent que des bandes étroites, situées le plus souvent au contact des diverses unités, dont ils ont permis le déplacement tangentiel: ainsi dans les Alpes francaises du N on les trouve directement sur le socle (ayant facilité le décollement de la couverture parautochtone), et à la base de diverses unités charriées (de la nappe des schistes lustrés le plus généralement). Leur plasticité, et l'augmentation de volume dû à la transformation de l'anhydrite en gypse commandent des phénomènes de bourrage et d'extravsement.

a) La solubilité des gypses se traduit par *des formes* de *relief typiques* en haute montagne, dans l'étage "alpin" des botanistes:

— *champs de dolines* en *entonnoirs* très nombreux des petites tailles, parfois coalescents. Ces entonnoirs servent de puits à neige.

— *dolines-puits,* dépressions en forme de cratère, quand la dissolution du gypse produit des effondrements dans les terrains surincombants (cargneules, schistes lustrés etc..)

Ces deux types de formes sont très bien représentés tant dans le Beaufortin (Col du Joly), qu'au N de la Vanoise (pourtour du Mont-Jovet, spécialement alpages de la Plagne) ou au Petit Mont-Cenis.

— *fentes de décollement* sur un escarpement par la dissolution des gypses sous-jacents: La Cheveliére, au-dessus du Lac des Fées, dans le Beaufortin.

— *vallées aveugles,* avec puits absorbants au contact des gypses et des terrains encaissants: système du lac Noir, au NW du plateau cristallin des Enclaves, en Beaufortin et l'ouvala de la Combe de la Nova (cf. infra).

— *les lapiés* du gypse, formes géantes, en *bad-lands,* sont relativement rares, et seulement présents en haute altitude: Petit Mont Blanc de Pralegnan 2.678 m).

b) *Des phénomènes sont indirectement liés à la dissolution des gypses.*

Les eaux sortant des bandes de gypse sont fortement minéralisées (jusqu'à saturation, cf. l'amas de tufs de la vallée de Treicol à 1700 m); elles entraînent des désordres dans les terrains argileux ou schisteux qu'elles imbibent: loupes de glissement, mouvements de masse, formation de laves torrentielles (*mud flow*) à haute viscosité, comme celles qui ont dévasté en 1965 le village de Pontamafrey en Maurienne (L. Anchierri 1966). A haute altitude deux karst du gypse, de faible surface, mais d'une extrême densité de formes permettent d'apprécier la rapidité actuelle d'évolution.

2°) Le karst du gypse extraordinaire de la Combe de la Nova (Beaufortin) (Fig. 1).

La Combe de la Nova est à la fois une auge glaciaire et une combe dans un anticlinal de la nappe sub-briançonnaise; calcaires et gypses triasiques y constituent une sorte de *"mont dérivé.* La résistance du gypse aux actions mécaniques des glaciers et à la cryoclastie est un fait bien connu dans les régions froides: aussi la bande de gypse est en saillie, mais soumise à une dissolution intense. Dans la partie N ou le gypse affleure, c'est une véritable écumoire: de nombreux entonnoirs, très profonds, souvent coalescents (se recoupant alors par une crête instable), et absorbants: puits à neige du gypse. Au S, les entonnoirs sont en général plus modestes, les gypse n'apparaît pas, ce sont des formes de suffosion dans les schistes susjacents, qui évoluent en niches de nivation ou en dolines-lacs.

La bande de gypse est en saillie par rapport à deux vallons limitrophes, et d'intéressants phénomènes s'observent sur ses deux rebords. Côté SE, un ruisseau se termine en vallée aveugle, et ressort partiellement 200 m plus loin dans un amphithèâtre de gypse. Côte NW, les aspects du rebord sont spectaculaires. Un ouvala important et dissymétrique recueille les eaux de fonte donnant un lac temporaire, qui s'écoule par une grotte-ponor; un autre ponor à l'amont absorbe un ruisseau. Plusieurs résurgences échancrent l'escarpment de gypse: la plus importante, à l'aval sort d'une grotte; elle est vraisemblablement aussi alimentée par les eaux du ruisseau SE. L'escarpement est découpé en monolithes instables et la comparaison des photographies prises en 1964 et 1974-1975, montrent une évolution par éboulement active, sur le rebord de l'ouvala (chute de blocs, modification des fentes) et dans la reculée de la résurgence principale.

L'alignement très net de nombreux entonnoirs, sur des directions de fractures, l'aspect des pertes et résurgences indiquent des réseaux souterrains individualisés, un recul des parois actif, par dissolution et actions mécaniques, un cavernement important, qui commande le soutirage dans les entonnoirs et les effondrements (W cote 2320).

Ce caractère spectaculaire des formes et l'activité des processus est à mettre en rapport à notre avis avec les deux conditions suivantes:

— *intensité spasmodique* de la dissolution, liée à la fusion nivale de juin.

— *"Jeunesse"* du développement des formes karstiques, liées au caractère tardif du déglacement de l'auge de la Nova (moraine tardiglaciaire, située à l'aval, aux Chapieux Derrière, vers 1860 m).

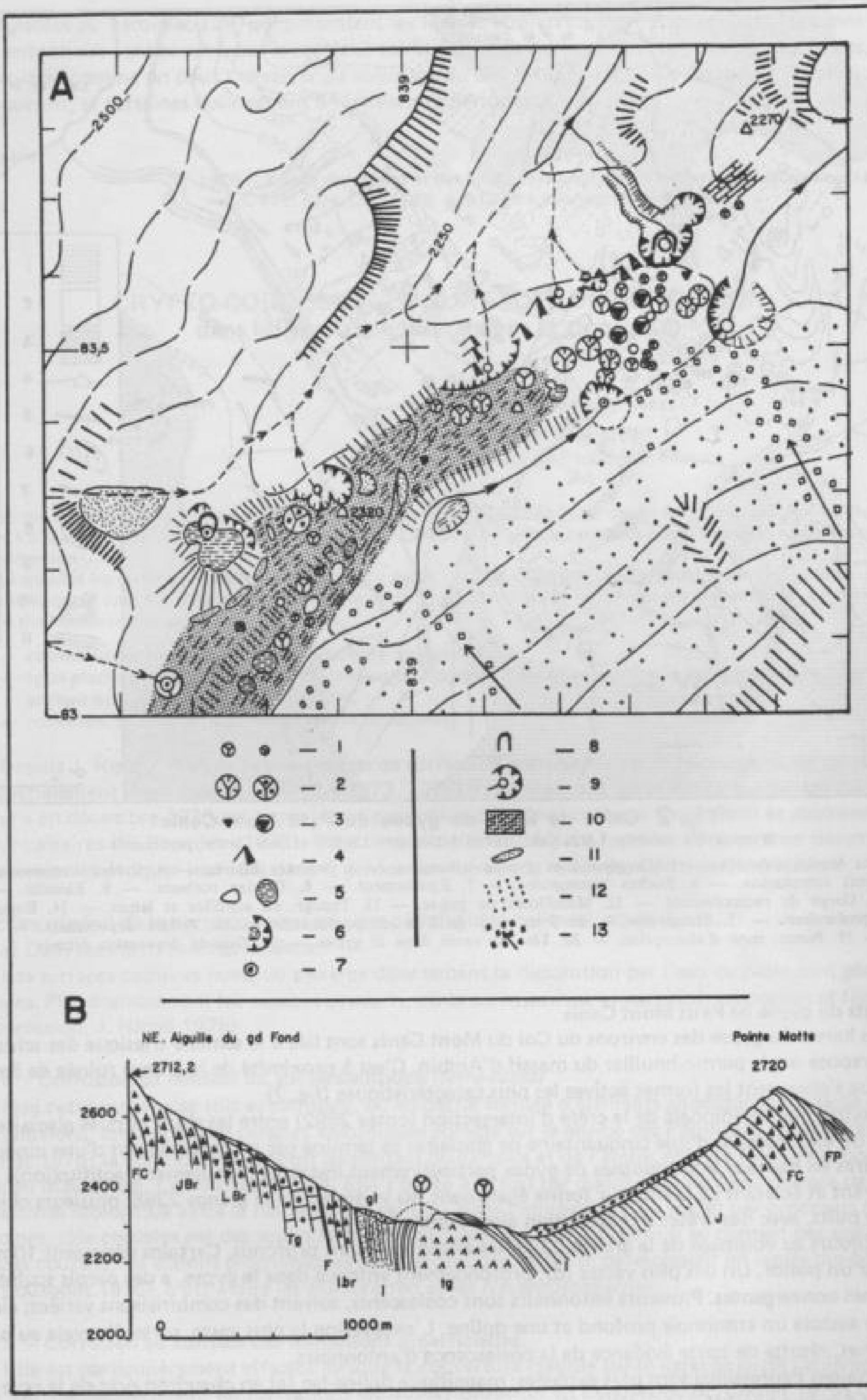


Fig. 1 Carte et coupe du karst du gypse de la Combe de la Neuva

a) Carte géomorphologique détaillée de la bande de gypse, d'après les clichés stéréoscopiques I.G.N. 3532/3533, n[os] 52-53 et nos levés de terrain : 1. Entonnoir, + de 5 m et — de 5 m de profondeur. — 2. Entonnoir cratériforme, + de 10 m, à blocs éboulés. — 3. Puits absorbant (dans l'entonnoir). — 4. Dépression effacée, laquet. — 5. Monolithes de gypse. — 6. Ouvala (avec lac temporaire). — 7. Ponor actif. — 8. Grotte. — 9. Reculée de source. — 10. Couverture de schistes liasiques. — 11. Niche de nivation. — 12. Eboulis cryoclastique. — 13. Blocs éboulés, couloir d'avalanches.

b) Coupe, d'après la carte géologique au 1/80 000[e], Albertville. Sigles de la zone subriançonnaise : Fl, Fc : flysch, flysch conglomératique ; J, Jbr : Jurassique calc., Jurassique bréchique ; l, lbr : lias schisteux, lias bréchique ; tg : trias gypses.

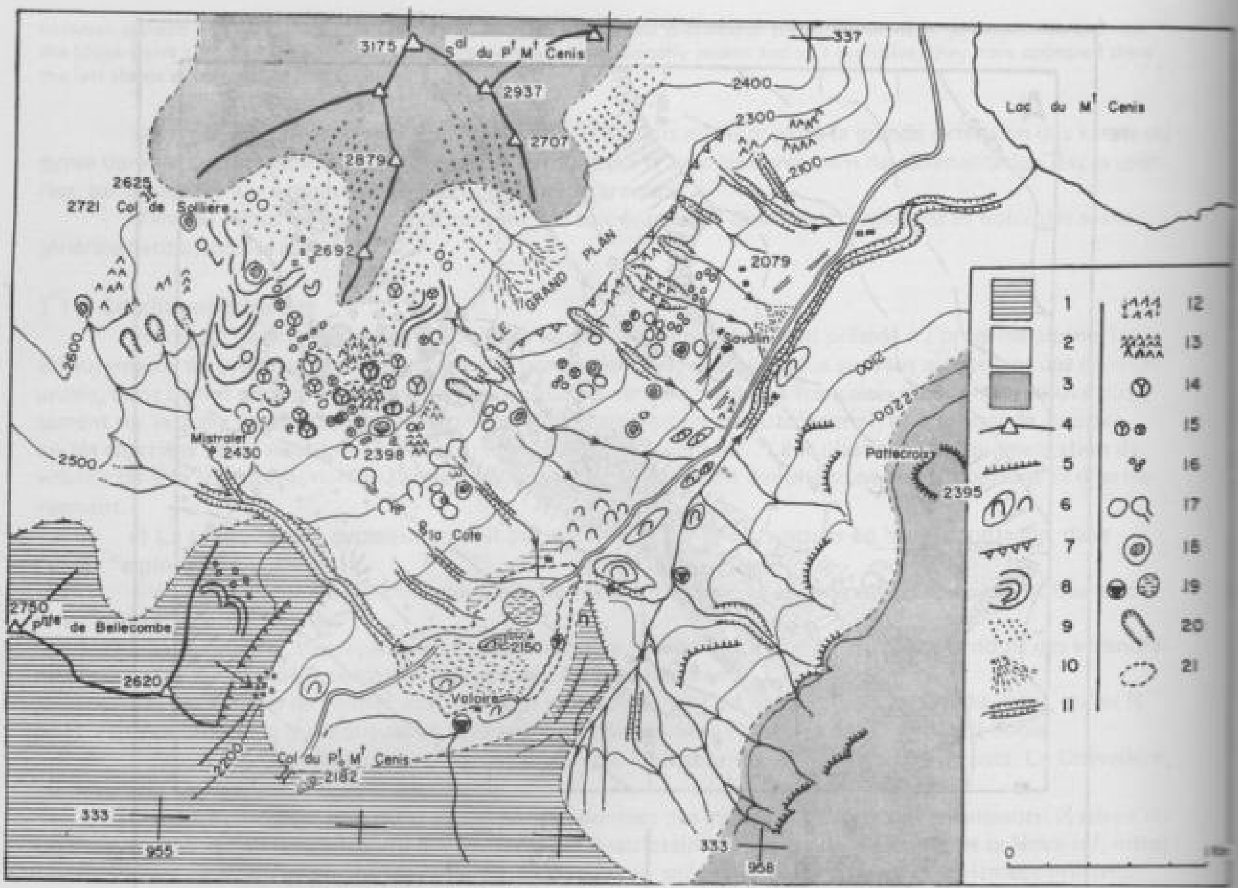


Fig. 2 Carte du karst du gypse du Petit Mont-Cenis

D'après les clichés I.G.N., 6, 3534-3634/250, n^{os} 128-129 et nos levés personnels.

1. Paléozoïque du Massif d'Ambin. — 2. Cargneules et gypses triasiques. — 3. Schistes lustrés. — 4. Crêtes d'intersection de cirques. — 5. Escarpements structuraux. — 6. Roches moutonnées. — 7. Epaulement. — 8. Glacier rocheux. — 9. Eboulis. — 10. Cône de déjection. — 11. Gorge de raccordement. — 12. Monolithes de gypse. — 13. Topogr. en aiguilles et lames. — 14. Entonnoirs moyens, + de 10 m de profondeur. — 15. Entonnoirs, + de 5 m et — de 5 m de profondeur. — 16. Petites dépressions. — 17. Dolines. — 18. Doline-lac. — 19. Ponor, zone d'absorption. — 20. Tête de ravin dans le gypse. — 21. Grande dépression fermée

3°) Les karsts du gypse de Petit Mont Cenis

Les karsts du gypse des environs du Col du Mont Cenis sont liés à la semelle triasique des schistes lustrés, qui repose sur le permo-houiller du massif d'Ambin. C'est à proximité de la grange ruinée de Savalin (2398 m) que s'observent les formes actives les plus caractéristiques (fig. 2).

L'extrémité méridionale de la crête d'intersection (cotée 2692) entre les deux cirques glaciaires se termine par un escarpement d'une cinquantaine de glaciaires se termine par un escarpement d'une cinquantaine de mètres en hauteur, *à monolithes* de gypse particulirement instables (éboulement, solifluxion). Le gypse, apparent et éclatant de blancheur forme également, au voisinage de la grange 2398, plusieurs chicots, perforées de puits, avec des crêtes d'intersection aigues entre ceux-ci.

Toujours au voisinage de la grange 2398, les entonnoirs sont profonds. Certains dépassent 10m, et s'ouvrent par un ponor. Un des plus vastes (d), profondément enfoncé dans le gypse, a des parois sculptées par des ravines convergentes. Plusieurs entonnoirs sont coalescents, suivant des combinaisons variées: ainsi le couple (e) associe un entonnoir profond et une doline. L'excavation la plus vaste, sorte d'ouvala au pied des monolithes, résulta de toute évidence de la coalescence d'entonnoirs.

Certaines dépressions sont plus évoluées: magnifique doline-lac (a) en chaudron près de la cote 2398, d'autres sont presque comblées, à moitié effacées, parfois ouvertes. Sur le versant en contre-bas de l'épaulement du Grand Plan, les entonnoirs sont encore nombreux; mais la forme la plus caractéristique est représentée ici par des têtes de ravines, profondément creusées dans le gypse, et provoquant localement la formation des monolithes. Enfin la petite plaine de Valoire tient à la fois de la cuvette de surcreusement glaciaire remblayée et du poljé karstique ouvert.

Conclusion — Vitesse et durée d'évolution

L'activité de la dissolution en haute montagne tient à la solubilité du gypse et de la forte minéralisation des eaux (teneurs en Ca SO_4 de 549 à 1762 mg/l à la Nova, selon les sources et les prélèvements) mais aussi à la quantité considérable des précipitations annuelles, de l'ordre de 1670 à 1813 mm en Beaufortin et avec une évapotranspiration minime. Ce qui permet d'estimer le taux d'ablation annuel (J. Nicod 1976) à 1,066 mm (plus d'un mètre par millénaire). La valeur du cavernement est plus importante quand il s'agit, comme à la Nova, d'un cours d'eau allogène.

Mais la durée d'évolution est courte. Ce sont les bandes de gypse les plus hautes donc les plus réce-

mment déglacées au Tardiglaciaire, qui présentent les formes les plus caractéristiques. Dans les zones plus basses les entonnoirs sont envahis par le matériel solifuidal, et deviennent des cuvettes peu marquées, souvent des dolines-lacs (comme on peut l'observer au voisinage du Col du Joly 1989 m). Toutefois l'évolution souterraine se poursuit, et certaines dolines sont à réouverture périodique.

Bibliographie

Nicod, J. 1976 – Karsts des gypses et des évaporites associées, *Annales de Géographie* LXXV no. 471, Sept. Oct. 1976, p. 513-554 (bibliographic détaillée).

CRYPTO-CORROSION ET SURFACES DE CORROSION
dans les karsts méditerranéens et tropicaux

J. Nicod
Institut de Geographie
29 rue Robert Schuman
13621 Aix en Provence, France

In the Mediterranean regions, crypto-karstic-corrosion (J. Nicod 1975) occur in fersiallitic soil (giving *Rundkarren* and *Kavernösen Karren*, or under cover of sands and alluvium. We ought to distinguish three cases of crypto-karstic corrosion: active, moderate, inherited.

In tropical karst, this process is very important under ferallitic clay and bauxit, blanket sands (Porto-Rico), alluvium and vertisoil (Narinda, who the part of groundwater is evident). Three types of landforms are characteristic of the crypto-karstic corrosion in the Mediterraneans:

– convex slopes (when frost phenomena were unimportant)
– local platform formed by corrosion (a solution planation), sometimes active in polje ground, or inherited in ancient polje and in polje rock-terraces.
– rock-fans, or solution karst pediment in limestones.

Depuis J. Roglic' (1952), la conception de surface de corrosion s'est développée, et de nombreux travaux, spécialement allemands (K.H. Pfeffer 1973, 1975) et français ont porté sur ce thème. Un colloque s'est réuni à Paris en décembre 1976 sur le problème particulier des cônes rocheux (*rock-fans*) et aplanissements partiels sur calcaires (G. Beaudet . 1978). Dans cette note nous désirons rappeler l'importance des processus de crypto-corrosion et évoquer leur rôle dans la genèse des formes de relief des karsts méditerranéens.

1°) Caractère général de la corrosion sous couvert pédologique colluvial, alluvial, etc.

a) Dans les karsts méditerranéens.

Les surfaces calcaires nues, où s'exerce directement la dissolution par l'eau de pluie sont généralement discontinues. Plus étendus sont les espaces couverts, où la corrosion est souterraine, en poches et fissures (crypto-corrosion, J. Nicod 1975).

1 – Corrosion au contact du sol fersiallitique *(terra-rossa)*

Que cette *terra-rossa* soit autochtone, ou en partie formée d'éléments allochtones (reste de sédiments argileux, alluvions, loess et même cendres volcaniques comme sur le Murge des Pouilles, d'après les analyses de K.H. Pfeffer 1975) la corrosion se produit au contact du calcaire et de l'argile, chaque fois que la poche ou fissure est bien drainée (M. Lamouroux 1975). Elle s'opère à la fois par *dissolution* de l'eau chargée de CO_2, du fait de l'activité biologique et de la haute teneur du CO_2 dans l'atmosphère du sol, et par processus *biochimiques,* (racines, rôle complexant des acides humiques et fulviques). La dissolution au contact des argiles donne des surfaces courbes, les actions biochimiques des perforations. Ainsi se développent les lapiés bio-pédogéniques (B. Bousquet 1976), c'est à dire les *Rundkarren* et les *Kavernösenkarren.*

2 – Corrosion au contact des formations superficielles.

Elle est particulièrement efficace lorsque la couverture meuble sur le karst se laisse facilement pénétrer par l'eau, particulièrement les formations sableuses résiduelles en Languedoc (E. Coulet 1975) ou les sables et produits d'altérations des basaltes néocomiens au Liban.

Les conditions climatiques modulent l'efficacité de la corrosion souterraine; des précipitations hivernales considérables, et une longue sècheresse estivale, comme dans l'étage méditerranéen du Mont-Liban, constituent les conditions favorables à la production de sol fersiallitique, donc à l'attaque des calcaires. Mais les conditions topographiques interviennent aussi, le fond des dépressions concentre l'humidité, d'où la relation vallons-dolines. L'effet maximum est obtenu par l'existence d'un aquifère dans l'épikarst; fond de poljé parfois marécageux (Busko Blato au S du poljé de Livno). Quand ces conditions sont réalisées, la crypto-corrosion est active (Liban, Montenegro, dépressions du karst dinarique, etc.) au contraire dans les karsts provençaux et languedociens, elle est seulement localement entretenue, et souvent simplement héritée (Plan de Canjuers) (J. Nicod 1975).

b) *Dans la zone intertropicale*

La crypto-corrosion s'exerce tout autant, bien que le caractère spectaculaire des formes subaériennes (lapiés en pinacles ou *"tsingy"*, entailles basales des mogotes, ou *Lösungsunterschneidung* du Turmkarst aient

1

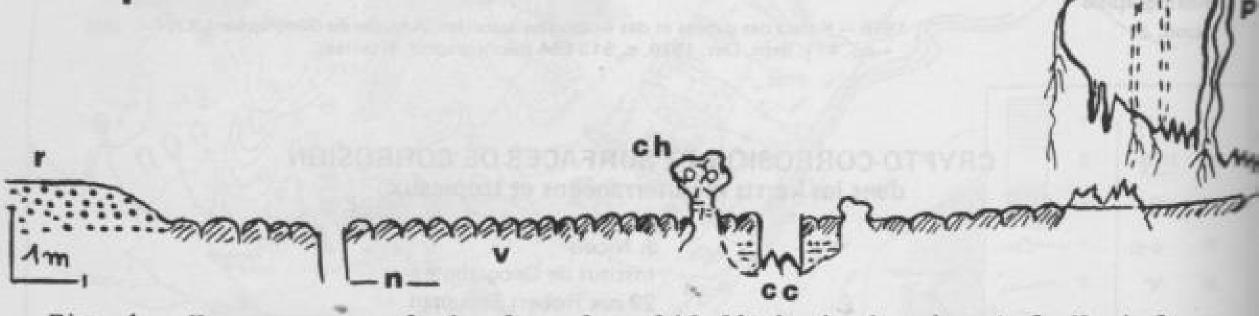


Fig. 1 - Une coupe sur la bordure du poljé d'Amboaboaka, karst de Narinda (NE Madagascar)

cc - calcaire corrodé au fond de la fosse pédologique 1
ch - chicot en champignon, l - lapiés de toit dans l'encoche basale de bordure, n - niveau de la nappe phréatique en saison sèche dans la fosse 2, r - remblaiement sableux - v. vertisol.

2

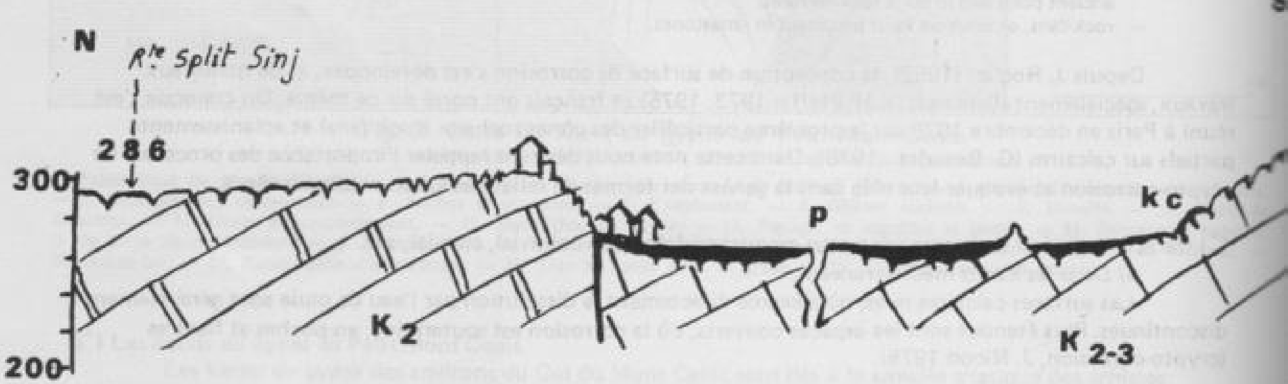


Fig. 2 - Les deux niveaux du Dugo-Poljé (route Split-Sinj)
f - faille, h - petit hum, K2 calcaires turoniens $K_2/_3$ calcaires turoniens et Sénoniens, Kc - knick de corrosion - p. ponor.

3

Fig. 3 - Cône rocheux (rock-fan) de la bergerie des Anges sur le Grand Plan de Canjuers (Var).

c- cailloutis cryoclastiques, l - lapiés, tr - restes de terra-rossa sur la surface de corrosion, p - ponor (Grand Aven) $\underline{J_9}$ calcaires portlandiens.

fait négliger son rôle. G.E. Wilford et J.R.D. Wall 1965 en ont présenté de beaux exemples dans la région de Bau (Sarawak), au contact des argiles ferrallitiques, de même K.G. Pfeffer (1975 p. 69) montre le développement des Kavernösen-karren dans un sol bauxitique. Nous en avons observé G. Rossi et moi-même, de nombreux exemples sur les plateaux calcaires de Madagascar, au contact des sols ferrallitiques issus des basaltes, ou des sables tertiaires. F.D. Miotke et W.H. Monroe (1976) signalent l'intensité des processus de crypto-corrosion dans le karst de Porto-Rico, sous la couverture du "blanket sands". Dans le polje d'Amboaboaka, dans le karst de Narinda (NW de Madagascar) (Fig.1) la corrosion s'exerce au contact des alluvions argilo-sableuses et du calcaire, et spécialement dans le vertisol, riche en montmorillonite, et en fonction de l'humectation par la nappe phréatique. Ce processus contribue tout autant que l'attaque basale des tourelles au développement du poljé. Dans certains cas surfaces de corrosion peuvent être légèrement inclinées, comme K.H. Pfeffer (1975, p. 74) l'a montré autour des mogotes à la Jamaique.

2°) — Les formes du relief dues à la crypto-corrosion dans les karsts méditerranéens

Dans le plupart des cas, le développement des formes a été entravé par les crises climatiques froides du Quaternaire, si bien que les relations corrosion-formes superficielles du karst ne sont pas toujours claires, les processus périglaciaires les ayant oblitérées.

a) *Les versants convexes de corrosion*

La corrosion sous couvent pédologique engendre des modelés arrondis, des pentes convexes: ces formes sont de règle dans les régions basses de l'Herzégovine et du Montenegro, où beaucoup de reliefs résiduels sont en *"Glavica"* (= tête, J. Roglic'), B. Bousquet (1976) insiste de son côté sur les relations entre versants convexes et lapiés *bio-pédogéniques* en Grèce occidentale. Par contre en Languedoc ou en Provence de tels reliefs ne subsistent qu'épisodiquement (buttes résiduelles du plateau des selues au N de Pourrières, Var).

b) *Les surfaces horizontales de corrosion* ou *"plans"* et *"plaines" karstiques*

C'est un trait classique des pays calcaires méditerranéens de présenter une grande variété de plans et éléments de surface d'origine variée. Certains aplanissements néogènes sont indubitablement des surfaces de corrosion comme la surface de Promina (Pliocène) dans l'arrière pays de Sibenik d'après J. Roglič 1952, ou celle de la Alcarria au NE de la Nouvelle Castille, qui recoupe les calcaires pontiens, d'après J. Vaudour 1975. Plus généralement, les pays calcaires du N de la Méditerranée ont connu au Miocène une longue période de biostasie favorable à la réalisation de vastes aplanissements de ce type. Malheureusement les processus restent hypothétiques.

Au contraire le rôle de la crypto-corrosion peut s'observer dans le fond des poljés actifs du karst dinarique, généralement des petits poljés proches du littoral, les autres ayant été largement remblayés par les matériaux périglaciaires (Lika, Livno, Duvno, etc. ou fluviatiles (Popovo). De même B. Bousquet (1976 p. 352) décrit les surfaces de corrosion des semi-poljés d'Epire. Rappelons que le Grand Plan de Caniuers est un ancien fond de poljé corrodé, l'abaissement d'environ 400 m du niveau des circulations souterraines au cours du Quaternaire l'ayant stérilisé. Dans le cas remarquable du petit poljé de Dugo, entre Split et Sinj, observé avec J. Roglic (Fig. 2), une surface de corrosion ancienne et simplement entretenue domine la surface active du fond du poljé.

c) *Les cônes rocheux* (rock-fans)

Ce sont des formes anciennes, héritées, dont l'interprétation génétique est délicate. Dans quelque cas remarquables ils se raccordent aux fonds corrodés d'anciens poljés: Grand Plan de Canjuers, et Plan de Majastre en Provence, Poljé de Rognes sur le Causse de Blandas, Canale de Pirro dans le Murge des Pouilles; ou à des plaines de corrosion (La Malle au dessus de Grasse, M. Julian 1976, plaines karstiques d'Epire, B. Bousquet *ibidem).*

La genèse de telles formes se situe dans un Quaternaire ancien lors des premières crises climatiques; elle suppose une inter-action de processus:

— écoulements de type aréolaire — infiltration bloquée par l'abondance de la *terra-rossa)* — nappe phréatique *(groundwater)* proche de la surface.	ces conditions permettent la corrosion du calcaire et les possibilites de déblaiement

Les relations fréquentes cônes rocheux — fonds de poljés, ne sont pas fortuites, mais traduisent des conditions favorables au développement de la crypto-corrosion, comme dans les karsts pédiments tropicaux (M. Sweeting 1972, p. 286).

Bibliographie
(limitée aux travaux récents et essentiels)

Beaudet, G. Birot, P. Bomer, G. Lhenaff, R. et Nicod, J. — 1976. Colloque sur les glacis et aplanissements partiels sur calcaires. *Bull. Ass. Geogr. Fr.*, no. 437-438.

Bonnefont, J.C. — 1972. La crête, étude morphogique, *these* Paris.

Bousquet, B. — 1974. La Grèce nord-occidentale: interpétation morphologique de l'Epire, de l'Acarnanie et des Iles Ioniennes, *these* Paris.

Büdel, J. — 1973. Reliefgenerationen der Poljenbildung im dinarischen Raum; Neue Ergbenisse in den Tropen und im Mittelmeeraum, *Geogr. Zeitschrift* — Beihefte, p. 134-142.

Coulet, E. 1975. Morphologie des plaines et des garrigues languedociennes. Thèse, Montpellier (6 vol. ronéo).
Julian, M. 1976. Les Alpes Maritimes franco-italiennes, étude géomorphologique, *these* — Aix (3 vol. ronéo).
Lamouroux, M. 1976. Le Karst libanais, sols de karst et altération des roches carbonatées. *Mem.et Doc. C.N.R.S.*, Phénomènes Karstiques IV, p. 15-26
Miotke, F.O. 1973. Die Tieferlegung der Oberflachen zwischen Mogoten in Puerto Rico; Neue Ergbenisse. *Geogr. Zeitschrift*, Beihefte, p. 34-43.
Neboit, F.D. 1975. Plateaux et collines de Lucanie orientale et des Pouilles, *These* Paris 1974.
Nicod, J. 1975. Corrosion de type crypto-karstique dans les karsts méditerranéens. *Bull. Ass. Geog. Fr., méditerranéans*, No. 428, pp. 284-297.
Oliva, P. 1972. Aspects et problemes geomorphologuiques de l'AntiAtlas Occidental. *Rev. Geog. Maroc*, no. 21, p. 43-78.
Pfeffer, K.H. 1975. Zur Genese von Oberflachenformen in Gebieten mit flachlagerden Carbonatgesteinen, Steiner Verlag.
Roglic', J. 1952. Le surfaces de corrosion dans le karst dinarique *8th Int. Geog. Congress, Washington*, p. 366-369.
Rossi, G. 1976. Karst et dissolution en milieu tropical, *Zeitschrift* fur Geomorphol. *Supplementband* 28, p. 124-152.
Rossi, G. 1977. L'Extrême Nord dé Madagascar, Thèse Aix. (2 vol. ronéo).
Sweeting, M.M. 1972. Karst Landforms, Macmillan.
Vaudour, J. 1975. Recherches sur la Terra Rossa de la Alcarria (Nouvelle Castille); *Mem et Doc. CNRS* Phénomènes Karstiques II, p. 49-79.
Wall, R.D. et Wilford, G.E. 1965. Karst topography in Sarawak, *Jour. Trop. Geogr.*, Singapore, p. 42-70.

BIOLOGICAL RESEARCHES OF PEGMATITE CAVES IN SLOVENIA (YUGOSLAVIA)

T. Novak
Institute for Karst Research
SAZU, Postojna, Yugoslavia

N. Sivec
Institute of Biology, University Ljubljana,
POB 141/3, Yugoslavia

Two caves were found in rotten pegmatites near the village Ravne na Koroškem, NE Slovenia. As they were the first registered underground features in Slovenia developed in noncarbonate rocks their biological inventories were of special interest for Slovene speleobiologists. Results could also be of interest for European biospeleology as faunistic lists from noncarbonate caves of Europe are rare.

Ecological Designation

Both caves — Jama pri Votli peči and Ravbarska luknja — are small (10 - 20m) economically unimportant features. Only results from the first cave are represented here (100% psychrometric air humidity and temperature 8 - 10°C were registered in the lower half at the last visit) because there are great external influences in the second. A contact zone between pegmatites and slates runs through the first cave and makes it still more attractive.

The nearest limestones are about 2 km far from the caves. We think this fact is important for differences in carbonate anion (the great deficiency of carbonate anion is expressed most in a poor malacofauna). Calcium is present in the pegmatites in low proportion (1-2%). Like the pegmatites the slates show relatively high pH value (8-9) which is altered near entrances because of the surrounding associations of Querco-Carpinetum, Piceetum and Pinetum from pH 8 to pH 3,9.

Materials and Methods

The best possible faunistic survey of both caves was our purpose. They have been explored by the same methods as neighbouring limestone caves for the possibility of comparison of their inventories:

1. Pit-fall traps with decomposing meat and monoethyleneglycol mixed with cherry and marascino essences were placed in the cave three times (30 traps at once on average).
2. Soil samples were gathered for malacofauna analysis (about 15kg).
3. Soil samples of about 0.2kg were taken previously from each pit-fall trap location for thorough drying in modified Tulgren's funnels.
4. Predators which mostly do not enter into the traps, were chiefly collected under stones.
5. Parietal fauna was caught by use of exhaustors and manually.

Revision of Collected Material

1. The following animals were caught into the pit-fall traps in bigger numbers (over 10):

Lithobius agilis, (Lithobiidae, Chilopoda),
Attemsiidae, (Diplopoda),
Trachysphaera (=Gervaisia) sp., (Trachisphaeridae, Diplopoda),
Tomoceros minor, (Tomoceridae, Collembola),
Antisphodrus (=Laemostenus) schreibersi, (Carabidae, Coleoptera),
Catops sp., (Catopidae, Coleoptera),
Atheta sp., (Staphylinidae, Coleoptera) and

Trichoceridae (Diptera).

Anophthalmus sp. nov., (Carabidae, Coleoptera), and Phoridae, Lycoridae (=Sciaridae), Limoniidae and Psychodidae, (all Diptera) were caught in smaller numbers.

2. Only single snail shells could be found in the soil materials:

Discus perspectivus, (Endodontidae),
Aegopis verticillus, (Zonitidae),
Daudebardia, sp., (Zonitidae),
Carychium tridentatum, (Ellobiidae),
Helicigona planospira, (Helicidae).

3. From Tullgren's funnels the subsequent fauna was gathered in bigger numbers:

Enchytraeidae, (Oligochaeta),
Acarina,
Protura,
Collembola.

We must point out that nearly all individuals of Oniscoidea (Isopoda), Symphyla, Pseudosorpiones, Campodeidae, (Diplura), Leptinus testaceus, (Leptinidae, Coleoptera) were also collected by this method although in smaller numbers.

4. New species of *Anophthalmus* the spider *Lephtyphantes* sp., (Linyphiidae) and opilion *Euscotolemon* sp (Phalangodidae) have been collected under the stones. Three beetle species of genus *Trechus,* (Carabidae) live in the soil of the entrance part of the cave: *T. croaticus, T. rotundipennis cordicollis* and *T.sp.* still undetermined).

The mushroom *Nematoloma capnoides* was found once on rotten wood on the floor of the cave.

5. From the cave walls, there was collected the following fauna:

Oxychilus (Riedelius) depressus, (Zonitidae, Gastropoda),
Aegopis verticillus, (Zonitidae, Gastropoda),
Helicigona planospira, (Helicidae),
Meta menardi, (Araneidae, Araneae),
Meta merianae, (Araneidae, Araneae),
Nesticus cellulanus, (Nesticidae, Araneae),
Nelima aurantiaca, (Phalangidae, Opiliones),
Machilis sp., (Machilidae, Thysanura),
Troglophilus cavicola, (Raphidophoridae, Saltatoria),
Scoliopteryx libatrix, (Geometridae, Lepidoptera),
Culicidae, (Diptera),
Speolepta leptogaster, (Mycetophilidae (=Fungivoridae), Diptera),
Rhinolophus hippossideros, (Chiroptera).

Some ants, thysanopterans and other typically epigeic animals that came into the cave incidentally are not listed here.

Some Statements

1. The snail species *Oxychilus (Riedelius) depressus* which appears in much greater extent in west Europe was found for the first time in Slovenia.

2. The small snail *Zospeum* and the small beetle *Aphaobiella tisnicensis,* common in southern neighbouring caves, were not found there. Their absence could be explained by this being their northern distribution border.

3. The opilion species *Nelima aurantiaca* was perceived in much smaller number here than in some limestone caves of the same dimensions.

4. Only specimens of *Troglophilus cavicola* were found in Jama pri Votli peči although in all surrounding limestone caves there is also *T.neglectus.* The last species can even be predominant there.

5. Every attention must be paid to the mural distribution: in October 1975 of 36 registered individuals of *Troglophilus* 35 were located on the slate walls as was the case for larvae of *Speolepta leptogaster. Oxychilus* and *Scoliopteryx* individuals were seen only on the pegmatites. The reasons for these placement differences have not been cleared up yet.

6. Fauna from two artificial cavities by Dravograd (7km far away) was looked over, too (25m; 7m long). These had been dug out in Paleozoic noncarbonate rocks, yet not in pegmatites. Although great external influences were evident in them we still thought them appropriate for rough comparison. In the longer cavern there were caught into pit-fall traps at the same occasion 50 individuals of the beetle species *Pterostichus fasciatopunctatus* (Carabidae); individuals of spider species *Nesticus celullaus* were gathered manually.

In the second one the beetle species *Antisphodrus schreibersi* was in 1972 found – the first location from noncarbonate territories of Slovenia. All other gathered fauna is typically epigeic.

Fig. 1. Location map of Slovenia.

Conclusion

General comparison of the fauna from Jama pri Votli peči with faunistic lists from surrounding carbonate caves shows nearly perfect agreement. The absence of some expected species could be explained by the proximity of their distributional borders. The faunistic composition except for Mollusca, is practically uninfluenced by the geological basis.

It seems that differences in population powers result mostly from the geological conditions (other physical and chemical properties). New specific biological balances are developed, uncommon to fauna settling caves in limestones.

Relations between the biological inventories and physical texture of rocks in which caves appear, shows that only soil species can be established in cavities of compact noncarbonate rocks. The cavities by Dravograd could represent this case. If, however, there are fissures or larger "empty" space connections in noncarbonates the hypogeic fauna can also enter them permanently and therefore become established in their cavities. Comparisons taken between the fauna from pegmatite caves by Ravne na Koroskem and from surrounding limestone caves show close general connection. Tectonic fissures are supposed to be the reason.

The isolated karst of Slovenia on one hand and numerous artificial cavities in noncarbonates with various geological and physical texture on the other seem to be ideal ground for studying these problems.

References

Bole, J. 1974, Rod Zospeum Bourg. 1856 (Gastropoda, Ellobiidae) v Jugoslaviji. = Die Gattung Zospeum Bourg. 1856 (Gastropoda, Ellobiidae) in Jugoslawien., Razprave SAZU 17/5: 249-291, Ljubljana.

Drobne, F. 1958: Prevalje — Uršlja gora, Geoloski izleti po Sloveniji: 200-207, MK Ljubljana.

Riedal, A., Velkovrh, F. 1977. Drie neue balkanische Zonitiden (Gastropoda) und neue Fune einiger selten Arten, Biol. vest., Ljubljana (in press).

Velkovrh, F. 1974. Razširjenost gastropodov po drobnih špranjah v krasu. = The Distribution of Gastropoda in Small Karstic Fissures, Naše jame, 15: 77-82, Ljubljana.

Vandel, A. 1964. Biospéologie, Gauthier Villars Editeur, Paris.

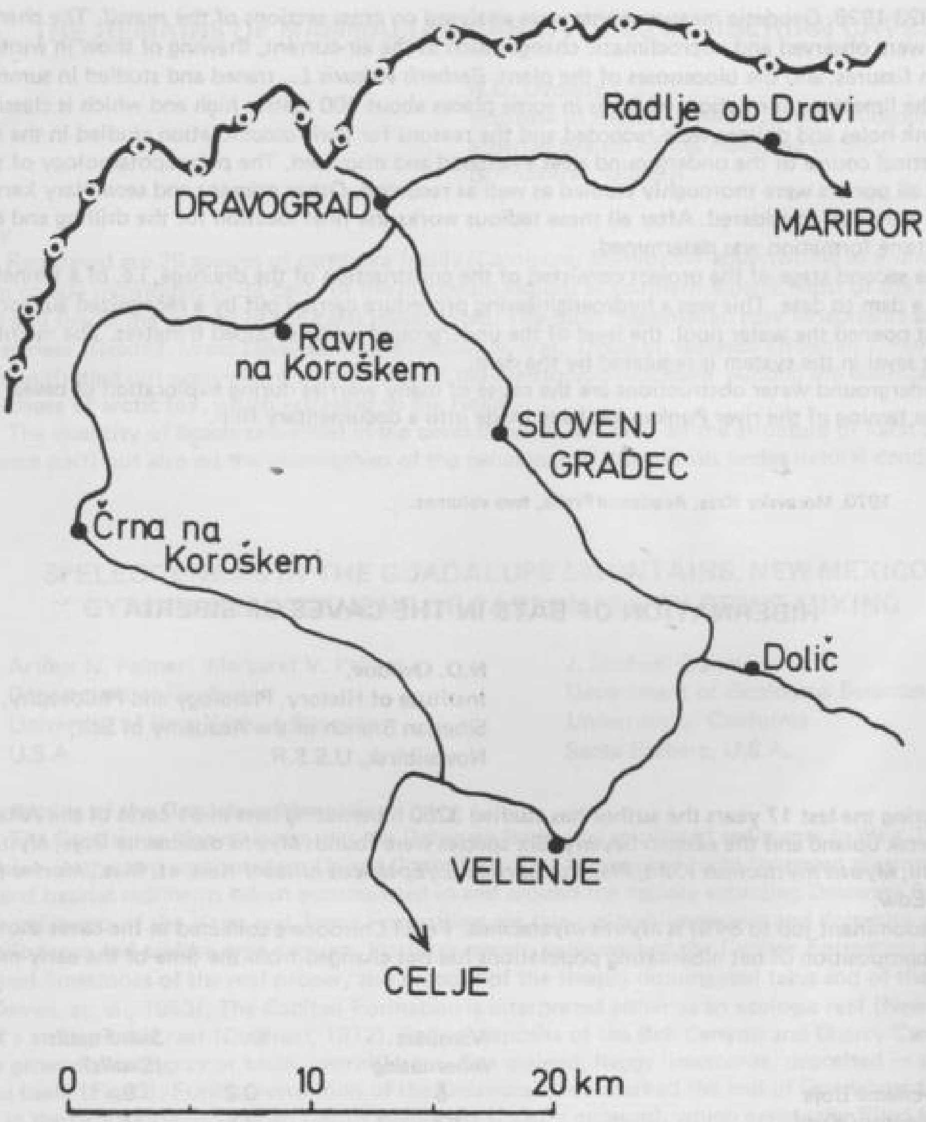


Fig. 2. Enlarged portion of Fig. 1. The Pegmatite Caves are near Ravne na Koroskem; the artifical cavities and caves are near Dravograd.

SUBTERRANEAN WATER OBSTRUCTING SPELAEOLOGICAL WORK AND THE BY-PASS OPERATIONS

O. Ondrousek, E. Coufalik, G. Cubuk,
M. Kala and H. Salm
M.R.C. Clinical Research Centre, Watford Rd,
Harrow, Middlesex. HA1 3UJ

The syphons, subterranean lakes and rivers filled with water which obstruct passages in the cavitary systems present serious problems to the spelaeologist and to his research work. Further exploration is possible only when water-levels are lowered, by means of installation of water pumps or by a proper drainage of the cavities of the limestone formation.

Such artificial drainage of the Punkva Caves in the Moravian Karst and lowering the level of underground water by 6 metres was successfully accomplished in 1932. Since then the subterranean course of the river Punkva has been known and a free passage on boats has been possible.

The right place for drilling and blasting this artificial drainage was discovered after a careful spelaeological research project, Professor Absolon, as leader.

In the first stage all data was carefully recorded, photographed and explored. Hydrological conditions were observed and the hydrography of the formation and its environment cartographically evaluated in a special map. Hypsometrical measurements under different meteorological conditions were carried out within

thě years 1923-1926. Geodetic measurements were analysed on cross sections of the massif. The changes of the climate were observed and microclimatic changes such as the air-current, thawing of snow in winter, escape of bats from fissures, and the biocenoses of the plant, *Berberis vulgaris L.*, traced and studied in summer. On the top of the limestone formation, which is in some places about 200 metres high and which is classified as a polje, the sink-holes and dolines were recorded and the reasons for their accumulation studied in the map and the hypothetical course of the underground river evaluated and discussed. The palaeopotamology of the river Punkva and all ponors were thoroughly studied as well as recorded. Other primary and secondary karstic phenomena were also considered. After all these tedious works the final location for the drilling and blasting of the limestone formation was determined.

The second stage of the project consisted of the construction of the drainage, i.e. of a tunnel which is operated as a dam to date. This was a hydroengineering procedure carried out by a recognized authority. When the last blast opened the water pool, the level of the underground water dropped 6 metres. The maintenance of the water level in the system is regulated by the dam.

Underground water obstructions are the cause of many worries during exploration of caves.

The taming of the river Punkva has been made into a documentary film.

Reference

Absolon, K. 1970. Moravsky Kras. Academia Praha, two volumes.

HIBERNATION OF BATS IN THE CAVES OF SIBERIA

N.D. Ovodov,
Institute of History, Philology and Philosophy,
Siberian Branch of the Academy of Sci.,
Novosibirsk, U.S.S.R.

During the last 17 years the author has studied 3280 hibernating bats in 51 caves of the Altay Mountains, Kuznetsk upland and the eastern Sayany. Six species were found: *Myotis dasicneme* Boje, *Myotis daubentoni* Kuhl, *Myotis mystacinus* Kuhl, *Plecotus auritus* L., *Eptesicus nilssoni* Keis. et. Blas., *Murina leucogaster* Miln-Edw.

Predominant (up to 84%) is *Myotis mystacinus.* Fossil Chiroptera collected in the caves show that the species composition of bat hibernating populations has not changed from the time of the early-middle Holocene.

Species	*Numbers hibernating*	%	*Sub-Fossils (Skulls)*	%
Myotis dasycneme Boje	5	0.2	9	1.0
Myotis daubentoni Kuhl	62	2.4	37	4.1
Myotis mystacinus Kuhl	2180	83.9	174	19.1
Plecotus auritus L	226	8.7	308	34.1
Eptesicus nilssoni Keis et Blas	104	4.0	259	29.0
Murina leucogaster Milne-Edw.	20	1.8	107	12.9
Totals	2597	100	894	100

MAMMALIAN FOSSILS FROM THE CAVES OF SIKHOTE-ALIN' (SOUTH-EAST USSR)

N.D. Ovodov,
Institute of History, Philology and Philosophy,
Siberian Branch of the Academy of Sci.,
Novosibirsk, U.S.S.R.

Summary

This paper presents the results of the study of 60,000 mammalian fossils from the caves of Sikhote-Alin'.

As a whole, 52 species of teriofauna were revealed for the Late Anthropogen. For the Late Pleistocene, mammoth fauna numbers 41 species dwelling in forests, in contrast to the large territory of Northern Eurasia.

As for the Holocene, 48 mammalian species are found. In the Late Pleistocene and Holocene, much like in the present, the mixing of southern and boreal forms were observed on the Ussuri territory.

The up-to-date teriofauna of the southern part of Sikhote-Alin' inherited 30 mammalia species from the Late Pleistocene and 34 ones from the Holocene.

THE REMAINS OF MAMMALIAN CARNIVORES IN SIBERIAN CAVES

N.D. Ovodov,
Institute of History, Philology and Philosophy of the
Siberian Branch of the Academy of Sci.,
Novosibirsk, U.S.S.R.

Summary

Registered are 20 species of carnivora fossils *(Carnivora, Mammalia)* appertaining as a whole to a minimum of 504 individuals in 32 caves of the mountain regions at southern Siberia. Most of the species classified still live in the regions of the karst investigated. The other mammalian cave inhabitants such as *Crocuta spelaea* (Goldf.), *Ursus (Spelaearctos) uralensis* N. Var., *Ursus* cf. *spelaeus* (Rosenm.), *Panthera spelaea* (Goldf) died out everywhere on the verge of the Pleistocene-Holocene. Among the collected fossils there are those of arctic fox, which retreated to the North.

The quantity of beasts presented in the caves depends not only on the structure of karst cavity, (its entrance part) but also on the peculiarities of the behaviour of the animals under natural conditions.

SPELEOGENESIS IN THE GUADALUPE MOUNTAINS, NEW MEXICO: GYPSUM REPLACEMENT OF CARBONATE BY BRINE MIXING

Arthur N. Palmer Margaret V. Palmer
Department of Geology
University of New York at Oneonta
U.S.A.

J. Michael Queen
Department of Geological Sciences,
University of California
Santa Barbara, U.S.A.

Geologic Setting of the Guadalupe Mountains

The Guadalupe Mountains border the Delaware Basin and associated sediments in West Texas and New Mexico, in the arid southwestern United States (Fig. 1). The exposed rocks represent platform, platform margin, and basinal sediments which accumulated in and around the rapidly subsiding Delaware Basin (Fig. 2). Platform sediments of the Yates and Tansil Formations are fine-grained limestones and dolomite with interbedded siltstones and sabkha-type gypsum. Platform margin sediments of the Capitan Formation are massive fine-grained limestones of the reef proper, and breccias of the steeply dipping reef talus and of the lobate debris flows (Newell, et. al., 1953). The Capitan Formation is interpreted either as an ecologic reef (Newell, et. al., 1953) or a stratigraphic reef (Dunham, 1972). Basinal deposits of the Bell Canyon and Cherry Canyon Formations are generally dark gray or black, petroliferous, fine grained, flaggy limestones, deposited in a starved, restricted basin (Fig. 3). Further restriction of the Delaware Basin marked the end of Guadalupe time, and resulted in the deposition of Ochoan Castile evaporites (mostly gypsum), which eventually filled the basin and covered the platform margin (Dunham, 1972).

The Guadalupe Mountains were uplifted as a north-east dipping, fault-bounded block during the Laramide Orogeny (upper Mesozoic-lower Cenozoic). During the Cenozoic, erosion and solution removed much of the Castile evaporites from the mountain front. Later, in the Pliocene, clastics of the Ogalala Formation buried much of the front; these were largely removed by Pleistocene erosion. At present the Guadalupe

Figure 1 - Paleogeographic reconstruction of the Permian Delaware Basin and surrounding environments. Also shown are the distribution of Permian Reefs (Hatches) and the location of the Guadalupe Mountains (after Newell et al., 1953).

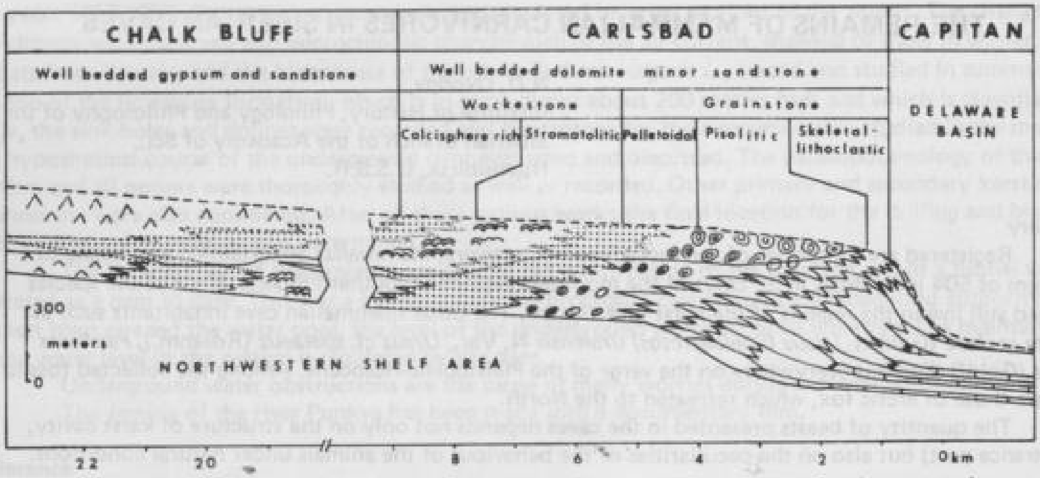


Figure 2 - Reconstructed section normal to the Guadalupe (Capitan) escarpment, showing the facies relationships and paleotopography. The irregular line truncating the facies marks the current topographic surface (from Dunham, 1972).

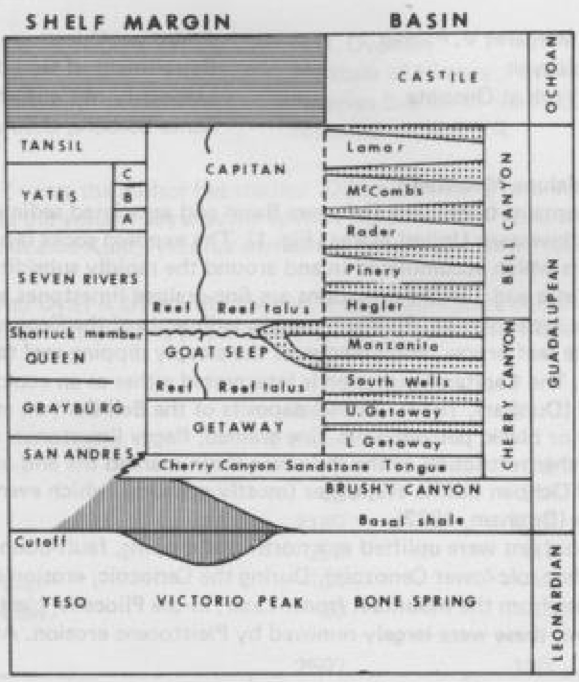


Figure 3 - Composite stratigraphic section for the Leonardian, Guadalupean, and Ochoan of the Guadalupe Mountains and Delaware Basin (from Newell et al., 1953).

Mountains reflect the original relief of the platform-basin transition.

Caves of the Guadalupe Mountains

The Guadalupe Mountains contain large, well decorated caves within the platform and marginal rocks: most famous are the Carlsbad Caverns. Guadalupean caverns are characterised by large joint controlled rooms and smaller rooms of a coarse spongework nature on many levels, or as subsequently altered by frequently massive collapse. Caves may be developed along joints, strata, or perhaps macropores. Typically, passages are rare and rooms are floored by sediment, travertine, or collapse blocks. Furthermore, surface karstification is rare, and the size of caves shows no relation to the associated areas of recharge: no ancient or recent recharge points are recognizable. While diverse phreatic structures are common, no early vadose features are seen.

Many of the caves contain thick (to 10 m) blocks of gypsum over distances as much as 1000 m within the caves. These beds were interpreted by Bretz (1949) and Good (1957) as being deposits lain down within the cave by gypsum-saturated waters. Bretz also drew attention to travertine showing evidence of phreatic solution: both gypsum deposition and the phreatic solution of gypsum and carbonate were believed to occur during a rise in base level following deposition of the Ogalala Formation.

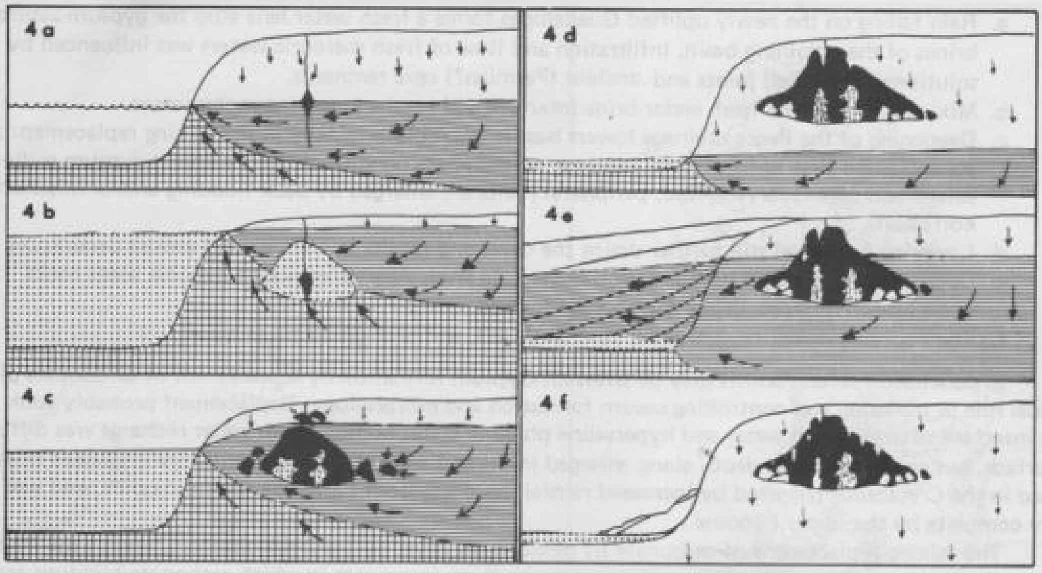


Figure 4 a-f - Schematic reconstruction of the events which resulted in gypsum replacement of carbonate, and the solution of gypsum and carbonate to form the caves of the Guadalupes. Gypsum: dots. Freshwater: horizontal lines. Brine: checks. Void: black. Arrows represent direction of water movement. See text for description.

Speleogenesis in the Guadalupe Mountains: Mixing Replacement

Several questions must be considered: Why are the Guadalupean caves so different from most other caves of demonstrable phreatic origin? What were the origin and nature of the waters which dissolved the caves? What is the origin of the gypsum in the gypsum blocks? What other factors controlled speleogenesis in the Guadalupe Mountains?

A careful re-examination of cavern morphology, stratigraphy and sedimentology has revealed several key relationships, and has led to a new interpretation of the origin of Guadalupe caves.

Evidence against gypsum deposition in a pre-existing void:

* Gypsum beds never include Pleistocene detrital sediments.
* Gypsum beds never overlie cavern-filling sediments or precipitates.
* Gypsum beds never fill the spongework which often closes peripheral joints and fissures.

Evidence bearing on gypsum as a replacement after carbonate:

* Gypsum blocks in Carlsbad Caverns and Cottonwood Cave may be found which display all the petrographic textures found in the surrounding carbonates: travertine, pisolites, fossils, breccias, bedding, and primary pores. Where no displacement or recrystallization of the gypsum has occurred these textures in the gypsum may be correlated bed for bed with the carbonate. The contact of this type of gypsum with the carbonate is knife sharp. Recrystallization of gypsum is very common.
* Little carbonate solution has taken place since deposition of the gypsum: what solution has followed gypsum deposition has been limited to enlargement of spongework.
* Alternating light and dark zones in the gypsum parallel to the cave wall or floor may cross primary bedding and are interpreted as bands of progressive gypsum replacement.
* Initial gypsum solution was phreatic, resulting in bizarre, unoriented gypsum blocks.
* Subsequent gypsum solution was vadose, resulting in vertically oriented drip holes. In addition, some late vadose depositional features, such as travertine have been replaced by gypsum along a diffuse front parallel to the surface. Similar replacement fabrics have been observed by the authors in other regions, and may have taken place in the vadose zone by the delivery of sulphate to the caves through permiable zones from nearby platform gypsum deposits.

Based on these observations, certain important conclusions may be drawn:

The first stage of speleogenesis was the massive replacement of carbonate by sulphate. Cave growth after replacement has been by solution of the gypsum (first phreatic, then vadose) and by enlargement of peripheral joints by the continued development of spongework.

However, two important questions remain: How did gypsum replacement occur? What was the nature of subsequent carbonate solution? Considering the works of Bögli (1964), Runnells (1969), and Plummer (1975) it is most reasonable to assume that replacement took place at the mixing zone between fresh meteoric phreatic waters originating in the newly risen Guadalupe Mountains, and gypsum-saturated brines of the still full Delaware Basin, by the reaction:

$$2H_2O + CaCO_3 + SO_4^{=} \longrightarrow CO_3^{=} + CaSO_4.2H_2O$$

We may thus revise the interpreted sequence of events leading to speleogenesis in the Guadalupes (Fig. 4):

a. Rain falling on the newly uplifted Guadalupes forms a fresh water lens atop the gypsum-saturated brines of the adjoining basin. Infiltration and flow of fresh meteoric waters was influenced by solutionally enlarged joints and ancient (Permian?) cave remnants.
b. Mixing occurs at the fresh water-brine interface and results in mixing replacement.
c. Deepening of the Pecos drainage lowers base level: rocks originally in the mixing replacement zone are subjected first to fresh water phreatic, then vadose conditions. Replacement gypsum is dissolved and often recrystallized; peripheral joints are enlarged by back flooding and/or Mischungskorrosion.
d. Lowering base level still further drains the caves and results in collapse and vadose decoration.
e. Deposition of the Ogalala Formation raises base level. Aggressive waters dissolve some rocks while elsewhere subaqueous deposits are formed.
f. The Ogalala Formation is eroded, base level falls, and decoration takes place.

In conclusion several points may be stressed. Gypsum formation by replacement of carbonates played a critical role in initiating and controlling cavern formation and morphology. Replacement probably took place in the interface between fresh water and hypersaline phreatic water bodies. Fresh water recharge was diffuse at the surface, but concentrated at depth along enlarged joints and ancient cave remnants. Speleogenesis commenced in the Cretaceous triggered by increased rainfall resulting from Laramide orogenic uplift, and was largely complete by the upper Pliocene.

The mixing-replacement of carbonate by gypsum has never before been observed. Such a mechanism is likely of great diagenetic and speleogenetic importance in environments in which carbonate buildups are laterally associated with large evaporite deposits: caves and carbonates of the evaporite basins of the Paleozoic and Mesozoic should be reviewed with this in mind.

Work is currently underway by the authors on the hydrology, geochemistry, petrography, and distribution of rocks associated with and responsible for mixing-replacement in the Guadalupe Mountains.

Acknowledgement

The authors wish to thank the United States Forest Service, the United States Park Service, and the Cave Research Foundation for their logistic support and cooperation, freely given throughout the course of the work; and Vassar College for a Faculty Grant-in-Aid to J.M.Q. for partial support of the 1975 field work. Especially thanks are given to Messrs. S. Ackerly, K. Hill, A. Hinds, D. Jagdow, J. Trout, and P. Van Cleave.

References

Bögli, A. 1964. Mischungskorrosion: Einbeitrag zum ver Karstungsproblem. *Erkund* 18:83-92.
Bretz, J.H. 1949. Carlsbad Caverns and other caves of the Guadalupe Block. *J. Geol.* 57:447-463.
Dunham, R.J. 1972. Capitan Reef, New Mexico and Texas: Facts and questions to aid interpretation and group discussion. *Soc. Econ. Paleontol. Mineral.*, Publ. 72:14.
Good, J.M. 1957. Non-carbonate deposits of Carlsbad Caverns, *Nat. Speleol. Soc. Bull.* 19:11-23.
Newell, N.D. Rigby, J.K. Fischer, A.G., Whiteman, A.J. Hickox, J.E. & Bradley, J.J. 1953. *The Permian Reef Complex of the Guadalupe Mountains region, Texas and New Mexico.* Freeman & Co., San Francisco, 236 p.
Plummer, L.N. 1975. Mixing of sea water with calcium carbonate ground water. *Geol. Soc. Am. Mem.* 142:219-238.
Runnells, D.D. 1969. Diagenesis, chemical sediments and the mixing of natural waters. *J. Sediment Petrol.* 39:1188-1201.

GEOLOGY AND ORIGIN OF THE CAVES OF BERMUDA

Arthur N. Palmer Margaret V. Palmer
Department of Geology
University of New York at Oneonta,
U.S.A.

J. Michael Queen
Department of Geological Sciences,
University of California,
Santa Barbara, U.S.A.

Geologic Setting

The Bermuda islands comprise 56 km^2 of Pleistocene limestones that rim the southeastern part of a submerged volcanic platform. Most of the limestones are eolian calcarenites bordered seaward by gently dipping beach facies and separated chronologically by paleosols. Major topographic features are determined by solutionally modified dunes, with individual dunes reaching maximum heights of 70 m. The major limestone formations are the Walsingham (early Pleistocene), Belmont (Yarmouth?), and Paget (late Pleistocene). With increasing age, but varying locally with the pattern of infiltration, the dune limestones become more indurated, less porous, more permeable, and lower in aragonite/calcite and Mg/Ca ratio (Land, et. al., 1967). Because of the high infiltration capacity there is no natural surface runoff. A phreatic lens of fresh water overlies salt water in the low-permeability Paget, but the lens is thin, with a diffuse lower boundary in the older, more permeable rocks (Vacher, 1974).

Caves

Known caves of Bermuda are nearly all in the Walsingham Formation, apparently because of its structural competence and the greater time span available for cave development in the older rocks (Fig. 1). However, a few small caves are also found in younger rocks. Caves are irregular in pattern and in distribution, and most

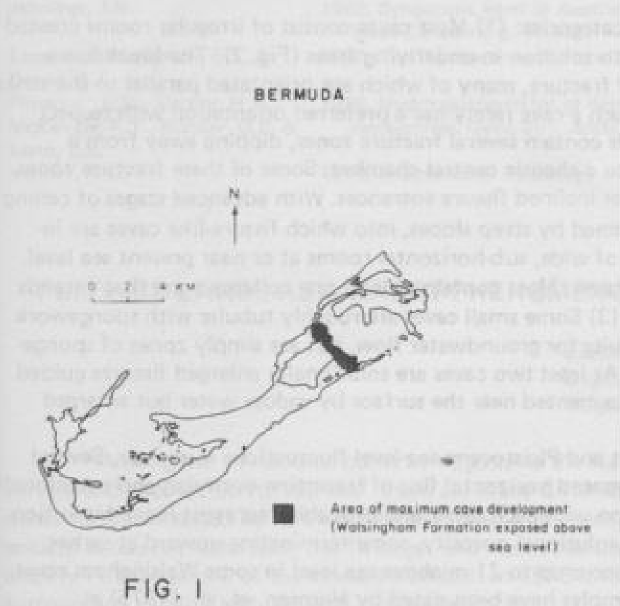
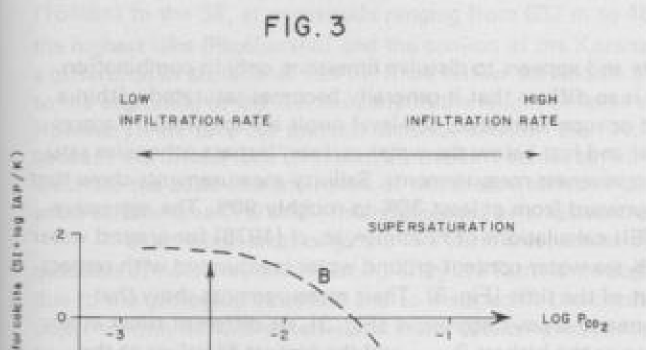


FIG. 1

FIG. 3



GENERALIZED VALUES OF SATURATION INDEX FOR CALCITE WITH RESPECT TO LOG P_{CO_2} FOR BERMUDA GROUND WATER
(partly from field measurements by Plummer et al., 1976).

A: low sea-water concentration (≦ 1%)
B: medium to high sea-water concentration (≧ 1%)
As permeability increases with time, SI values increase from approximately curve A to curve B.
Curves represent average values at any given measurement site; some measurements show considerable scatter at intermediate P_{CO_2} values.

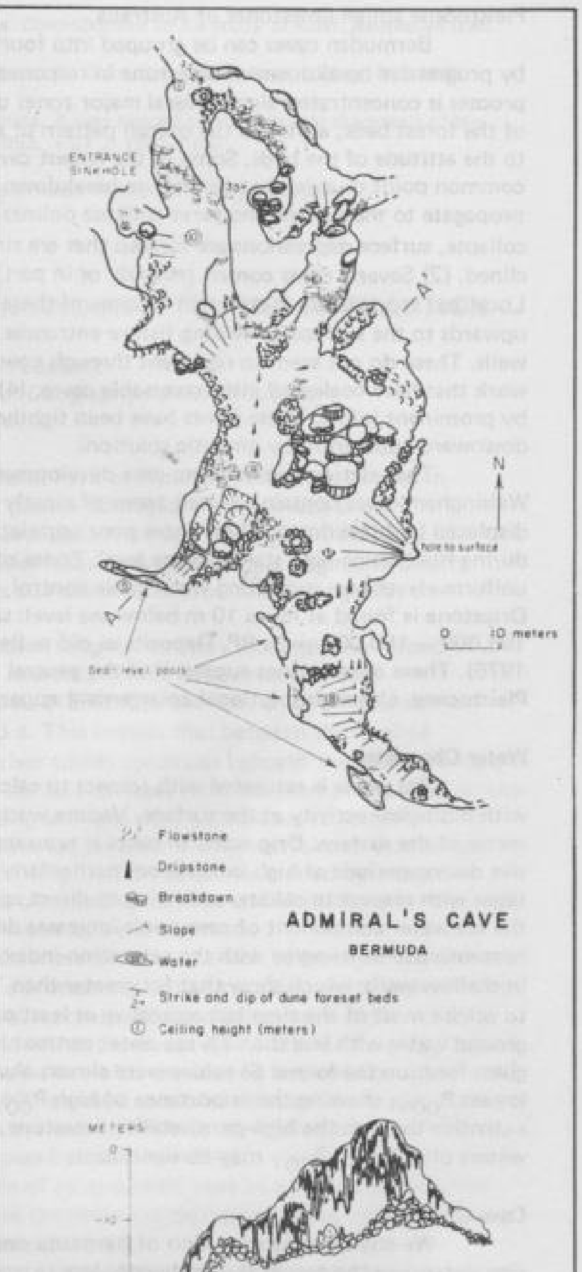


FIG. 2

are dominated by extensive breakdown that masks their original solutional form. Most caves are located between 10 m above and below present sea level, although some of the largest (formed almost entirely by collapse) are found as high as 35 m above sea level. Nearly every cave can be traversed downward to sea-level pools of brackish water. Such pools, some of which are at least 12 m deep, fluctuate with the tides with an average daily amplitude of roughly 45 cm. Readily identified solutional cave features are limited almost exclusively to isolated zones of spongework or wall and ceiling pockets, although rare solutional fissures occur along joints or partings. With only minor exceptions, solution features in caves have no preferred gravitational orientation, which suggests a phreatic origin. Extensive travertine is found commonly extending below sea level and in places overlying breakdown. Cave morphology is rather similar to that described by Jennings (1968) in

Pleistocene eolian limestones of Australia.

Bermudan caves can be grouped into four categories: (1) Most caves consist of irregular rooms created by progressive breakdown of limestone in response to solution in underlying areas (Fig. 2). The breakdown process is concentrated along several major zones of fracture, many of which are orientated parallel to the strike of the forest beds, although the overall pattern of such a cave rarely has a preferred orientation with respect to the attitude of the beds. Some of the largest caves contain several fracture zones, dipping away from a common point or axis, that contribute breakdown to a chaotic central chamber. Some of these fracture zones propagate to the surface and form collapse dolines or inclined fissure entrances. With advanced stages of ceiling collapse, surface depressions are formed that are rimmed by steep slopes, into which fissure-like caves are inclined. (2) Several caves consist (entirely or in part) of wide, sub-horizontal rooms at or near present sea level. Localized spongework is common in some of these caves. Most contain at least one collapse zone that extends upwards to the surface, providing fissure entrances. (3) Some small caves are roughly tubular with spongework walls. These do not seem to represent through conduits for groundwater flow, but are simply zones of spongework that have coalesced into traversable caves. (4) At least two caves are solutionally enlarged fissures guided by prominent joints. These joints have been tightly cemented near the surface by vadose water but enlarged downward apparently by phreatic solution.

The relationship between cave development and Pleistocene sea-level fluctuations is unclear. Several Walsingham caves contain isolated zones of closely spaced horizontal fins of travertine overlying and occasionally displaced by breakdown. These show poor correlation with each other and probably represent local deposition during fluctuating high stands of sea level. Zones of solutional porosity, some terminating upward at rather uniform elevations, suggesting water-table control, occur up to 21 m above sea level in some Walsingham caves. Dripstone is found as far as 10 m below sea level; samples have been dated by Harmon, et. al., (1975) at 195,000 — 150,000 years BP. Deposits as old as Belmont occur in certain Walsingham caves (Plummer, et. al., 1976). These observations suggest that the general form of the major Walsingham caves was attained early in the Pleistocene, although solutional enlargement appears to continue today (as shown below).

Water Chemistry

Sea water is saturated with respect to calcite and appears to dissolve limestone only in combination with biological activity at the surface. Vadose water is so diffuse that it generally becomes saturated within a meter of the surface. Drip water in caves is saturated or supersaturated. Sea-level pools are solutionally aggressive during periods of high infiltration, particularly at and just below the water surface, but are otherwise saturated with respect to calcite, according to direct aggressiveness measurements. Salinity measurements show that the sea-water component of cave pools increases downward from at least 35% to roughly 90%. The aggressiveness measurements agree with the saturation-index (SI) calculations of Plummer, et. al (1976) for ground water in shallow wells, which show that for greater than 1% sea water content ground water is saturated with respect to calcite most of the time but aggressive at least part of the time (Fig. 3). Their measurements show that ground water with less than 1% sea water content is nearly always aggressive (Fig. 3). At different times at any given location the lowest SI values were almost always at the highest P_{CO_2} and the highest SI values at the lowest P_{CO_2}, showing the importance of high-P_{CO_2} vadose water to the solution process. Degassing is apparently extensive through the high-permeability limestone, and Mischungskorrosion (Bögli, 1964) between saturated waters of different P_{CO_2} may be significant.

Cave Origin

We envisage the evolution of Bermuda caves as follows: (1) Spongework is formed by locally aggressive water near the top of the freshwater lens in young limestone. At positive SI values for calcite, sparry calcite is precipitated as intergranular cement, while aragonite and high-Mg calcite are dissolved. (2) As the limestone becomes more indurated, less porous, but more permeable, the fresh-water lens becomes thinner and more diffuse. The sea-water content of the ground water increases and periods of aggressiveness become less frequent (Fig. 3). (3) As the percentage of water increases, the high Mg content of the sea water inhibits the crystallization of sparry calcite; under these conditions only aragonite and high-Mg calcite can be precipitated (Folk, 1974), but their solubility is too great for them to form at the levels of saturation found in the cave pools. Tidal flushing maintains the high Mg content of the water. During periods of high infiltration both calcite and aragonite are dissolved but are not precipitated even during periods of saturation. The rate of solution is slow because of the low velocity of water movement and because the water appears to be saturated most of the time. There is no readily visible solution or deposition on the cave walls at present sea level. (4) As solution continues, breakdown blocks subside into underlying voids, creating the irregular rooms and fissure entrances so commonly seen in Bermuda caves.

Acknowledgements

Field and laboratory work was partially supported by a National Science Foundation grant to the Bermuda Biological Station for Research (1975). Many thanks to the numerous land owners who allowed us free access to their property and caves.

References

Bögli, A. 1964, Mischungskorrosion: Ein Beitrag zum Verkarstungsproblem: *Erdkunde*, v.18, p.83-92.

Folk, R.L. 1974, The natural history of crystalline calcium carbonate: effect of magnesium content and salinity: *Jour. Sed. Petrology*, v. 44, p. 40-53.

Harmon, R.S. Thompson, P., Schwarcz, H.P. & Ford, D.C. 1975, Uranium-series dating of speleothems: *Natl. Speleol. Soc. Bull.*, v. 37, p. 21-33.

Jennings, J.N. — 1968, Syngenetic karst in Australia: *Contributions to the study of karst, Australian Natl. Univ. Canberra*, p. 41-110.

Land, L.S. McKenzie, F.T. & Gould, S.J. — 1967, The Pleistocene history of Bermuda: *Geol. Soc. Amer. Bull.*, v.78, p. 993-1006.

Plummer, L.N., Vacher, H.L., McKenzie, F.T., Bricker, O.P. & Land, L.S. — 1976, Hydrogeochemistry of Bermuda: A case history of groundwater diagenesis of biocalcarenites: *Geol. Soc. Amer. Bull.*, v.87, p.1301-1316.

Vacher, H.L. — 1974, Groundwater hydrology of Bermuda: *Public Works Dept.*, 87p.

PLITVICE LAKES AS A KARST PHENOMENON AND AS A TOURIST ATTRACTION

Zlatko Pepeonik
Dept. of Geography, Univ. of Zagreb,
Yugoslavia

Among the 14 national parks in Yugoslavia the National Park of Plitvice Lakes is unequalled in variety and beauty. On its 192 km^2 there are many different geomorphological forms, much ancient, dense forest inhabited by rare wildlife and, most important, abundant fresh and clean water; we have ancient cataracts, waterfalls, the 16 larger and numerous smaller lakes with their unique origin and beauty classify Plitvice as one of the world's wonders. In 1949 it was put under state protection along with the surrounding vicinity and declared a National Park.

Its geographical position is very convenient. It is located roughly half-way along the main road running between Zagreb and the coast, only 90 km from the nearest point of the Adriatic at Senj.

The lakes stretch SW - NE between the Mt Mala Kapela (1280m) to the NW, and Mt Plješevica (1649m) to the SE, at an altitude ranging from 637 m to 483 n. This implies that between the level of the highest lake (Proščansko) and the canyon of the Korana river which continues beneath the lakes, we have a difference in altitude of 154 m. If we follow the middle of the lake surfaces from the start of the highest lake to the beginning of the Korana canyon the length of lakes along with the waterfalls comes to roughly 10 km. However, if we take the shortest distance between the first waterfall beneath the highest lake to the last one beneath the lowest lake (Novakovica Brod) it comes to 4.5 km (Fig. 1). The abovementioned data can best illustrate the basic characteristics of this area: a series of lakes of varied shape, size and altitude, on a relatively small surface area (1.9 km^2) interconnected by a network of waterfalls and cataracts.

Since these lakes originate in a karst area, whose main characteristics is a lack of water, it raises the question of how they come about. They are formed through a process of the natural damming of a river valley due to the geological structure and to the specific bio-chemical make-up. The geological basis of the valley's upper section is made of loose and water-retaining dolomite in which the wider valley with the larger lakes is formed (Upper Lakes). In the lower section the basis is limestone in which the canyon with smaller lakes was formed (Lower Lakes). The lake valley gets approximately 1400 to 1500 mm of precipitation per year. It has only four major tributaries. Three of them flow directly into the lakes (Rivers Crna., Bijela., and Rječica), while the brook Plitvica falls as a 78 m waterfall into the canyon by the lowest lake.

In the post-Pleistocene period, when the temperature of air and water rose to a sufficient level, the slopes around the lakes were covered by varied vegetation, and the more exposed areas of the river bed were covered by colonies of travertine-forming plants, mainly algae and mosses.

The vegetation and microorganisms of the humus strata formed on the loose dolomite base, enriched the surface water with carbon dioxide (CO_2) and thus implemented the quicker solution of the dolomite and the increase of concentration of calcite carbonate ($CaCO_3$) in the water in the form of unstable calcite bicarbonate [$Ca(HCO_3)_2$]. Water thus saturated with $Ca(HCO_3)_2$ flowed over travertine-forming mosses growing on river rapids where, through bio-chemical and mechanical processes freed the dissolved $CaCO_3$ and encrusted it on the plants:

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 - CO_2 = CaCO_3 + H_2O$$

Among the travertine-forming plants, dominant are the *Bryum* mosses on rapids and *Cratoneuron* mosses under waterfalls. Their encrustation caused the growth of specific natural biological dams behind which the lakes were formed (Fig. 2). When Bryum-travertine, which grows in the direction of the river flow, and the Cratoneuron-travertine which grows vertically, join, the unique phenomenon of travertine caves often appears.

For the separation of bicarbonate, i.e. sedimentation of travertine, the optimal water speed ranges from 0.5 - 1.5 m/sec. and with a temperature above 14°C. The process of creating the travertine dams is going on today before our eyes. These fragile dams with their bountiful life, waterfalls and most of all beautiful lakes attracting many scholars and tourists. Due to this phenomenon Plitvice lakes are today the most visited national park in Yugoslavia.

In 1861 the first small building intended for travellers, with only two rooms, was erected. "The Society for the Development and Improvement of the Plitvice lakes and their Surroundings" was founded in 1893 in Zagreb, with the intention of protecting and maintaining the beauties of this area for recreation. This is one of the first movements of this type in Europe. The first recorded number of tourists was 1000 in the

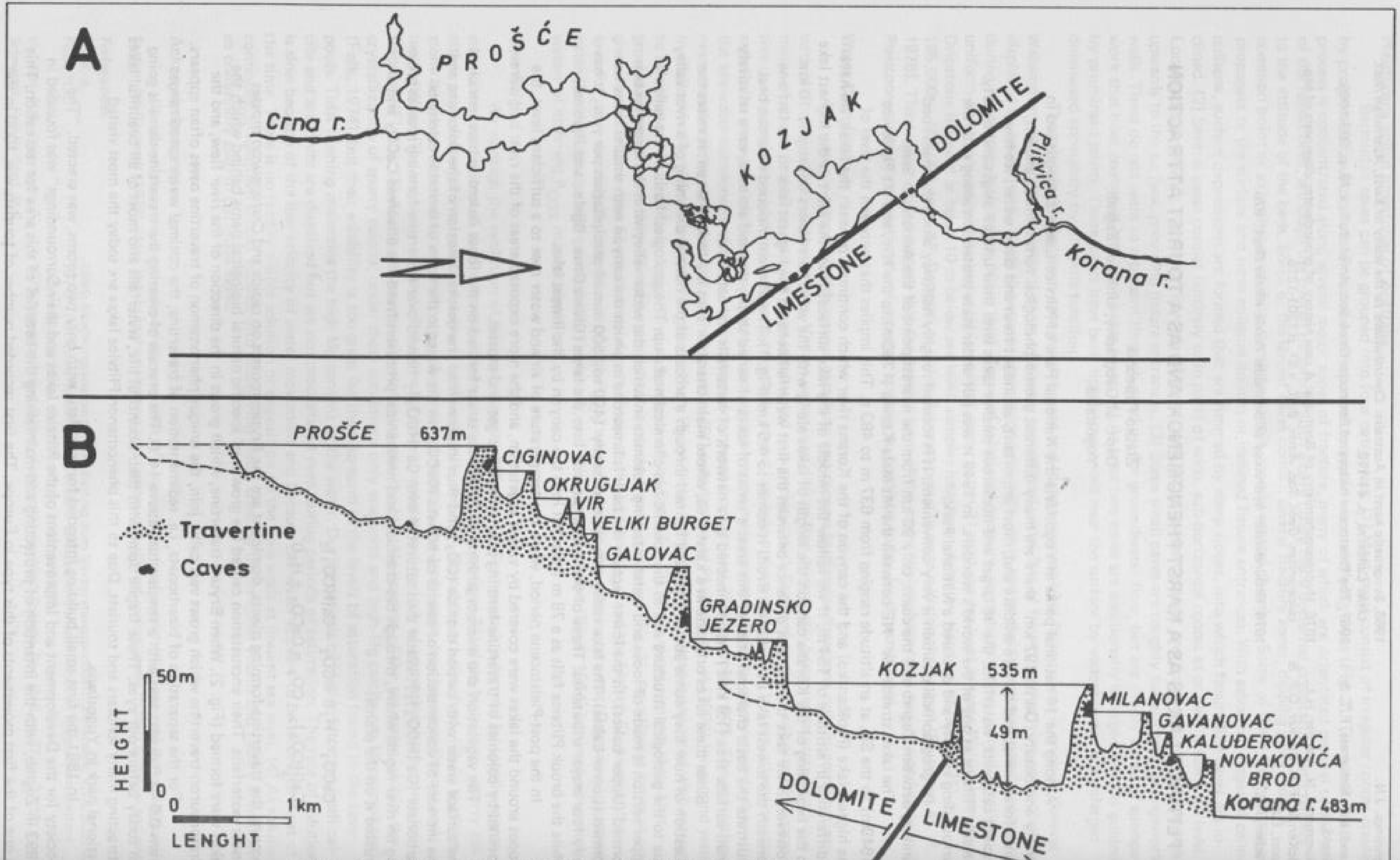


Fig. 1. Plan and profile of Plitvice lakes.

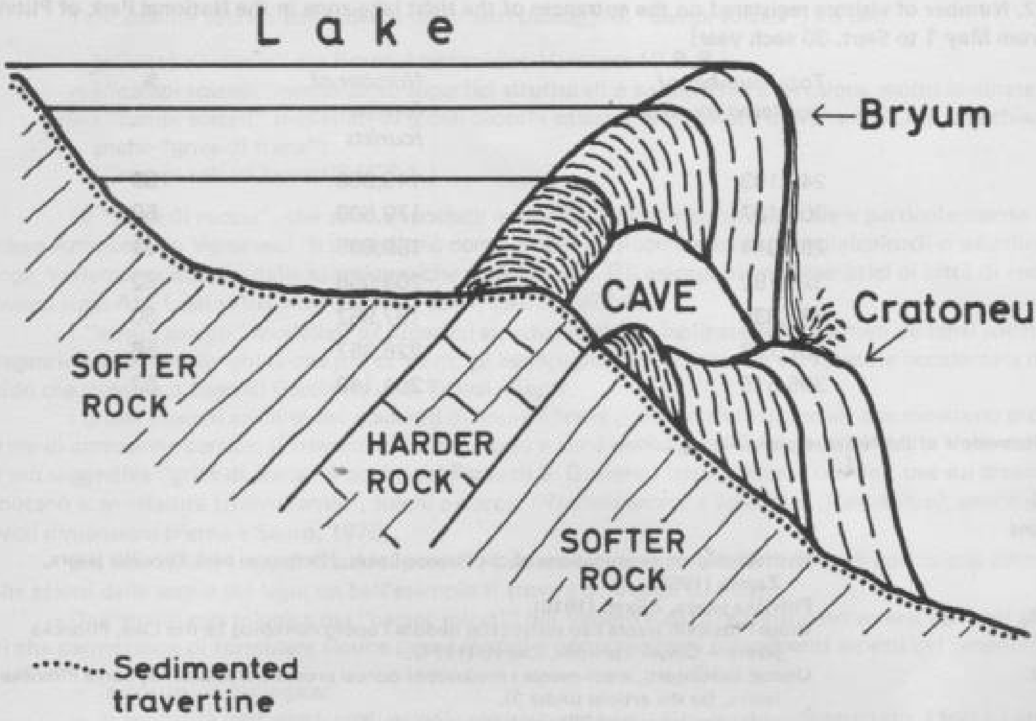


Fig. 2. Diagram illustrating the origin of travertine dams.

year 1894. The Society initiated the building of roads and paths along the lakes as well as the first hotel with 28 rooms in 1896. This opened the doors to foreign tourists. The hotel's modernisation and expansion in 1922 and the construction of the railway near that área (the station Vrhovine is 31 km away) enlarged the number of visitors to 4000 in 1927 and by the war, in 1938 to 8000 with 24000 nights spent (of which a quarter were foreign tourists).

During the war all the hotels and accompanying buildings were completely destroyed. It was only in 1951 that the first modest accommodation was built. The first hotel "Plitvice" was completed in 1958; then the hotel "Bellevue" in 1963, and finally the largest most modern "Jezero" in 1970. At the same time related catering establishments, camps, tourist settlements etc. were built.

This can be followed in the constantly growing number of hotel's visitors (Table 1). In 1955 for the first time more than 10,000 night-guests were registered, out of which only one fourth were foreign tourists; while in the last four years their number varies between 105,000 and 130,000 including 75 – 90% foreign tourists.

Because of relatively small numbers of nights spent we can see that this National Park is not a place where tourists choose to spend a longer period of time. Visitors see the lakes and waterfalls, perhaps spend a night, and then go on. The total number of visitors, including those who do not sleep there, is estimated at a half million approximately per year, over the last few years, the exact data cannot be obtained because the number of visitors is only documented for the high season, i.e. from May 1 to Sept. 30 (Table 2).

This large number of visitors, which will probably double in the foreseeable future, requires from the administration of the Park the undertaking of measures to protect the natural harmony and beauty of this unique phenomenon.

TABLE 1. Total number of tourists as registered night guests at Plitvice lakes

Year	*Total No. of visitors*	*No of foreign tourists*	*%*	*Total No. of nights*	*Nights spent by foreign tourists*	*%*
1955	11,759	2,928	25	16,141	3,717	23
1960	21,569	11,408	53	46,949	17,632	38
1965	45,071	29,253	65	100,977	55,022	55
1970	79,900	69,800	87	108,000	96,200	89
1975	129,000	105,000	81	224,000	186,000	83

Source: Statistički godišnjak Jugoslavije, Beograd (1955-1976)

TABLE 2. Number of visitors registered on the entrances of the tight lake-zone in the National Park of Plitvice Lakes (from May 1 to Sept. 30 each year)

Year	*Total number of registered tourists*	*Number of foreign tourists*	%
1970	247,193	143,000	39
1971	305,137	179,600	59
1972	262,344	159,605	61
1973	328,782	203,056	62
1974	332,635	197,852	60
1975	407,793	226,357	56
1976	395,515	204,149	52

Source: Documents of the National park Plitvice Lakes

References

Emili, H. Hydrobiological examinations of the Plitvice-Lakes, Nacionalni park Plitvička jezera, Zagreb (1958).

Franić, D. Plitvička jezera, Zagreb (1910).

Marković, S. Uloga Plitvičkih jezera kao turističkog sjedišta i općeg razvojnog žarišta Like, Plitvička jezera — Čovjek i priroda, Zagreb (1974).

Movčan, J. Utjecaj sadašnjosti, vrednovanje i medusobni odnosi prostora Nacionalnog parka Plitvička jezera, (as the articial under 3).

Polšak, A. Geološki aspekti zaštite Plitvičkih jezera (as No. 3).

Pevalek, I. The Biodynamic of the Lakes of Plitvice and their Protection (as No. 1)

Roglić, J. Unsko-Koranska zaravan i Plitvička jezera, *Geografski glasnik* XIII, Zagreb (1953).

Roglić, J. Nacionalni park Plitvička jezera i njegova pouka, *Geografski horizont* 1-4, Zagreb (1974).

Stojić, S. Nacionalni parkovi Jugoslavije . . . , Beograd (1972)

Vidakovič, P. Dosadašnji privredni razvoj i buduće vrednovanje plitvičkog područja, (as No. 3).

Nacionalni park "Plitvice", Generalni uredajni plan, Plitvička jezera (1971).

RECENTI RICERCHE SUI CAMPI SOLCATI DEL VENETO E DEL TRENTINO

Giuliano Perna
Via Marsala 13 —
38100 Trento (Italia)

Ugo Sauro
Instituto d Geografia — Via del Santo 26 —
35100 Padova (Italia)

Several limestone pavement landscapes of Veneto and Trentino (Southern Alps) whose distribution is linked with "zonal" and "azonal" factors, are here described. Among the "zonal" landscapes of limestone pavements two types are recognizable: a "glacio-karstic high mountain" type and a "glacio-karstic submediterranean" one. "Azonal" types of limestone pavements are the "rock cities" of Rosso Ammonitico Veronese, the limestone pavements on steeply dipping structural surfaces, those on rockfall niches and blocks, and the "lacustrine" ones.

Some particular aspects are discussed: the biological corrosion (responsible for the formation of solution pans and of "alveoli" the morphogenesis of the hollows, of the grikes, of the bedding planes; the connections between the development of some complex forms (solution "pan-runnel") and the environmental vicissitudes of Post-glacial Age; and finally the corrosion velocity in some environments.

The significance of small solution forms in providing some indications of the age of the huge rockfalls in limestone, which took place in the Adige and Sarca valleys in Holocene, is also outlined.

Negli ultimi anni campi solcati del Veneto e del Trentino (Italia nord-orientale) sono stati oggetto di numerosi studi da parte di varie Autori fra cui: Benetti A. (1975), Corra'G. (1970, 72, 74, 76), De Fanti A. (1971), Perna G. (1974, 74b, 74c, 75, 76) Sauro U. (1973a, 73b, 73c, 1974, 1975).

Queste ricerche hanno fornito nuovi dati utili per l'interpretazione delle piccole forme di corrosione carsica.

Quale sintesi delle conoscenze acquisite ed illustrazione sia della piccole forme che di alcuni dei più bei paesaggi di campi solcati del Veneto e del Trentino, G. Perna e U.

I paesaggi glaciocarsici di alta montagna (P.G.M.) trovano ampia espressione nel Veneto sia sulle Alpi Dolomitiche (M. Civetta, M. Marmarole), sia sui più alti Gruppi Prealpini (M. Cavallo, Altopiano di Asiago, M. Baldo) interessati da ghiacciai o nivai locali anche in epoche recenti. Aspetti particolarmente suggestivi assumono i paesaggi di corrosione nel Gruppo della Civetta ove sono ben evidenti l'azione della neve e della corrosione biologica nel modellamento carsico (De Fanti 1971).

I "paesaggi glaciocarsici submediterranei" (P.G.S.) occupano un'area limitata al settore più meridionale della valle dell'Adige a nord ovest di Verona: qui la lingua glaciale wurmiana ha "montonato" i calcari puri del Giurese inferiore; durante il Post-glaciale le soluzioni acquose hanno scolpito su queste superfici levigate dei "campi solcati libreri" (*Rundhockerkarst)*, mentre di tipo submediterraneo poco favorevoli alla pedogenesi (Sauro, 1973b). Le località più caratteristiche dei centri di Canale e di Ceraino (Corra', 1972; Sauro, 1973b; Perna, 1974).

Tipicamente azonali sono invece molti altri paesaggi di "campi solcati", fra cui:

- le "città di roccia" del Rosso Ammonitico Veronese (C.R.R.);
- i "campi solcati" modellati su superfici strutturali o su superfici di erosione molto inclinate (C.S.I.);
- i "campi solcati" modellati su grossi blocchi calcarei di macereto di frana (C.S.F.), che chiameremo anche "grize di frana";
- i "campi solcati lacustri" (C.S.L.).

Le "città di roccia", che sono impostate in una formazione calcarea sottile e particolarmente resistente (Rosso Ammonitico Veronese), si presentano come gruppi di blocchi rocciosi parallelepipedi o subcilindrici o a fungo, vaviamente scolpiti dalle azioni carsiche e periglaciali. Gli esempi più caratteristici di città di roccia si trovano sugli Alti Lessini Veronesi (Corra', 1974; Sauro, 1973a).

I "campi solcati" modellati su superfici strutturali molto inclinate sono formati da tanti solchi paralleli (Regenrinnenkarren) lunghi anche più di 10 m; gli esempi più belli si trovano sul versante occidentale del M. Baldo che domina il Lago di Garda (es: Val Trovai, Nago).

I grossi blocchi calcarei dei macereti di enormi frane postglaciali (*marocche*) che mostrano piccole forme di corrosione carsica, si trovano in un territorio a nord del Lago di Garda e nella vicina Valle dell'Adige. La più suggestiva "griza di frana" è quella del Passo di S. Giovanni (strada Mori-Torbole), ove sui grossi blocchi si notano scannelature (*Rillenkarren*), solchi a doccia *(Rinnenkarren)* e vaschette *(Kamenitze)*, anche di ragguardevoli dimensioni (Perna e Sauro, 1976).

Sul litorale del Lago di Garda si possono osservare alcune particolari forme di corrosione determinate dalle azioni delle acque del lago; un bell'esempio si trova a S. Vigilio (Garda).

Dall'analisi morfologica dei "campi solcati" del Veneto e del Trentino sono emersi vari dati significativi che permettono di formulare alcune prime ipotesi e considerazioni sui seguenti aspetti del fenomeno carsico:

- la corrosion biologica;
- le modalità dell'apertura di piccole cavità carsiche quali le cavità di interstrato, i fori e i crepacci;
- i rapporti fra le condizioni ambientali del Postglaciale (successione paleoclimatica) e la morfogenesi di qualche forma complessa;
- l'età delle piccole forme di corrosione.

Le azioni di corrosione biologica (fitocarsismo) si sono rivelate importanti in tutti gli ambienti considerati, man hanno portato a risultati morfologici sostanzialmente diversi a seconda che le superfici interessate fossero subverticali o poco inclinate. Sulle superfici subverticali, sovrastate da zolle di suolo vegetale che lasciano colare acqua, si notano numerose piccole cavità alveolari (diametri di ogni cavità intorno a 1-2 centimetri), che rendono la roccia spugnosa. Ogni "alveolo" è occupato da una colonia di microorganismi vegetali responsabile dell'evoluzione della cavità (De Fanti, 1971).

Sulle superfici poco inclinate di roccia nuda il "fitocarsismo" porta alla formazione della vaschette carsiche (Perne, 1974). Il primo momento della morfogenesi delle vaschette (Kamenitze) consiste nell'insediamento di una colonia di microfite di forma circolare e del diametro di pochi centimetri; questa colonia „scava" una piccola depressione a "ciotoletta" da cui può derivare una vaschetta o una "coppa" di soluzione; l'attacco biologico localizzato in corrispondenza di una vaschetta, si può propagare verso il basso ad opera della soluzione acquosa trabocca dai minuti bacini durante le piogge.

L'apertura di piccole cavità "anastomotiche" quali i fori, i crepacci e le cavità di interstrato, non è necessariamente legata a condizioni di "carso coperto" ma si verifica anche sui campi solcati "liberi".

Vari aspetti morfologici dimostrano che in molti casi l'apertura della cavità è proceduta da fenomeni di attacco della roccia localizzati lungo alcune discontinuità; sembra che questi fenomeni di attacco, non sempre ben definibili, determinino un aumento della porosità fino a provocare, talvolta, una "circolazione di porosità" che precede l'apertura vera e propria (Sauro, 1974, 1975a,b).

Alcune forme complesse e polifasiche (es: "solchi a vaschetta") presenti negli ambienti glaciocarsici di tipo submediterraneo forniscono qualche indicazione morfoclimatica e morfocronologica: infatti il loro sviluppo è stato condizionato da un'alternanza fra periodi in cui all'interno del solco esistevano zolle di suolo vegetale e periodi in cui le depressioni erano libere; ciò senza dubbio in rapporto con le condizioni paleoclimatiche locali (Sauro, 1973c).

Quasi tutte le forme di corrosione dei paesaggi glacio-carsici submediterranei sono posteriori al ritiro della lingua glaciale wurmiana (meno di 15.000 anni). La carsificazione postglaciale ha portato allo sviluppo di tutti i princine postglaciale ha portato forme di corrosione: a Canale si sono formate vaschette molto grandi e profonde (la più grande è lunga 4 m; la massima profondità supera i 40 cm) crepacci langhi anche oltre 50 cm, numerosi fori con diametri di alcuni decimetri, ecc.

La presenza e le dimensioni delle piccole forme di corrosione carsica sugli enormi blocchi delle "frane — marocche" fornisce un'indicazione sull'età delle frane; un'altra indicazione viene data dai fossili (es: coralli) sporgenti di alcuni millimetri (fino a 2 cm), che rappresentano in qualche caso la misura dello spessore di roccia corrosa dêpo il franamento. Sulla base di questi indizi la maggior parte della "marocche" risultarebbe piuttosto recente (probabilmente di età protostorica). Cio é, confermato anche da una datazione col metodo del madiocarbonio (cinco 3000 a.B.P.), melativa alla "marocca" di Molveno.

La "frana-marocca" del passo di S. Giovanni ha interessato delle rocce montonate già in precedenza carsificate; in oltre alcuni dei blocchi del macereto si sono mossi anche dopo il primo episodio di caduta, come dimostra la posizione inclinata del fondo delle vaschette che si erano formate su questi blochhi (di norma il fondo della Kamenitze è piatto e suborizzontale) (Perna e Sauro 1976).

Con l'intento di approfondim questi ed altri aspetti dell'evoluzione delle piccole forme di corrosione carsica sono state iniziate ricerche più dettagliate; in particolare si sta cercando di analizzare alcuni ambienti di campi solcati in collaborazione con vari specialisti (petrografo, pedologo, botanico ecc.). Sono state tra l'altro disegnate alcune carte geomorfologiche a grandissima scala dei campi solcati che dovrebbero costituire la base per l'elaborazione di carte ambientali complete, utili per cogliere i vari aspetti della morfogenesi carsica (Sauro, 1975).

Recenti Pubblicazioni Sui Campi Solcati Del Veneto E Del Trentino

Benetti, A. 1975. *Osservazione sui fenomeni carsici e paracarsici della "Conca di Camposilvano" nei Monti Lessini Veronesi.* Studi Trent. Sc. Nat. 52I3, 41-57.

Corra'G. 1970. *Influenza del carsismo, della tettonica e del glacialismo sui fenomeni di erosione accelerata sul versante occidentale del M. Baldo,* Natura Alpina 21/4, 141-153.

Corra'G. 1972. *Morfologie carsiche nella zona di Canale in Val Lagarina (Val d'Adige meridionale).* Studi Trent. Sc. Nat. A., 49/2, 127-160.

Corra 'G. 197 ' *Il ruolo del Rosso Ammonitico nella geomorfologia dei Monti Lessini* Studi Trent. Sc. Nat., vol. 5 /IA 39-91.

Corra'G. 1976. *Attraverso i Monti e le valli della Lessinia.* Com. Scient. C.A.I., Itinerari Natural. e Geogr., 12, 149.

De Fanti, A. 1972. *Forme di corrosione dovute a microorganismi osservate nel Gruppo della Civetta (Alpi Dolomitiche).* Boll. Soc. Geogr. It., 12, 605-618.

Perna, G. 1974a. *Il fitocarsismo nella formazione della Kamenitze (vaschette di corrosione).* Natura Alpina, 25I1, 25-34.

Perna, G. 1974b. *Le frane glaciali e postglaciali nel Trentino Meridionale ("Marocche" e "Laste").* Boll. Com. Glac. It., 22, 59-66.

Perna, G. 1974c. *Fenomeni di dissoluzione carsica superficiale.* 12° Congr. Naz. Speleol., S. Pellegrino Terme (in corso di stampa).

Perna, G. 1975. *Laste e marocche nel Basso Trentino.* Economia Trentina, a. 1975, n. 4, 37-44.

Perna, G., Sauro, U. 1976. *Karren, Grize e Kamenitze.* Economia Trentina, 1976/2, 41-56.

Sauro, U. 1973a. *Il paesaggio degli Alti Lessini: studio geomorfologico.* Mus. Civ. St. Nat. Verona, Mem. f.s. 6, pp. 161, Verona.

Sauro, U. 1973b. *Forme di corrosione carsica su rocce montonate nella Val Lagarina meridionale,* Universo, 53/2, 309-344.

Sauro, U. 1973c. *Observations on some great solution runnels with nested solution pans of the Venetian Prealps,* Actes 6° Congr. Intern. Speleol. Olomuc, Ba 039, 353-361.

Sauro, U. 1974. *Le cavita planari subhorizzontali nel quadro della morfogenesi dei campi solcati,* Atti 12° Congr. Naz. Speleol. It . S. Pellegrino Terme in corso di Stampa.

Sauro, U. 1975. *The geomorphological mapping of "Karrenfelder" using very large scales: an example in "Karst Processes and relevant Landforms"* edited by I' Gams, 189-199; Ljubljana.

THE PIERRE SAINT MARTIN KARST

J. F. Pernette
Delegue Departemental de la
Federation Francaise de Speleologie
33760 Escoussans, France

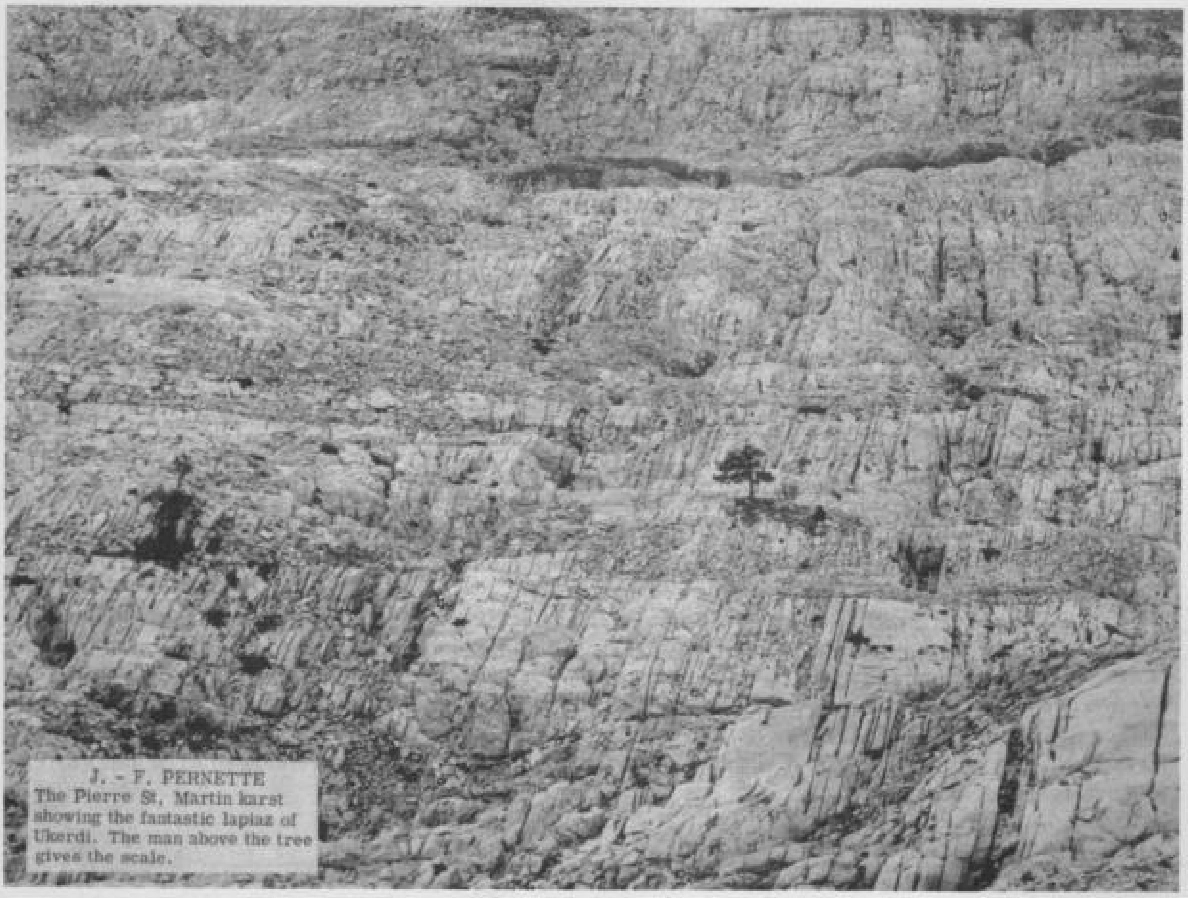
The Pierre St. Martin karst is situed in the Pyrenees mountains on both the French Basses-Pyrenees department and Spain's Navarra and Huesca provinces. Bounded on the north-east by the "Soum Coye", in the east by the "Pic d'Anie" and the "Table des trois rois", in the south by a line from the Table des trois rois to the "rio Bellagua", and in the west by the "Gorges de Kakouetta", it has a geological, morphological and hydrological unity.

A geological unity firstly because it is made of a mass of Upper Cretaceous limestone known as "Calcaire des Canyons" about 400m thick which lies between shales at the bottom and a protecting cover a formation of silicified limestone and brown shaly limestone. The limestone layers are almost horizontal on the Spanish side and bent towards the south on the French side; but the whole area is an anticlinal structure plunging westwards where the shales appear at the bottoms of canyons such as Kakouetta. Many big faults as well as a lot of smaller ones, oriented NE/SW and SE/NW are situated all over the karst and have a great importance for hydrology.

Morphologically the characters are easily discernible: From the top we find first "Les Alpages" of the protecting shield; then from 2300m to 1800m, the zone of barren Lapiez, known as "Arres" (e.g. Arres d'Anie; Larra in Spanish); From 1800m to 1500m the "Bracas" is a zone of lapiaz with woods; and finally steep slopes with dense forests reaching down to the canyons.

As far as hydrology is concerned, with a geology so simple, it is not hard to deduce, especially when one knows the resurgence situated at Schist level at the bottom of the canyons. There are 3 main resurgences: The St Vincent river which resurges in the Bivouac Cave (Bentia) with a 2.37m^3/s discharge, the Cascade river which resurges from a cliff-side cave, and the St Georges river which resurges in Laminako Lecia (Illamina) with a 5.64^3/s annual average discharge.

All the precipitation makes its way vertically through the 400m thick limestone until it reaches the impermeable shale. Following the faults, it forms rivers which run on the tilted shale down to the canyons. Something else possible to deduct, although much harder, was to "guess" the progress of the rivers by following the faults in the surface. Before any caver ever entered a system, F. Ravier had predicted where they were



J. - F. PERNETTE
The Pierre St. Martin karst showing the fantastic lapiaz of Ukerdi. The man above the tree gives the scale.

to be found and so far he has not failed.

But to explore these rivers is not so simple either. After a few attempts to enter by the resurgences in Ste Engrace, the PSM karst was searched, and in 1950 the Gouffre Lepineux is discovered. It is the 334m single-drop shaft where M. Loubens died and which is improperly known as "gouffre de la Pierre St Martin". A river is found at -450m and appears to resurge (after dye-tests) at one of the resurgences, Bentia. The river is called St Vincent and was explored from 1954 to 1960 to the depth of 1006m. The explorations were facilitated by the EDF tunnel, dug in order to capture the waterfall in the Verna room at -734m. While digging, a new grotto named Arphidia was discovered and explored to -490 m. Arphidia + PSM, connected by the man-made tunnel is then 1474 m deep!

After more research on the plateau with exploration of hundreds of shafts, some of them very deep, the St Vincent river was rediscovered in 1966 at the bottom of the D9 (-405 m), baptized "Gouffre de la Tete Sauvage. The new world record became -117 m since the D9 is 165 m higher. Almost ten years later, in 1975, two new entrances were found within 15 days, the first after exploring the nasty M3 to the depth of 400 m. This shaft, named "Gouffre J. Moreau", leads to one of the St Vincent tributaries; the "rio Larumbe". The second was found after descending the SC3, called afterwards "Gouffre du Beffroi", to a depth of -370 m where a connection was made with the upstream end of the Bassaburuko tributary. The change of elevation between the M3 and the lowest point in the cave (Puits Parment) is 1274 m. SC3 being 58m higher; the new world record is -1332 meters. Meanwhile, over 35km of passageways had been explored.

Another river was expected flowing parallel to the St Vincent but at a lower level. In 1970, the "Gouffre Lonne-Peyret" was found at 1652 m and lead to a river at -360 m. After dye tests, the river (5.5 km long and 750 m deep) exits at the same resurgence as St Vincent.

A very unexpected river was found in 1975 further north. At the bottom of the "Couey Lodge" at only -240m, a small streamway flows eastwards, escaping completely from the general PSM structure: this small neighbour is 5km long and 620m deep.

The main problem was still to find the fabulous St Georges river and the Cascade river, or at least one of their tributaries. More investigations are being made on the Spanish side in the wild remote areas of Anallarra and Ukerdi, the St Georges being expected there. In 1973 the "Gouffre des Caou-Cougues" (FR3) was found at 2050m and after several wet pits totalling 410m, a river was found. Unfortunately, a narrow siphon stops human exploration after only 1 km. Two dye tests were made, but with no results and the cave is abandoned. In 1975 the AN3, called "Pozo Estella" was descended to the depth of 440m in a dry system of pits with no results. The 4 l/s of water encountered at -200m disappear in a narrow, wet and flood-prone new shaft. In 1976, this nasty new pit was descended but the water killed one of the cavers on his way up. At the bottom very wide river-passages were found. No end is in sight in either direction so far and 2 km have already been explored . . . .

Is it the St Georges? Further exploration will tell us; for now after over 40 years of research, only one of the resurgences has given part of its secrets. Yet thousands of pits have been explored, three deaths

and several accidents, many expeditions with a lot of excellent cavers from all over the world, have been necessary for the exploration of such huge and difficult caves. And if we remember that the St Georges discharge is twice as large as the St Vincent's, that its course is much higher, we cant help thinking about the fantastic adventure which is about to begin.

REJUVENATION OF AGGRESSIVENESS IN CALCIUM CARBONATE SOLUTIONS BY MEANS OF MAGNESIUM CARBONATE

R.G. Picknett
28 Potters Way, Laverstock, Salisbury, Wiltshire, U.K.

As a result of some pH measurements made on calcite solutions it had been surmised (Picknett, 1972) that low concentrations of magnesium carbonate in solution caused an anomalous effect on calcite solubility. This has now been confirmed by direct measurement of the solubility of calcite in water containing various amounts of magnesium carbonate (Picknett and Stenner, 1977).

The chemical principle termed the Common Ion Effect (Picknett, 1977) indicates that magnesium carbonate in solution should reduce the solubility of calcite. In fact this only happens when the molar ratio of magnesium to calcium in solution is greater than about 0.1; for smaller ratios calcite solubility is enhanced, the maximum change being obtained at ratios of 0.03 and 0.04. It is only with ratios greater than about 0.15 that calcite solubility obeys the quantitative predictions of the Common Ion Effect.

This anomalous influence of magnesium carbonate on calcite solution is considered to be important in karst, as will now be explained.

Dissolution in the Depths of Karst

A feature of karst is that the dissolution of calcium carbonate takes place, not only near the surface, but also deep underground, which leads to the conclusion that there must be processes creating aggressiveness in these deep parts. Carbon dioxide exchange between the water and air must undoubtedly be one such process, but there is evidence of dissolution in the deep phreatic zone where such carbon dioxide exchange cannot be responsible. Temperature change is another possibility: a 1°C drop in the temperature of a saturated solution of calcite can cause a 2% loss in saturation. In many cases, however, the possibility of such a temperature change in the phreatic zone may be discounted. Aggressiveness from the oxidation of pyrites in limestone to sulphuric acid has long been known (Evans, 1900), but pyrites is not always present in limestones.

Bray (1976) has provided evidence of aggressiveness from the oxidation of dissolved organic matter in caves in South Wales, and this must be reckoned as one likely explanation, although the extent of the effect is as yet hard to assess. Aggressiveness due to mixing saturated calcite solutions of differing compositions (Bögli, 1964, 1971) is widely recognised as a possibility, but the magnitude of the change in saturation is often very small in practice. For example, if it is considered that typical hardness values for the waters being mixed are 0.75 mM and 1.25 mM (see, for example, Stenner, 1970 or Bray, 1976), then the aggressiveness gained on mixing saturated waters is only about 0.5%. Of course, over geological times even such a small change can produce a significant effect in karst, but it will now be shown that another possibility can give much larger changes in saturation.

Aggressiveness due to magnesium carbonate

We are here concerned with carbonated water at constant temperature kept from contact with air in order to prevent loss of carbon dioxide which would change calcite solubility. This state of affairs occurs, for example, in water-filled passages deep in karst. From the experimental data of Picknett and Stenner (1977) it is possible to construct calcite solubility curves for such water when it contains various amounts of magnesium carbonate. The results depend on the carbon dioxide concentration of the water, and Figures 1 and 2 show examples of two typical carbon dioxide concentrations. Like all such diagrams, the solubility curves divide the graphs into zones of aggressiveness and supersaturation, as indicated.

Start with the case of a saturated calcite solution with no magnesium carbonate present, as represented by the point A in Figure 1. If magnesium carbonate is rapidly added until its concentration is 0.04 mM, say, then the solution will move from A to B, and it is clear that the result is a considerable loss of calcite saturation. The loss is represented by the vertical distance between B and the solubility curve, i.e. the distance BC, and in this example it corresponds to an aggressiveness of 0.12 mM of calcium carbonate. In other words each litre of solution can now dissolve a further 12 mg of calcite before reaching saturation.

This is of significance in karst. Consider a water-filled passage in a limestone formed of relatively pure calcite. The water in the passage will soon become saturated with calcite and will then cause no further dissolution in its onward journey. Now suppose that the water subsequently enters a limestone formed of magnesium calcite. The magnesium carbonate in the rock will dissolve and, by doing so, will enhance calcite solubility in the manner described above, so that the bulk calcite of the limestone is also attacked. Aggressiveness amounting to 12% of the original calcite solubility can be created in this way, which must have a profound solutional effect at the junction of the two types of limestone.

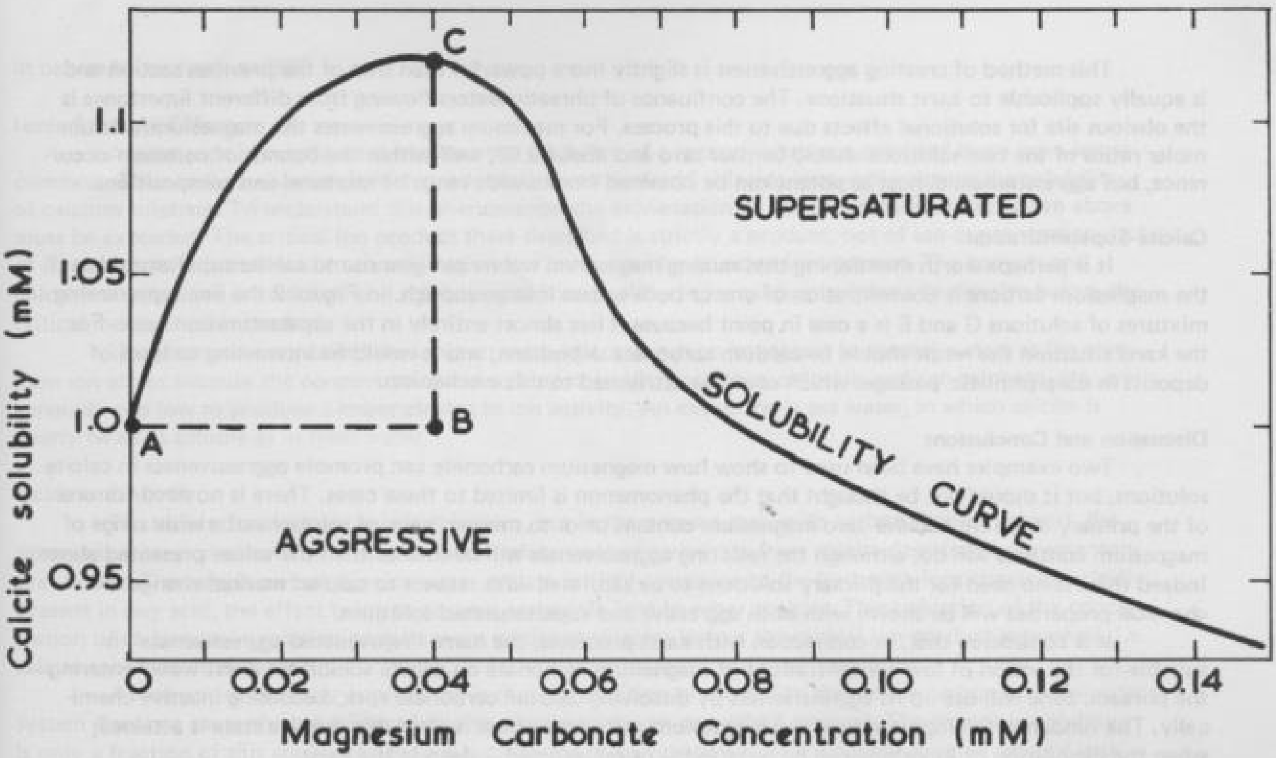


FIG.1.

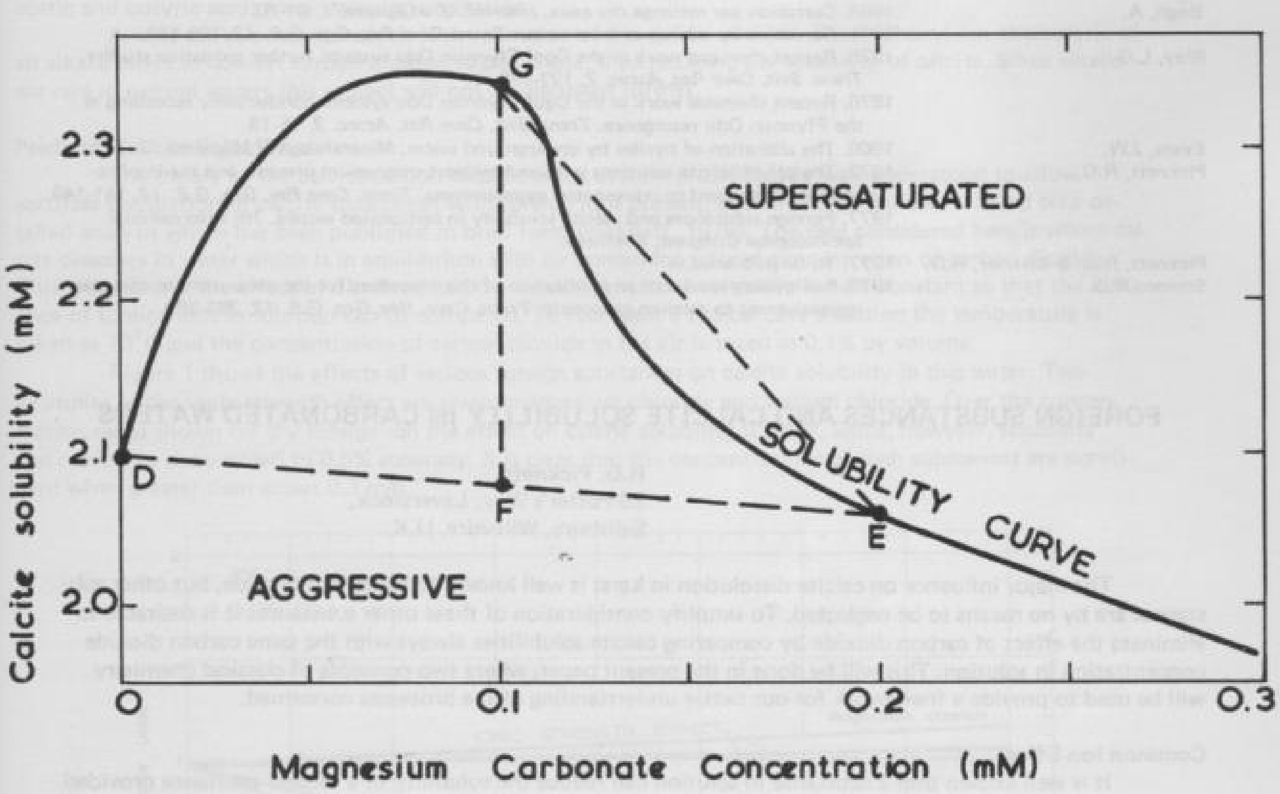


FIG. 2.

Aggressiveness due to mixing magnesian waters

Mixing saturated waters containing differing amounts of magnesium carbonate is another way of creating aggressiveness. The effect is at a maximum when one of the solutions saturated with calcite contains no magnesium carbonate, as at D in Figure 2. If this solution is mixed with any saturated solution containing magnesium carbonate, such as at E, the resulting mixture will be represented by a point on the line DE, which is in the aggressive zone. For equal proportions of the two solutions the mixture is represented by the point F midway on the line, and the aggressiveness is given by the length FG.

This method of creating aggressiveness is slightly more powerful than that of the previous section and is equally applicable to karst situations. The confluence of phreatic waters flowing from different limestones is the obvious site for solutional effects due to this process. For maximum aggressiveness the magnesium/calcium molar ratios of the two solutions should be near zero and about 0.09, well within the bounds of common occurrence, but aggressiveness almost as potent can be obtained from a wide range of mixtures and compositions.

Calcite Supersaturation

It is perhaps worth mentioning that mixing magnesium waters can give rise to calcite supersaturation if the magnesium carbonate concentration of one or both waters is large enough. In Figure 2 the line representing mixtures of solutions G and E is a case in point because it lies almost entirely in the supersaturation zone. For the karst situation the result should be calcium carbonate deposition, and it would be interesting to learn of deposits in deep phreatic passages which could be attributed to this mechanism.

Discussion and Conclusions

Two examples have been used to show how magnesium carbonate can promote aggressiveness in calcite solutions, but it should not be thought that the phenomenon is limited to these cases. There is no need for one of the primary solutions to have zero magnesium content prior to mixing: pairs of solutions of a wide range of magnesium contents will do, although the resulting aggressiveness will be smaller than the values presented above. Indeed there is no need for the primary solutions to be saturated with respect to calcite: marked change in chemical properties will be shown with both aggressive and supersaturated solutions.

It is considered that, in connection with karst processes, the name "rejuvenated aggressiveness" is suitable for the action of low concentrations of magnesium carbonate on calcite solubility. Karst water entering the phreatic zone will use up its aggressiveness by dissolving calcium carbonate rock, becoming inactive chemically. The fundamental importance of the magnesium carbonate effect is after this inactive state is attained, when the dissolution of limestone can be restarted – or rejuvenated – deep in the karst.

References

Bögli, A. 1964. Corrosion par mélange des eaux. *Internat. J. of Speleo. 1,* 61-70.

1971. Corrosion by mixing of karst water. *Trans. Cave Res. Grp. G.B. 13,* 109-114.

Bray, L.G. 1975. Recent chemical work in the Ogof Ffynnon Ddu system: further oxidation studies. *Trans. Brit. Cave Res. Assoc. 2,* 127-132.

1976. Recent chemical work in the Ogof Ffynnon Ddu system: conductivity recording at the Ffynnon Ddu resurgence. *Trans. Brit. Cave Res. Assoc. 3,* 15-19.

Evans, J.W. 1900. The alteration of pyrites by underground water. *Mineralogical Magazine 12,* 371.

Picknett, R.G. 1972. The pH of calcite solutions with and without magnesium present, and the implications with regard to rejuvenated aggressiveness. *Trans. Cave Res. Grp. G.B. 14,* 141-149.

1977. Foreign substances and calcite solubility in carbonated waters. 7th International Speleological Congress, Sheffield.

Picknett, R.G. & Stenner, R.D. 1977. To be published.

Stenner R.D. 1970. Preliminary results of an application of the procedure for the measurement of water aggressiveness to calcium carbonate. *Trans. Cave. Res. Grp. G.B. 12,* 283-289.

FOREIGN SUBSTANCES AND CALCITE SOLUBILITY IN CARBONATED WATERS

R.G. Picknett
28 Potter's Way, Laverstock,
Salisbury, Wiltshire, U.K.

The major influence on calcite dissolution in karst is well known to be carbon dioxide, but other substances are by no means to be neglected. To simplify consideration of these other substances it is desirable to eliminate the effect of carbon dioxide by comparing calcite solubilities always with the same carbon dioxide concentration in solution. This will be done in the present paper, where two concepts of classical chemistry will be used to provide a framework for our better understanding of the processes concerned.

Common Ion Effect

It is well known that a substance in solution can reduce the solubility of a second substance provided the two have an ion in common. Thus sodium sulphate will reduce the solubility of calcium sulphate, the common ion in this case being sulphate. The key to understanding this behaviour lies in the fact that a substance in water will only continue to dissolve until the product of the concentrations of all the primary ions produced reaches a certain critical value; thereafter the solution is saturated. (This is a simplification of reality, but suffices for the present). In water calcium sulphate dissolves to produce equal quantities of calcium and sulphate ions. If sulphate ions from, say, sodium sulphate are already present in the water, then less calcium sulphate can dissolve before the ion concentration product reaches the critical value, i.e. the solubility of the calcium sulphate is reduced.

This common ion effect, as it is known, is widespread and can greatly influence solubility. In the case of calcite (calcium carbonate) the primary ions produced in solution are calcium and carbonate, and calcite solubility is altered by the presence of any substance giving one or other of these ions. Calcium sulphate and magnesium carbonate are important examples of such substances, the latter readily reducing calcite solubility

in nature by as much as 20%.

Ionic Strength Effect

A substance in solution can increase the solubility of a second substance provided there is no ion in common. Thus sodium chloride, which produces only sodium and chloride ions, will enhance the solubility of calcium sulphate. To understand this phenomenon the explanation of the common ion effect given above must be extended. The critical ion product there described is strictly a product, not of ion concentration, but of ion activity. This is related to concentration but is affected by all other ions present. The sodium and chloride ions reduce the calcium and sulphate activities to allow more calcium sulphate to dissolve before the critical ion product is reached.

This phenomenon, called the ionic strength effect, is not so important in natural waters as the common ion effect because the concentrations of sodium chloride, potassium chloride, sodium sulphate, etc. are generally too low to produce a major change in ion activity. An exception is sea water, in which calcite is nearly twice as soluble as in fresh water.

Acids and Alkalis

That acids dissolve calcite is well known, but in the present case, with carbon dioxide present, the process is more complicated than the simple displacement of carbonate from calcite described by elementary text-books. The calcite-carbon dioxide-water system is highly sensitive to the hydrogen ions characteristically present in any acid, the effect being to convert carbonate ions to other entities. This reduction of the concentration of carbonate in solution permits more calcite to dissolve before the critical ion product is reached, i.e. calcite solubility is increased.

A fact not sufficiently appreciated is that the addition of an acid to the calcite-carbon dioxide-water system does not cause the solubility of calcite to increase by an equivalent amount. The change in solubility is only a fraction of this equivalent change because the dissolving power of the carbon dioxide present is reduced by the foreign acid. This applies almost irrespective of the strength of the foreign acid, i.e. it applies in karst to the strong sulphuric acid from the oxidation of sulphide ore as well as to the much weaker formic, acetic and butyric acids from decaying vegetation.

Alkalis act in a manner which is the converse of the action of acids. The hydroxyl ion characteric of all alkalis tends to convert carbon dioxide to carbonate, thus reducing the solubility of calcite. Since alkalis are rare in natural waters this subject will not be discussed further.

Predicted Calcite Solubilities

The theory of the calcite-carbon dioxide-water system is sufficiently well understood to allow accurate calculation of calcite solubilities with foreign ions present, and what now follows is based on a detailed analysis which has been published in brief form (Picknett, 1976). The case considered here is where calcite dissolves in water which is in equilibrium with air containing a fixed concentration of carbon dioxide. This ensures that the effect of dissolved carbon dioxide on calcite solubility is held constant so that the influence of foreign ions in solution can be compared. To represent a typical cave situation the temperature is taken as 10°C and the concentration of carbon dioxide in the air is taken as 0.1% by volume.

Figure 1 shows the effects of various foreign substances on calcite solubility in this water. Two examples of the ionic strength effect are given: magnesium chloride and sodium chloride. Over the concentration range shown for the foreign ion the effect on calcite solubility is small. Since, however, solubility can readily be determined to 0.5% accuracy, it is clear that the concentrations of such substances are significant when greater than about 0.3 mM.

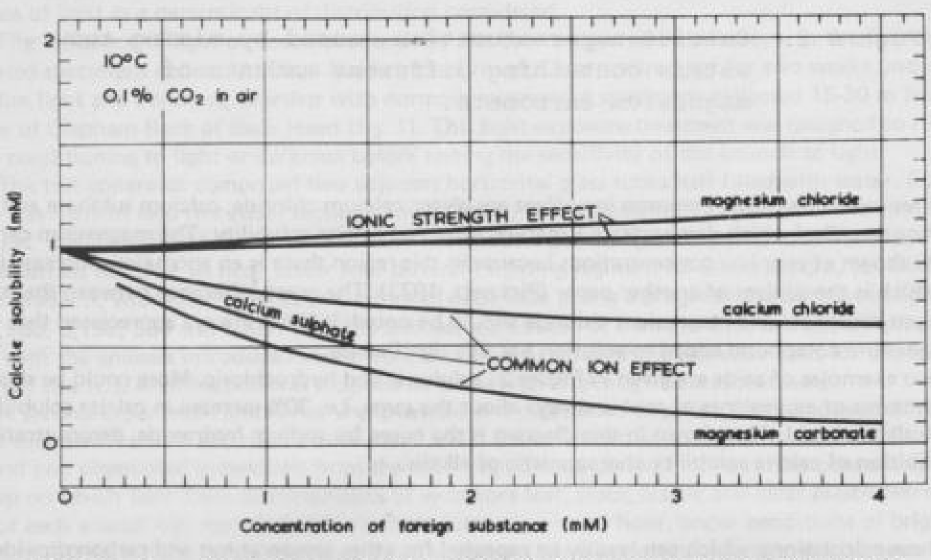


Figure 1. Examples of the common ion and ionic strength effects influencing calcite solubility.

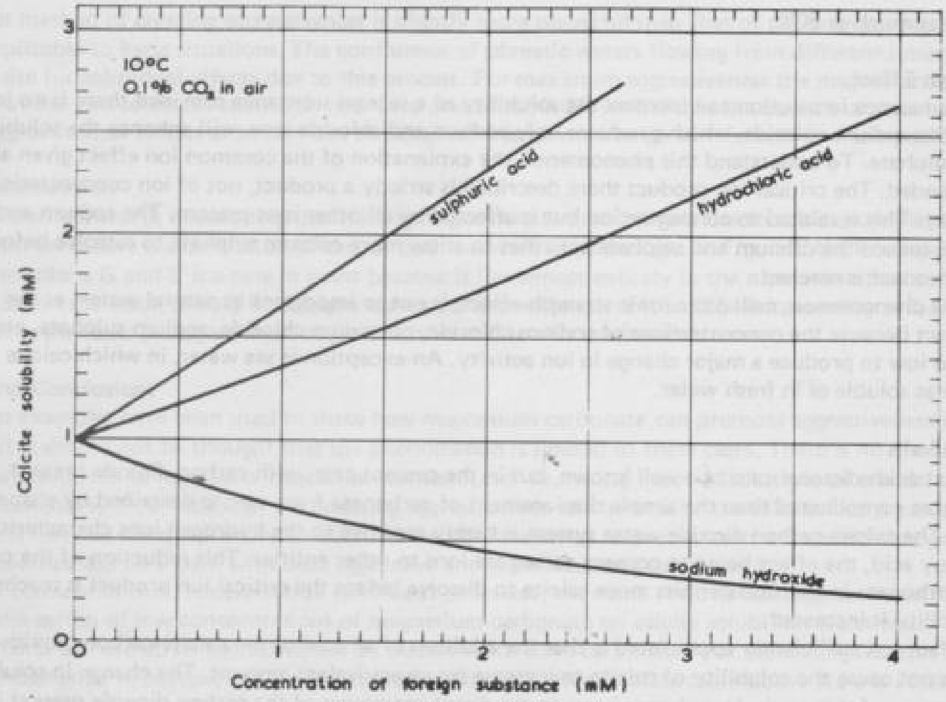


Figure 2. Examples of the effects of acids and alkalis on calcite solubility.

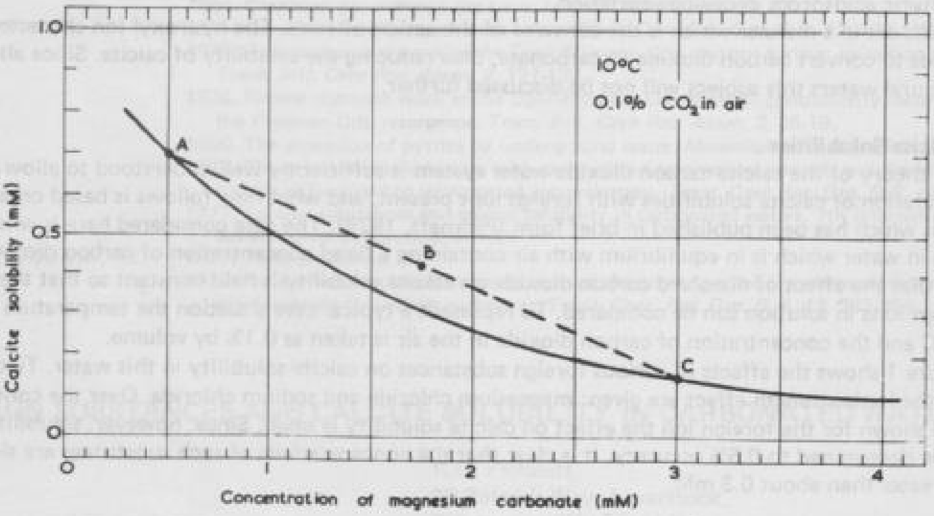


Figure 3. Calcite supersaturation caused by mixing two waters containing different amounts of magnesium carbonate.

Three examples of the common ion effect are given: calcium chloride, calcium sulphate and magnesium carbonate, all of which demonstrate a marked effect on calcite solubility. The magnesium carbonate curve is now shown at very low concentrations because in this region there is an anomalous increase in calcite solubility which is the subject of another paper (Picknett, 1977). The great difference between the curves for magnesium carbonate and magnesium chloride should be noted; it is not always appreciated that the type of magnesium compound added to solution has this significance.

Two examples of acids are given in Figure 2: sulphuric and hydrochloric. More could be shown, but the effect in terms of equivalents of acid is always about the same, i.e. 30% increase in calcite solubility for 1 milli-equivalent of acid. Also shown in this diagram is the curve for sodium hydroxide, demonstrating the marked inhibition of calcite solubility characteristic of alkalis.

Discussion

These calculations, which can readily be repeated for other temperatures and carbon dioxide contents, demonstrate how calcite solubility is affected by a wide variety of substances. This is important for those investigations where the degree of saturation of a spring water is evaluated, perhaps as an indicator of

the type of underground flow (Jacobson & Langmuir, 1970; Shuster & White, 1971). It is also important in speleogenesis because it is connected with phenomena arising from mixing waters.

The change in calcite saturation caused by mixing two saturated waters is well known (Mischungs-korrosion effect, Bögli, 1964). Runnells (1969) suggested that this was a widespread phenomenon associated with the presence of foreign substances, and it can now be demonstrated that this is true. Take any of the saturation curves of Figures 1 and 2. Any two points on this curve represent two saturated solutions of differing composition, and the straight line joining them represents mixtures of these solutions. The magnesium carbonate curve of Figure3 is an example. Solutions A and C, containing 0.5 and 3 mM of magnesium carbonate, when mixed in equal proportions give solution B. Now B lies above the saturation curve and must represent water supersaturated with calcite: in fact the supersaturation is over 30% in this example.

The important point is the curvature of the saturation curve: the greater the curvature, the greater is the mixing effect on the degree of saturation with calcite. All the examples of Figures 1 and 2 are curved to some extent, but it is clear that magnesium carbonate gives the greatest effect.

Finally it must be made clear that there are complicating effects with impurities in the solid calcite and absorption of heavy metal ions. These cannot be neglected but are too diverse to be discussed in this short paper.

References

Bögli, A. 1964. Corrosion par mélange des eaux. Internat. J. of Speleo. *1* (1-2), 61-70.

Jacobson, R.L. & Langmuir, D. 1970. The chemical history of some spring waters in carbonate rocks. *Ground Water 8* (3), 5-9.

Picknett, R.G. 1976. The chemistry of cave waters. *In* The Science of Speleology. Ford, T.D. & Cullingford, C.H.D. (eds). *Academic Press,* London.

Picknett, R.G. 1977. Rejuvenation of aggressiveness in calcium carbonate solutions by means of magnesium carbonate. 7th International Speleological Congress, Sheffield.

Runnells, D.D. 1969. Diagenesis due to the mixing of natural waters: a hypothesis. *Nature 224,* 361-363.

Shuster, E.T. & White, W.B. 1971. Seasonal fluctuations in the chemistry of limestone springs: a possible means for characterising carbonate aquifers. J. *Hydrology 14,* 93-128.

DISTRIBUTION AND RESPONSE TO LIGHT OF UNPIGMENTED AND PIGMENTED GAMMARUS PULEX L (CRUSTACEA, AMPHIPODA)

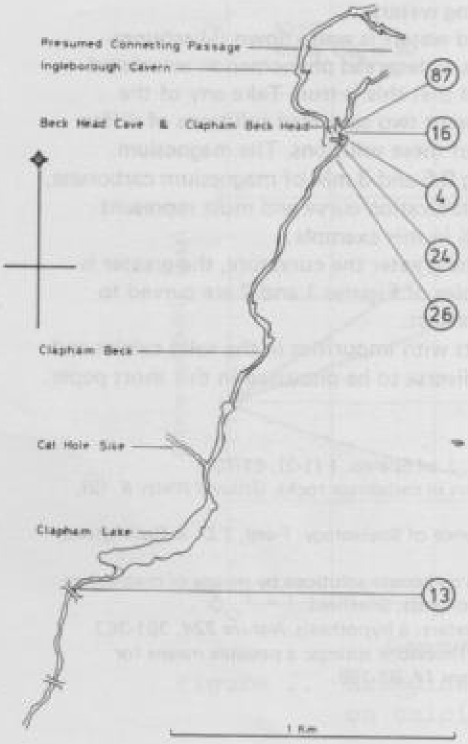
Trevor G. Piearce and Mary Cox
Department of Biological Sciences,
University of Lancaster
Lancaster, England.

Specimens of the common freshwater shrimp *Gammarus pulex* L. are usually dark grey in colour in epigean waters but often have reduced pigmentation in the hypogean zone (Hazelton and Glennie, 1962). Elsewhere it has been shown (Piearce and Cox, 1977) that individuals of a pale yellow-orange colour (hereafter referred to as unpigmented) form an appreciable proportion of the total *G. pulex* population of the upper reaches of a small northern English stream, Clapham Beck. Fig. 1 summarises the results of observations made from 18th August to 4th December 1976. Details of the site and sampling technique have been given in the previous paper, together with evidence suggesting that the unpigmented epigean specimens are derived from a population inhabiting the extensive underground waterways that supply water to Clapham Beck. In the present paper the response to light of unpigmented *G. pulex* is compared with that of pigmented specimens, and the possible significance of light as a determinant of distribution considered.

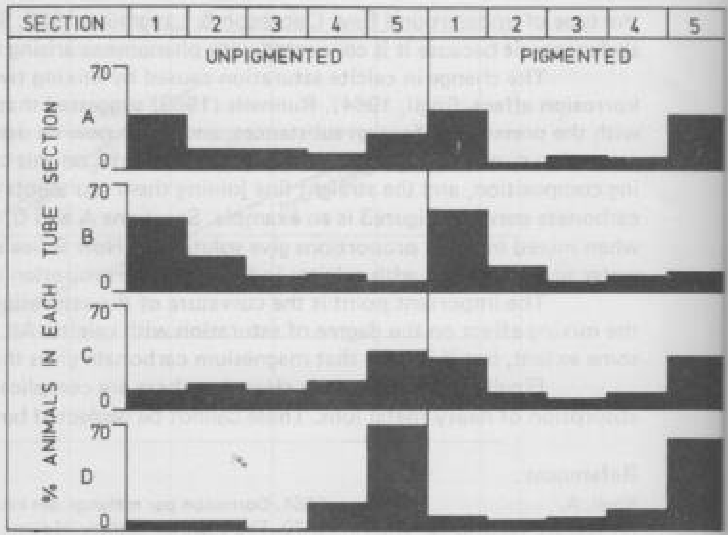
The influence of light on locomotor activity has been measured in two ways. In the first experiment, unpigmented specimens collected 600 m inside Ingleborough Cavern were kept for two weeks under a diurnal cycle of dim light and darkness, together with normally pigmented specimens collected 15-30 m from the emergence of Clapham Beck at Beck Head (fig. 1). This light exposure treatment was designed to reduce the effects of conditioning to light or darkness before testing the sensitivity of the animals to light.

The test apparatus comprised two adjacent horizontal glass tubes half filled with water. Each 90 cm long tube was marked into five equal sections. In each trial, five animals were placed in one terminal section of each tube, the positions of the specimens after ten minutes providing an index of locomotor activity. Six trials were carried out over an hour under four different lighting regimes, (a) uniform light, (B) uniform dark, (C) a light gradient, with filters over four sections of each tube giving a progressive reduction in light intensity (5,500, 3,900, 3,150, 330 and 5 lux) with the animals introduced at the light end, and (D) a light gradient as above, with the animals introduced at the dark end. Five batches of animals were used for (A) and (C), three for (B) and (D). Illumination was supplied by a "daylight lighting" fluorescent lamp.

A second experiment employed unpigmented and pigmented *G. pulex* freshly collected from two lengths of Clapham Beck; 0-25 m from Beck Head and 1.9 km further downstream. In each trial two unpigmented and two pigmented individuals from the same region were placed in a Petri dish containing water 5 mm deep on which four 2 cm diameter discs of sycamore leaf, black plastic and clear plastic were floated. The position of each animal was recorded at ten minute intervals over an hour, under conditions of bright (5,700 lux) and dim (40 lux) illumination provided by a fluorescent lamp as before. Additional trials were run with animals taken from the stream source and kept for a week under a diurnal cycle of bright light and darkness, and animals from the downstream zone kept for a week in darkness. Twenty animals freshly collected from



2



3

Fig.1. Percentage of unpigmented specimens in samples of Gammarus pulex from Clapham Beck. Sample sizes (from top to bottom) 95, 75, 47, 128, 65, 342 individuals.

Fig. 2. Light responses of Gammarus pulex, (A) in uniform light, (B) in uniform darkness, (C) and (D) in a light gradient (tube section one brightly lit). For explanation see text.

Fig. 3. Light responses of Gammarus pulex, (A) from source, (B) from downstream, (C) from source, light-adapted, (D) from downstream, dark-adapted. For explanation see text.

the stream source were used in the first series of trials, ten animals in all others.

The X^2 test was used to examine the results which are expressed in percentage terms in Figs. 2 and 3 to facilitate visual comparison. In the first experiment animals were seen to move rapidly along the tubes under uniform lighting, tending to come to rest in the terminal regions, a tendency most marked for pigmented specimens. Significant differences were observed in the distribution of both forms in uniform light compared with uniform darkness ($P < 0.001$) and the data suggests that both forms are more active in the light than in darkness and so disperse more rapidly in the light. There was a significant difference in the distribution of the two forms after introduction at the light end of a gradient ($P < 0.001$), unpigmented specimens tending to move further away than pigmented ones. Even after two weeks of acclimatisation to light of low intensity some residual differences in sensitivity between the two forms apparently persisted.

The conditions of the second experiment probably approximated more closely to those in the field in that small-scale refuges were provided. A clear preference for black, rather than clear plastic discs was shown by both forms (unpigmented, $P < 0.01$; pigmented $P < 0.001$). Incompletely opaque leaf discs were strongly preferred over completely opaque plastic ones (for both forms $P < 0.001$); light was not the only factor involved in refuge selection.

The partitioning between "beneath discs" and "free" categories in bright light was significantly different from that in dim illumination for animals from the stream source (unpigmented, $P < 0.001$; pigmented

P < 0.01) and animals collected 1.9 km downstream and subsequently dark-adapted (unpigmented, P < 0.01; pigmented, P< 0.001). Bright illumination apparently stimulates activity in these animals. No such influence of light was detected in naturally or artificially light-adapted *G. pulex*. For freshly collected specimens from the stream source the two forms differed in the proportion of "free" specimens (under bright illumination, P < 0.001). The absence of such a difference in specimens collected further downstream suggests that a considerable amount of light adaptation by unpigmented specimens has occurred. The proportion of *G. pulex* under discs was markedly higher for animals freshly collected from the stream source than for any others; further work is needed to determine the reason for this.

Ginet (1960) has shown that unpigmented *G. pulex* from the hypogean zone was killed by high light intensities that are tolerated by pigmented epigean animals. Under field conditions bright light is unlikely to cause mortality directly since specimens will be stimulated actively to seek dark refuges. We have shown that the increase in locomotory activity in bright light is less in pigmented *G. pulex* from the stream than in unpigmented specimens from the cave and near the stream source, results in agreement with those of Wautier and Troiani (1960) who found that the respiratory rate of this species increased on exposure to light, the increase being greatest in animals from dark and dimly illuminated habitats.

Laboratory and field experiments have demonstrated that the tendency towards a nocturnal peak of downstream drifting in epigean populations of *G. pulex* is controlled by the diurnal variation in light intensity (Elliott, 1965; Muller, 1966). Unpigmented animals passively washed, or actively migrating, out from underground, may initially be at some competitive disadvantage relative to pigmented epigean specimens, their greater sensitivity to light restricting both the length of time during the day available for free movement and also the range of microhabitats open to exploitation. Minckley (1961) records that where the cavernicolous isopod *Asellus stygius* (Packard) occurs in the epigean zone it is abundant in dark microhabitats.

In conclusion, the results of these preliminary experiments suggest that differences in light responses between unpigmented and pigmented forms may contribute to differences in distribution and activity, these being much more marked at the stream source than elsewhere.

Acknowledgements

We wish to thank Dr. J.A. Farrer for permission to collect samples, Dr. M.R. Kelly for assistance with field and map work, Mr. P.W.H. Flint for technical assistance in the preparation of figures, and Dr. G.J. Paxman for much useful discussion.

References

Elliott, J.M. 1965. Daily fluctuations of drift invertebrates in a Dartmoor stream. *Nature*, Lond, *205*, 1127-1129.

Ginet, R. 1960. Ecologie, ethologie et biologie de *Niphargus* (Amphipodes Gammarides hypoges) *Ann. Speleol, 15*, (1-2), 127-376.

Hazelton, M. & Glennie, E.A. 1962. Cave fauna and flora. *British Caving*, (Ed. by C.H.D. Cullingford). pp. 347-395. Routledge and Kegan Paul Ltd., London.

Minckley, W.L. 1961. Occurrence of subterranean isopods in the epigean environment. *Am. Midl. Nat. 63*, 452-455.

Muller, K. 1963. Zur Periodik von *Gammarus pulex*. *Oikos 17*, 207-211.

Piearce, T.G. & Cox, M. 1977. The distribution of unpigmented and pigmented *Gammarus pulex* L. in two streams in northern England. *Naturalist*, in the press.

Wautier, J. & Troiani, D. 1960. Contribution à l'étude du métabolisme respiratoire de quelques Gammaridae. *Ann. Stat. Centrale Hydrobiol. appliq. 8*, 7-50.

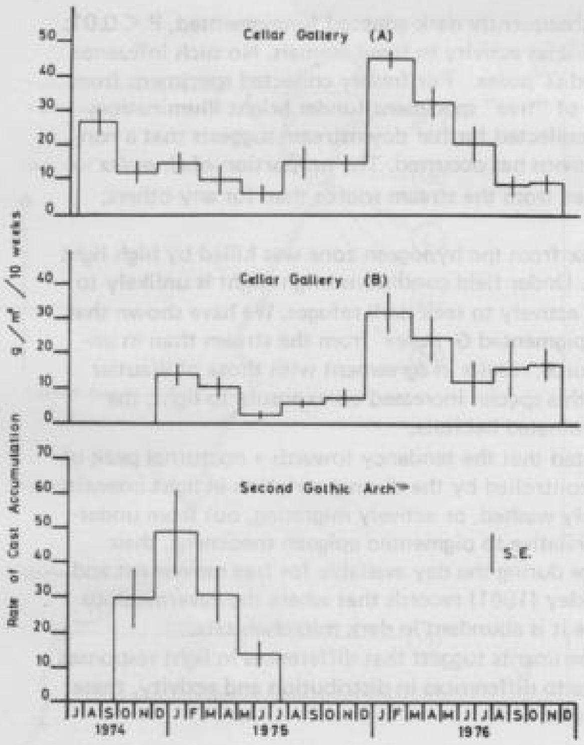
THE ACTIVITY OF LUMBRICIDAE IN A NORTHERN ENGLISH CAVE

Trevor G. Piearce and Elizabeth J. Wells
Department of Biological Sciences,
University of Lancaster, England

The rate of accumulation of earthworm casts provides a means of monitoring the activity of these animals over a long period of time with the minimum of disturbance. This paper reports on the results of an investigation into the activity of earthworms of the family Lumbricidae in Ingleborough Cavern, Yorkshire, using this technique.

Details of the physical features of the two sites studied, Cellar Gallery and the Second Gothic Arch, have been given elsewhere (Piearce, 1975). Cellar Gallery is a phreatic tube approximately 200 m long, which begins 400 m from the cave entrance. It slopes gently downwards for much of its length, terminating at the Second Gothic Arch. Banks of fine sediment in Cellar Gallery have deep accumulations of earthworm casts over much of the surface, while at the Second Gothic Arch earthworm casts predominate with faecal pellets similar to those of the millipede *Polymicrodon polydesmoides* (Leach), which has been recorded from the cave, forming a substantial minor component.

In July 1974 thirty 10 cm square quadrats were laid at 50 cm intervals on a transect along a bank of cast-covered sediment at the cave entrance end of Cellar Gallery. The sediment surface within the quadrats was cleared of casts and subsequent deposition monitored at approximately 10 week intervals. Casts in every third quadrat were allowed to accumulate until the experiment ended in December 1976. In a parallel experiment begun in December 1974, cast accumulation has been measured within quadrats adjacent to those above, in



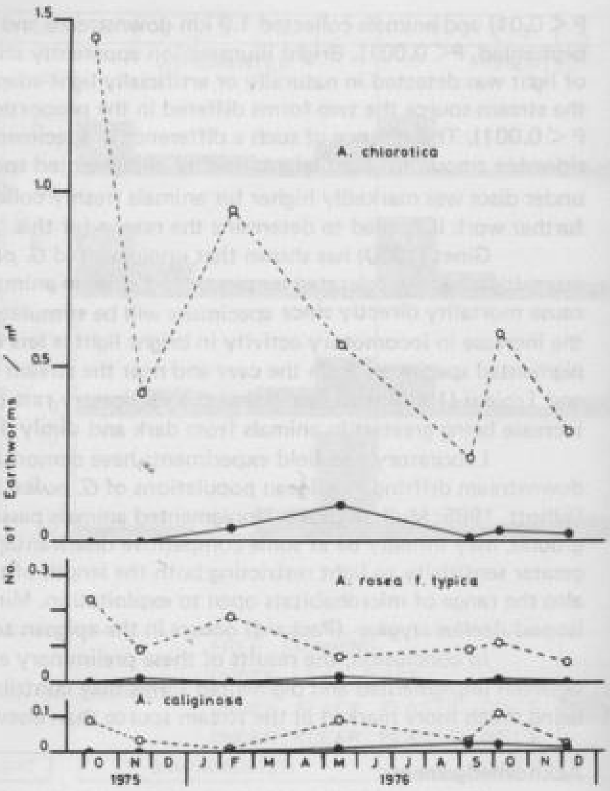


Fig. 1. Rate of earthworm cast accumulation in Cellar Gallery (A) after removal of casts. (B) after compression of the surface, and at the Second Gothic Arch after removal of casts.

Fig. 2. Density of earthworms in Cellar Gallery. Open circles immature, closed circles mature specimens.

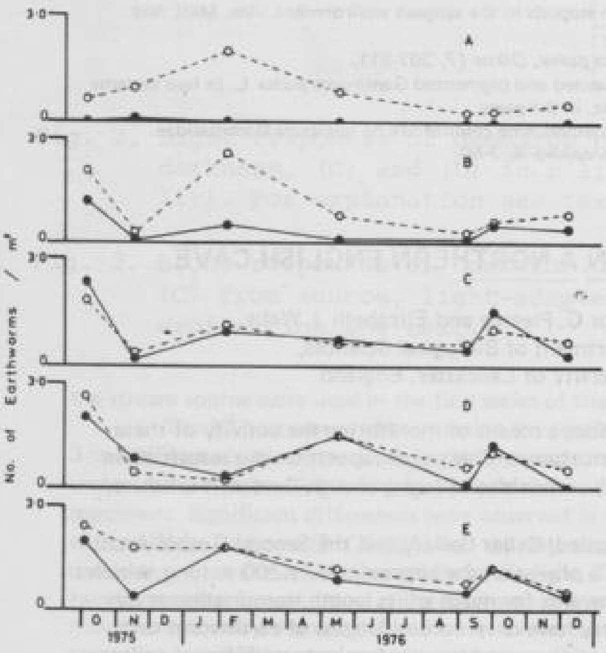


Fig. 3. Densities of earthworms along five adjacent 20 m. lengths of Cellar Gallery. Site (A) nearest cave entrance, includes region in which cast accumulation was measured. Open circles left hand side (facing away from cave entrance), closed circles right hand side.

which the surface casts were initially compressed to form a smooth surface. In September 1974 twenty-four 20 cm square quadrats were set in an 8 x 3 array at the Second Gothic Arch site and cast accumulation measured after removal of casts as before. Casts were weighed after drying to constant weight at 100°C.

Densities of earthworms on the sediment surface along a 100 m length of Cellar Gallery have been recorded at regular intervals from October 1975. In December 1976 ten 50 cm square plots equally spaced along the right hand side (facing away from the cave entrance) of this region were excavated to a depth of 8 cm and the earthworms carefully sorted out by hand.

At the Cellar Gallery site both techniques showed a similar pattern of accumulation (Fig. 1). A winter peak and subsequent decline was followed by an increase in late summer and winter, again followed by a decline. The Second Gothic Arch experiment was terminated in September 1975 by violent flooding which dispersed all surface accumulations. The data obtained shows a similar trend to that in Cellar Gallery, but a much higher rate of deposition of casts. The above flooding did not apparently extend to the Cellar Gallery site but there were signs in March 1976 that gentle flooding had penetrated this far later in the winter. The mean rate of accumulation in quadrats where casts were routinely removed was similar to those in those left for the duration of the experiment (only 2% lower for the first technique, 13% for the second).

Allolobophora chlorotica (Savigny) was the most abundant earthworm species in Cellar Gallery, with smaller densities of *A. rosea* (Savigny) f. *typica* and *A. calignosa* (Savigny) (Fig. 2). There were peaks in density in October 1975 and 1976 and February 1976 (Fig. 3). Since the density of earthworms in the section that included the quadrats followed a similar trend to that of cast accumulation, it seems reasonable to suggest that throughout Cellar Gallery an autumn and winter peak of casting activity precedes a spring and summer decline. The excavated plots yielded 11 *A.chlorotica*, including 2 mature specimens, 7 *A.rosea* f. *typica*, of which one was mature, and 4 immature *A.caliginosa*. Four immature *A.chlorotica* and one *A.calignosa* were curled up in a state of aestivation.

The layer of surface material worked by earthworms at the Cellar Gallery site amounts to 2.93 kg/m^2 (based on the 30 samples of casts removed in setting up the experiment). To achieve this cover at the mean rate of accumulation measured would take 16-21 years. Earthworm activity may have been higher when the surface layer of sediment was originally deposited, nevertheless it seems probable that casts have been steadily accumulating in the section investigated, in the absence of rain and the other agents of erosion present outside caves, for at least a decade. This is consistent with a report that the last severe flooding of Cellar Gallery occurred 10 years ago (R.A. Jarman, pers. comm.). The age of the earthworm-worked layer at the Second Gothic Arch site, estimated in the same way, but on the basis of much more limited data, was 5 years.

The constantly favourable humidity and temperature of these cave sites, and the absence of earthworm predators, may lead to the abundance and activity of these animals being limited by the quantitative and qualitative paucity of the food supply (Piearce, 1975). Such limitation would be relaxed by the input of detritus with winter flooding. The following evidence supports this interpretation.

a. Earthworm density in the cave is very low compared with that in fertile soils (see, for example, reviews by Satchell, 1967, Bouché, 1972, and Edwards and Lofty, 1972). Juberthie and Mëstrov (1965) recorded much higher densities near a cave entrance, but significantly the clay sediments in their study were organically richer than those that we have examined.
b. Casts accumulate most rapidly at times of year when flooding is frequent.
c. The rate of accumulation is highest at the site of most frequent and severe flooding, least in the region of Cellar Gallery most remote from flooding.
d. The proportion of mature worms is low compared with that in populations outside caves (Gerard, 1967).
e. A substantial proportion of animals were aestivating at a time of year when Lumbricidae are active outside caves (Gerard, 1967).

Much of the water that periodically floods the caves comes from a surface stream, Fell Beck (Ford, 1975). A mature specimen of *A.chlorotica* was collected from debris in the centre of this stream, where it had presumably been carried by the current, in October 1976. Earthworms washed in by winter floods may contribute to the Cellar Gallery and Second Gothic Arch populations, as may animals actively migrating away from the regions of severest winter flooding. However, it seems unlikely that the population in Cellar Gallery depends on such recruitment for its continued existence since active earthworms, including specimens in breeding condition, can be seen on the surface all the year round. A cocoon of a form characteristic of *A.chlorotica* (illustration in Gerard, 1964) was found on the surface of sediment in Cellar Gallery in October, 1976, confirming that the earthworms are reproductively active in this part of the cave.

It is a pleasure to record our thanks to Dr. J.A. Farrer, Mr. R.A. Jarman and Mr. A. Hurworth for permission to work in Ingleborough Cavern, to Mr. D. Checkley for assistance with field work, Mr. P.W.H. Flint for technical assistance in the preparation of illustrations, and all the cave guides for their willing cooperation. The investigation was supported in part by a Natural Environment Research Council studentship award.

References

Bouché, M.B. 1972. Lombriciens de France — Écologie et Systematique. Institut national de la Recherche argronomique. *Annales de zoologie ecologie Animale.* No. 72-2 Service des Publications, Versailles.

Edwards, C.A. & Lofty, J.R. 1972. *Biology of Earthworms,* Chapman & Hall Ltd., London.

Ford, T.D. 1975. *Ingleborough Cavern and Gaping Gill.* Dalesman Pub. Co. Ltd., Clapham, Yorkshire. 3rd. edn.

Gerard, B.M. 1964. The Linnaean Society of London Synopses of the British Fauna. No. 6 Lumbricidae (Annelida).

Gerard, B.M. 1967. Factors affecting earthworms in pastures. *Jour. Anim. Ecol.* 36, 235-252.

Juberthie, C. & Mëstrov, M. 1965. Sur les oligochètes terrestres des sediments argileux des grottes. *Ann. Speleol.* 20, 209-236.

Piearce, T.G. 1975. Observations on the fauna and flora of Ingleborough Cavern, Yorkshire. *Trans. Brit. Cave Res. Assoc.* 2 (3), 107-115.

Satchell, J.E. 1967. Lumbricidae, in *Soil Biology,* (Ed. by A. Burges and F. Raw). pp. 259-322. Academic Press, London and N.Y.

CAVE DIVING, THE PRESENT AND THE FUTURE

F.T. Piskula.
Chairman, UIS Commission on Cave Diving.
Nam SNP 19, 61400 Brno, Czechoslovakia.

Cave diving has evolved to a certain standard, though equipment and techniques can differ to some degree. These standards are given namely by general environmental features encountered in all caves, like darkness, closed environment, orientation requirements etc., while differences originate from specific features, like size of caves, length of syphons, accessibility, depth, silt conditions, current etc.

Standard cave diving equipment and techniques are commonly known to cave divers.

Besides this standard equipment and techniques special ones have evolved. They are techniques and equipment for extreme cave diving (depth and/or distance), for cartography and for special measurements and observations.

Extreme penetration requires a large supply of breathing medium. Three systems are known to be used successfully in caves. Spanish cave divers (E. Petit and others) have successfully used Draeger FGG III mixed gas apparatus. This semi-closed unit provides up to 1.6 hours of time at the depth range of 50-100 m. German cave diver Jochen Hasenmayer uses high pressure tanks with filling pressure over 300 bar. American cave divers (S. Exley, Underwater Speleology, 1976) use a technique of tank staging, which means placing tanks inside the syphon on a "stage", which is done on the dive before the exploratory dive. More details on latest improvements of this technique can be found in Underwater Speleology, No. 2., 1976.

I want to complete this review by mentioning briefly results of cave diving. Cave divers have done considerable exploratory work. Most of the results are well documented and have been published in various periodicals. These are in most cases cartographic works, photography and films, various observation, etc. Cave diving permits exploration under water and behind sumps as well as scientific research in those areas. However, there are very few speleo-scientists among cave divers. Also cooperation of cave divers with scientists is at it's beginning. Really scientific speleological research is in cave diving practically non-existent. This author believes, that it would be very desirable to utilize potential possibilities that cave diving offers to scientists.

Now I would like to discuss future of cave diving. This is not intended to make any prognosis but rather to point out possible improvements, where developmental effort should be concentrated. Here are the points of concern:

1). Basic cave diving equipment has reached a certain degree of perfection. However, there are still some items that could be improved.

Protective cover to prevent damage of tank valve and of a regulator should become a standard part of equipment, possibly with some improvement over existing designs.

Important item is also buoyancy compensator. Existing systems do not provide any backup in case of puncture, also trim control characteristics should be improved.

Protection against cold is very important too. More common use of dry inflatable suits (Unisuit and similar) can be expected. However, some improvement in their design to prevent air shift problems should be done.

Lines would require some standardisation in length and direction marking. Length should be marked by suitable colour code, which can also mark direction. Besides this, suitable marking should be designed to tell direction out of the cave by touch even in zero visibility. A good system of fixing the line in conduits with smooth walls would be also very useful.

2). Special equipment for cave diving would require a great deal of development. Here come namely instruments for under water communication and for orientation under low or zero visibility.

Communication devices for this purpose could include: underwater acoustic beeper for signalling by means of morse code, acoustic or ultrasonic walkie-talkie, or another suitable principle. Existing designs should be carefully tested in caves.

Devices for low visibility orientation would range from simplest one — a small reel with about 10 m of searching line to be used to find the guide line if the diver gets lost from it, to more complicated, like sonars for detection of passages and rooms, and ultrasonic relocators (system Scanar and similar ones) for maintaining buddy contact and location of other divers if the team get's separated (each diver would carry a transmitter and a repeater of the Scanar system).

Instruments with acoustic or touch reading, which could be used under zero visibility also come into this group. Instruments should include compass, underwater pressure gauge and possibly a depth gauge. No such instruments are being currently produced, they must be developed first.

Of course, special new techniques will have to be developed for efficient use of this instrumentation.

3). Cartography, equipment and techniques. In the first phase, common use of existing measuring systems should be considered, with some improvement of recording of measured values (for example on a tape recorder), photographic profile measurements, etc. In the second phase, automation of measurement and recording should be considered, with possible subsequent processing of collected data on a computer. Aim of the developmental effort should be to make cartographic measurements as fast as possible and to eliminate manual recording of measured data (writing under icy water can be quite difficult and quite slow). It must be remembered that diver's time under water is quite limited and so his performance can be increased considerably by limitation of lengthy manual work.

4). Scientific application of cave diving is probably the area, where the greatest development can be

expected. Cave diving could help in many scientific studies, for example in hydrology, speleomorphology, sedimentology, speleogenesis, speleo-biology, speleo-paleontology, etc. Cave divers should make first steps towards achieving cooperation with scientists in the above mentioned disciplines.

5). Training and education should be oriented to development of training standards for training of novice cave divers and also to educate experienced cave divers so that they would be able to collect scientific data on their dives. This education should be also oriented towards implementation of latest developments in cave diving. It is believed that good training and education would give proper basis to development of other areas of cave diving.

References

Leger, Bertrand 1973. Où en est la plongée souteraine francaise? *Bulletin d'Information de l'Equipe Speleo de Bruxelles,* no. 57.

Lloyd, Oliver, C. 1975. *A Cave Diver's Training Manual,* The Cave Diving Group, England.

Mount, Tom. 1973. *Safe Cave Diving,* NACD, Miami.

Plongée Recherche, Bulletin d'information Comité de Recherches Souteraines Avancées, Angoulème, 1975.

Rey, Bertrand 1975. l'Expedition "Fontaine de Vaucluse", *Sports sousmarins,* no. 26, pp. 11-15.

Underwater Speleology, Vol. 1-3, National Speleological Society, Bloomington, 1974-1976.

THE UIS COMMISSION FOR CAVE DIVING AND ITS WORK

Frantisek Tomas Piskula
UIS Commission for Cave Diving
Nam. SNP 19
614 00 BRNO, Czechoslovakia

Cave diving is gaining growing importance as a means of speleological exploration and research and as an underwater or amphibian type of caving. However, the danger involved, with consequent growth of cave diving accident rate, as well as growing need for imporvement of cave diver's performances and efficiency, showed the necessity of improved exchange of information on an international scale. This was the primary reason for forming the new Commission for Cave Diving at the 6th International Speleological Congress in 1973.

Since that time the Commission has gone some way towards achieving its goals. This paper is intended to inform you about the Commission's work in the past period and about plans for the future. If we compare this with the paper on Commission's work presented at the 2nd International Conference on Cave Diving we can see that both Commission's structure and its program have evolved with the time, so that more effective work could be performed. National Representatives, similar to the UIS structure did not prove to be very practical, namely because some countries have several organisations dealing with cave diving none of them being representative for the whole nation. Also discussion with the UIS General Secretary as well as our practical experiences were very helpful for us to make useful changes.

The major change is the omission of a system of National Representatives, while a system of Working Groups after slight modification performs most of the Commission's work.

Aims of the Commission are following:

1. To help in the development of cave diving all over the world, and to make it more safe.
2. To assist in the international exchange of experience and to solve important problems in cave diving.
3. To contribute to the effective utilization of cave diving as a means of scientific research in other branches of speleology.

To reach these aims, the Commission shall follow this program:

1. Gather information on all aspects of cave diving, i.e. equipment, methods and techniques of cave diving, training, safety and rescue, accidents, cave diving photography, cartography and scientific application of cave diving.
2. Compile and process this information and distribute the results among cave divers and other people interested.
3. When possible, conduct own research to complement the compiled information, for example by tests of equipment, techniques and safety procedures.
4. Organise international meetings of cave divers (camps, conferences, etc), to contribute to more effective exchange of information.
5. When sufficient amount of information has been collected, method and safety recommendations shall be issued, based on carefully processed and evaluated information.
6. Publish periodical "Cave Diving Developments" as the main means of international exchange of information and utilize also other possibilities of publication and information exchange.
7. When possible, conduct also other activities, that would contribute to reaching the aims of the commission.
8. Cooperate with other commissions of UIS, with World Underwater Federation (CMAS) and with other organisations having underwater exploration of caves in their program.

Structure of the Commission

Based on the UIS statute and on the discussion with the UIS Executive Committee members, following structure has been established:

The Commission is composed of Executive Committee, Board of Working Group Coordinators and Members.

Work of the Commission

The Commission is organized in Working Groups, which are established to deal with a particular area related to cave diving. Working groups can be temporary or permanent, depending upon their subject.

Work of each working group is directed by a Coordinator, according to Group's aims and Commission Chairman's instructions. Coordinator gathers information on the subject of work from the group members, evaluates it and assignes the members work related to the group's aims.

The Coordinator informs regularly (at least quarterly) the Commission Chairman about work of his group and submits an annual report on this work and its results.

Working Group Members (each commission member can be a member of one or more Working Groups) submitting the results to the Group Coordinator and performing partial tasks related to the Group's work, according to Coordinator's requests. They also submit to the Coordinator any suggestions, objections, remarks etc., regarding the group's work.

Working Groups

System of Working Groups is still developing because there is a lack of coordinators for some of the groups. However, the most important ones are already active, and it is believed that the remaining ones will be gradually activated too.

Following Groups have been established or proposed:

1. Equipment and Techniques.
2. Training and Education.
3. Safety, Rescue and Recovery
4. Accident and Dive Statistics.
5. Cartography.
6. Photography and Filming
7. Scientific Application of Cave Diving
8. Medical Aspects of Cave Diving.
9. Library and Bibliography.

Each group will at first gather all accessible information on present state of development in their particular field of activity. Then it will work towards achieving the most effective development of this particular subject.

Aims of the working groups are implied in their names. For more detailed description I refer again to my paper on the Commission's work at the 2nd International Conference on Cave Diving.

The only group to be mentioned in more detail is one for the Scientific Application of Cave Diving. This group should not duplicate work of other UIS commissions, but it will serve to maintain close cooperation of Cave Diving Commission with scientific commissions of the UIS. The purpose of this cooperation is to provide speleological sciences with a useful working tool and to provide cave divers with rewarding fields of activity. It is believed, that besides experienced cave divers, scientists specialized in areas where cave diving could provide some help, should be members of this working group. It could be very useful, if other UIS commissions would examine whether underwater exploration, observation, measurement, taking samples, etc., could help to solve some of their problems. Then a suitable working program could be worked out in cooperation with the Working Group for Scientific Application of Cave Diving.

Activities of the Commission since 1973

In this period the work was primarily oriented to activation of system of working groups. This proved to be far more difficult and slower than expected, nevertheless, working groups for Accident and Dive Statistics, Safety, Rescue and Recovery, Cartography and Scientific Application of Cave Diving have started their activity.

Accident statistics provide valuable information, upon which safety recommendations could be based, both for equipment and for techniques. This also helps to determine dangerous equipment and procedures.

Group for Safety, Rescue and Recovery gathers information about equipment techniques, special training, etc., which could be necessary for rescue of people from behind a sump. According to the arrangement between UIS Rescue Commission and Cave Diving Commission, Rescue Commission deals with first aid and transportation of injured or otherwise incapacitated people through dry or semi-dry parts of the cave, while the Cave Diving Commission deals with rescue of divers underwater and transport of injured people through the syphon.

Group for Cartography, besides providing information on actual techniques of underwater mapping of caves, should cooperate also with the Commission for Conventional Signs, so that their system could be modified to be suitable also for underwater parts of caves.

Group for scientific application examines possibilites of utilization of cave diving, so that basic materials could be provided to anybody interested in this aspect.

An important event organised by the Commission for Cave Diving was the 2nd International Confer-

ence on Cave Diving, held in September 1-7, 1975 in Vilanova i la Geltru, near Barcelona, Spain. This successful meeting provided an excellent opportunity for international exchange of experience.

An important aspect of the Commission's activity is the arrangement about cooperation between our commission and CMAS (Confederation mondiale des activitees subaquatiques) commission for Fresh Water and Cave Diving. Among other things, Chairman of each commission should be delegated as a member to the other commission.

Commission also plans to publish magazine "Cave Diving Developments". Though there is considerable delay in this operation, it is believed, that by the 7th Speleological Congress first issue should be published. This magazine should not be used solely for publication of articles on cave diving. Publication of scientific articles on problems where cave diving could be useful are also welcome.

Last but not least of aspects of commission's work are better contacts among cave divers all over the world. Unofficial personal correspondence, visits, etc., are very good means of exchange of information.

Conclusions

The UIS Commission for Cave Diving has started its work quite successfully. Aims, programs and basic structure have been established, though not fully activated. A successful international conference was organized in the 1975 and international exchange of information is being conducted. There are plans to activate remaining working groups and to proceed towards evaluation of the information and making our own recommendations. Also more application of cave diving in speleological science is expected. We believe that cave divers and other speleologists will help us to achieve the commission's aims.

CALCIUM HARDNESS FLUCTUATIONS IN THE SHOW-CAVE SECTION OF WHITE SCAR CAVE, INGLETON, YORKSHIRE

A.F. Pitty, J.L. Bracewell and R.A. Halliwell,
Geography Dept., University of Hull,
Hull, U.K.

It is 20 years since J. Corbel (1957) challenged the cave research and karst world to consider his hypothesis, based on the law which describes the increased solubility of carbon dioxide at lower temperatures. This law, he argued, would indicate that the solution of limestones is more intense in a colder environment. On the other hand, the increase in biochemical reaction rates at higher temperatures was the law used as the basis for counter-arguments favouring warmer, humid tropical environments as the regions of most intense solution and cave development. The ensuing debate included three characteristics. First, solute concentration of karst and cave waters was sometimes confused with denudation rates (solute concentration x discharge). Secondly, data collected from a scatter of latitudes, often on one occasion only in remote areas, could be used to demonstrate the apparent applicability of either law. Thirdly, there persists a lack of comparative data with which to compare the findings in Poole's Cavern, Derbyshire (Pitty, 1966), in which seepages from the cave roof showed clearly a high *positive* correlation of calcium carbonate with antecedent air temperatures.

It has been argued that one of the main advantages of collecting field samples and data, as opposed to armchair modelling or theorising, is the chance of observing an unusual event. This may result in the influence or character of one of many variables being prominently in evidence (Pitty, 1971). Thus cave water data which chanced to be collected in Britain during the exceptionally hot dry 1976 summer has particular relevance to consideration of the influence of temperature on cave water characteristics. The following account relates to data collected at 19 underground sites and on 13 occasions between March 1976 and January 1977 in the section of White Scar Cave which is open to the public (Fig. 1). The samples, collected and analysed by Bracewell (1977), was an exercise adjunct to research beyond the show cave, consisting of fortnightly sampling by Halliwell and helpers, between November 1975 and November 1976, and the installation of continuous recording equipment in July 1976 by Pitty and Halliwell.

Mean calcium hardness values

a) Main stream hardness

The mean calcium hardness values of the main stream are typical of a sizeable underground stream in Yorkshire (Halliwell *et. al.* 1975), being 102ppm (Site 1) at the barrier which marks the inner end of the show cave. Downstream, values are 99ppm (Site 12 – underneath the floorboards), 104ppm (Site 14 – below the Second Waterfall) and 101ppm (Site 17 – downstream from the First Waterfall).

b) Comparison with previous observations of the White Scar Cave stream

Downstream from the first waterfall (Site 17) the mean calcium hardness of 101ppm is in close agreement with the mean value of 105ppm for Halliwell's sampling period from November 1975 to November 1976 (29 values). It also closely approximates to samples collected at the surface resurgence by Pitty in 1964-65 (mean value 98ppm from 30 samples). Thus the mean hardnesses are representative of the general conditions of solute flow despite the extreme weather conditions which occurred during the March 1976 to January 1977 period.

c) Inlets and seepages

The most voluminous tributary inlet in the show-cave section (Site 13) and its entry with a hardness of 144ppm probably explains the slight increase in the mainstream at Site 14. Site 8, a cave seepage which streams in wet weather, and the seepage in the mined Entrance passage (Site 19) both have a mean of 142ppm. The highest hardness of 188ppm was recorded at points where water issues over flowstone (Site 9 – the Ebbing and Flowing inlet, and Site 18 – the Glory Hole). The remaining six sites fall between the 151ppm of the stagnant pool (Site 6) and 177ppm of the tributary inlet (Site 4).

Correlation of seasonal fluctuations in calcium hardnesses with air temperatures

a) The positive correlation observed at all sites

The seasonal pattern of hardness values were correlated with antecedent air temperatures recorded at Malham Tarn Field Centre, the nearest climatic station. These calculations followed the procedure described by Pitty (1966). At every site the association between calcium hardness and some antecedent air temperature interval was found to be consistently and clearly positive. Correlation coefficients between hardnesses and average temperature for the week prior to each sampling date, except Site 16 ($r = 0.50$, $N = 11$), was 0.62 or higher for the main stream and 0.76 or higher for the inlets and seepages. As observed in Poole's Cavern and Peak Cavern in Derbyshire and in nearby Ingleborough Cavern, Yorkshire, the antecedent interval with the closest fit varied from site to site, but with a much shorter lag than observed in the two Derbyshire Caverns.

b) The main stream

The main stream's hardness (Site 1) correlates most closely with the 7-13 day antecedent interval ($r = 0.65$, $N=13$). A secondary 'peak' for the 42-62 day interval ($r = 0.58$) may be noteworthy, as the association with intervening intervals is less marked (e.g. for the 21-27 day period, $r = 0.42$) despite the inevitably high autocorrelation between adjacent air temperatures. Downstream, the same secondary 'peak' persists in the pattern of solute fluctuations and is just as close a fit ($r = 0.85$) as for any shorter term interval since correlations for any week or any spread between 1 and 5 weeks prior to sampling do not exceed $r = 0.85$. The addition of the main tributary, correlated most closely with temperatures immediately prior to sampling ($r = 0{,}72$ for the 0-6 day interval) imposes the influence of a short-term effect. In consequence, where the stream leaves the cave (Site 17), the 7-13 day period ($r = 0.86$) becomes the overall characteristic of solute fluctuations in the combined flows in the main stream at this point.

C) Inlets

The positive association between air temperatures and hardness is clearly marked for all inlets. With the exception of Sites 13 and 16 ($r = 0.71$), the 0-13 day interval correlations, for example, range between $r = 0.87$ (Site 19,$N=10$) and $r = 0.93$ (Site 3, $N=13$ and Site 6, $N=11$). On the other hand, the influences of one specific interval is not identified, since the fit indicated by the correlation coefficients is equally close for the 0 - 6, 0 - 13, 0 - 20, 0 - 34 and the 7 - 13 day temperatures for all the remaining inlets.

Correlation of seasonal fluctuations in calcium hardnesses with rainfall

a) The generally observed inverse correlation between precipitation and hardness

Solute concentrations were also correlated with rainfall amounts for ranges and spans of times prior to each sampling day. None of the intervals mentioned in the following discussion showed statistically significant departure from the normal distribution.

b) Lags in the dilution effect in the main stream

The cave stream showed an apparent dilution effect, with hardness declining after rainfall. However, a short-term effect (e.g. for day 0-6 $r = 0.58$) was less marked than a longer-term association (for days 63-83, $r = -0.72$) At the downstream end of the show cave, the net effect of tributary and seepage additions is to leave the short-term (0-1 day) and broad span (0-34 day) with the closest fits with the hardness data ($r = 0.74$). These correlations suggest a slow underground movement of water in tributaries beyond the show cave. The changes in correlations within the show cave illustrate how solute patterns change within the source of an underground stream.

c) Inlets and seepages

The correlations of cave inlet and seepage hardness with precipitation are unlike the general patterns observed in Poole's Cavern, Peak Cavern, and Ingleborough Cavern. At most sites in these earlier studies, antecedent temperature was an over-riding, positive control at most sampling points. In the case of White Scar, however, nearly all inlets appear to experience a significant drop in hardness after rainfall. This inverse correlation is.marked, although not as close as the positive fit with temperature data. The inverse correlation with precipitation and the broad 0-34 day span gives the closest fit in nearly all cases, with coefficients between -0.68 and -0.82 for sites with 10 or more observations.

One slight exception amongst the inlets and seepages is Site 15 where the correlations is not prominent and is most close for the short 0-1 day interval ($r = -0.65$). The main exceptions are Site 13 and especially Site 16 where the main effect is a lagged *positive* correlation with precipitation (42-62 day period, $r = 0.82$). These are the two waterfall sites with water issuing from small open passages. For Site 3, the same lag occurs (42-62 day period, $r = 0.61$).

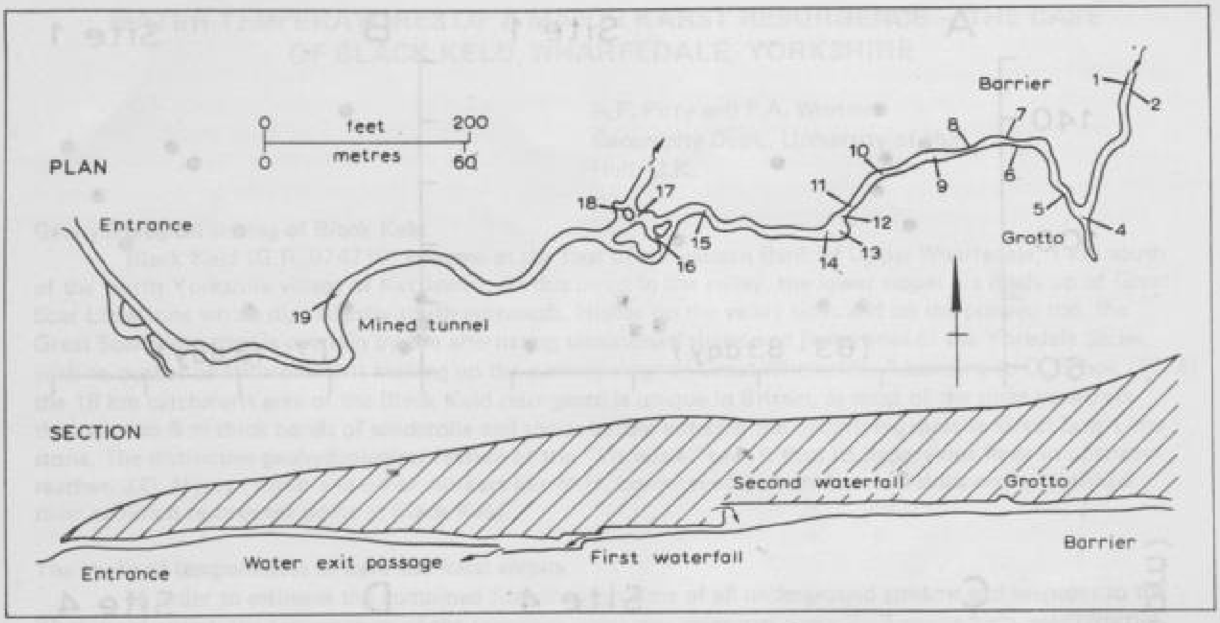


Fig. 1. Plan and section of WhiteScar show cave with sampling sites (based on Waltham 1976).

Conclusion

Compared with other cave waters studied in Derbyshire and Yorkshire, only sites 5 and 15 are strictly comparable, in that they are seepages which issue dropwise from tight joints. The other sources, apart from the main stream, all emerge from small openings and are sampled after flowing as a film or cascade over flowstone formations. Nonetheless, the positive control of temperature is clearly evident and the precipitation effect least marked at the two seepages (Sites 5 and 15). Possibly the notable and general pattern of negative associations between solute concentration and precipitation is related to the processes within the cave, as these small streams flow some distance in open fissues and bedding planes, and over depositional features before being sampled. On the other hand different geohydrological characteristics could be reflected in the data and correlations. The strata are low in the Lower Carboniferous sequence, contain impurities and are interstratified with several thin shale bends. In addition, the scree and open-scar landsurface is at no great distance above the sampling points. The strata are approximately 25m thick above Site 7 and not much more than 35m at the inner end of the show-cave. The importance of precipitation in modifying the seasonal trend of hardness data suggests that there is a greater opening of joints above White Scar than above caves investigated in earlier studies.

It is hoped to offer more conclusive generalisations about the geohydrology in the vicinity of White Scar when the regular, intensive sampling has been submitted to multiple correlation and regression analysis and when the data from the continuous recording instruments near Site 1 are more extensive. In addition the significance of water temperature relationships, observed in the present investigation and illustrated in Figure 2.F, have yet to be evaluated.

Acknowledgements

The authors wish to thank the owners and management of White Scar Cave for permission to collect the samples described in this study and are indebted to the staff of the Malham Tarn Field Centre for the climatic data.

References

Bracewell, J.L. 1977. *White Scar Cave, a study of an underground environment.* Unpublished undergraduate dissertation, University of Hull, to be presented 1977.

Corbel, J. 1957. *Les Karsts du Nord-Ouest de l'Europe.* Memoires et documents 12 Institut des Etudes Rhodaniennes de l'Universitie de Lyon.

Halliwell, R.A. *Aspects of Limestone Waters near Ingleton, North Yorkshire.* Unpublished PhD thesis, University of Hull presented 1977.

Halliwell, R.A., Cavanagh, A.H. A.F. Pitty. 1975. The influence of the pre-Carboniferous basement rocks on karst development in the in the Ingleton area of north-west Yorkshire. *in* I. Gams (ed). *Karst Processes and relevant landforms,* Ljubljana.

Pitty, A.F. 1966. *An approach to the study of karst water,* University of Hull. Occasional Papers in Geography 5.

Pitty, A.F. 1974. Karst water studies in and around Ingleborough Cavern. Chapter 7 *in* A.C. Waltham (ed). *The Limestones and Caves of North-west England.* David & Charles, Newton Abbott.

Pitty, A.F. 1971. *Introduction to geomorphology.* Methuen, London, 526pp.

Waltham, A.C. 1976. *White Scar Caves.* White Scar Caves Ltd.

Waltham, A.C. 1977. White Scar Cave, Ingleton. *Trans. Brit. Cave Res. Assoc.,* vol. 4, in press.

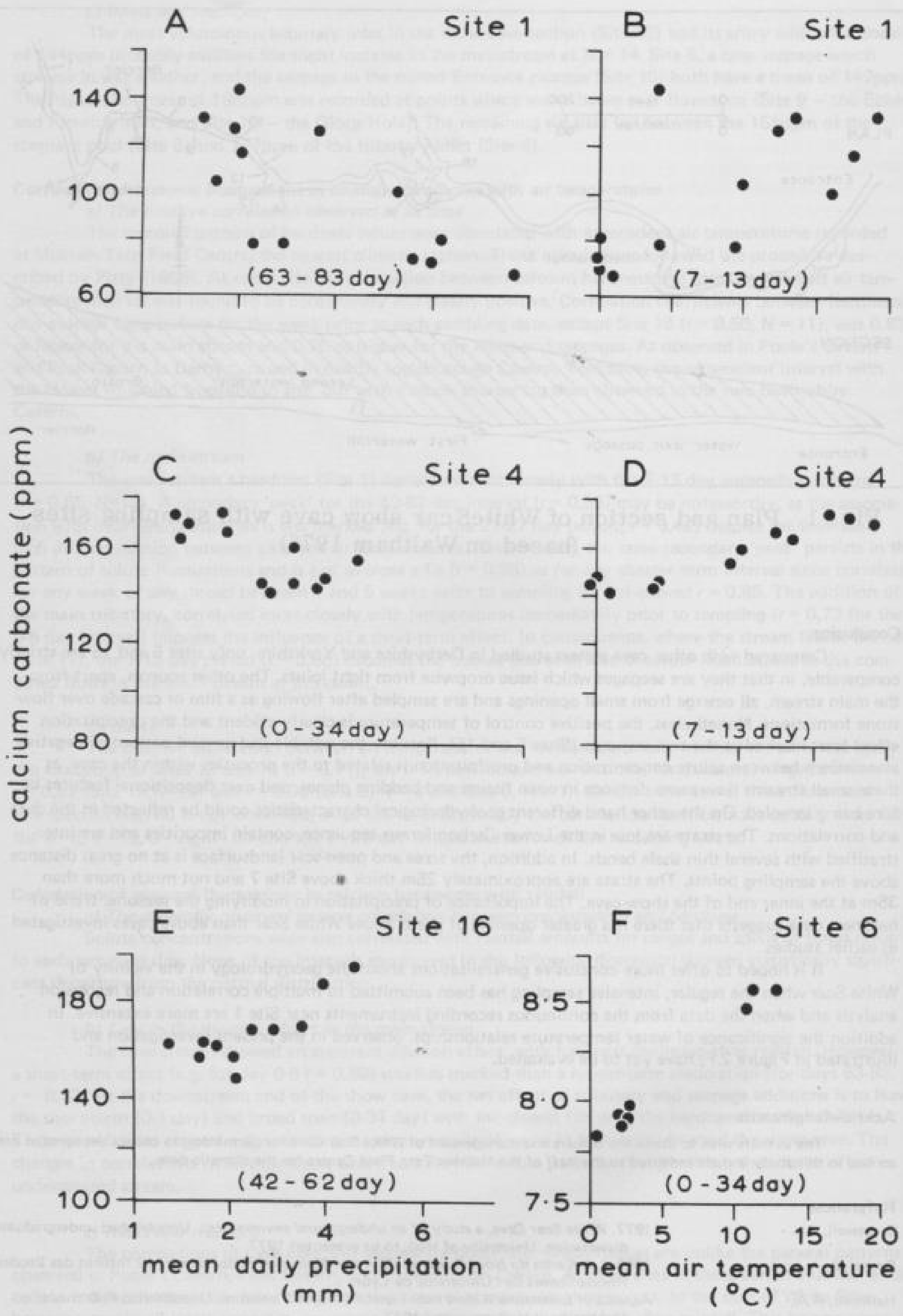


Fig. 2. Typical responses in White Scar Cave water characteristics. (the time intervals display the closest fit observed. Figs. 2 A–E refer to $CaCO_3$ concentration and Fig. 2 F to water temeratures ofa pool).

WATER TEMPERATURES OF A MAJOR KARST RESURGENCE – THE CASE OF BLACK KELD, WHARFEDALE, YORKSHIRE

A.F. Pitty and P.A. Whittel
Geography Dept., University of Hull,
Hull, U.K.

Geohydrological setting of Black Keld

Black Keld (G.R. 974710) emerges at the foot of the eastern flank of Upper Wharfedale, 1 km south of the North Yorkshire village of Kettlewell. At this point in the valley, the lower slopes are made up of Great Scar Limestone which dips slightly south-eastwards. Higher up the valley sides and on the plateau top, the Great Scar Limestone is overlain by the alternating sandstones, shales and limestones of the Yoredale Series, with an outlier of Millstone Grit making up the summit ridge of Great Whernside. According to D. Brook (1974) the 18 km catchment area of the Black Keld resurgence is unique in Britain, as most of the sinks penetrate through two 6 m thick bands of sandstone and shales before entering the underlying massive Great Scar Limestone. The distinctive geohydrological feature of the "Yoredale" cave is thus its impervious floor in upstream reaches. J.O. Myers (1950) and other workers like M.H. Long have dye-tested several sinks and established their common resurgence point at Black Keld.

The study of temperatures of cave and karst waters

In order to estimate the combined flow-through time of all underground streams and seepages to the Black Keld outlet, the temperature of the resurging water was measured every 2 - 3 weeks for a year (Whittel, 1977). The annual variation of water temperatures has a coefficient of variation of 18.33 per cent, with an observed range of 4.2°C. These variations indicate the degree of narrowing of the water temperature fluctuations during passage underground, as the coefficient of variation in the nearby surface river is 50.8 per cent at Kettlewell Bridge.

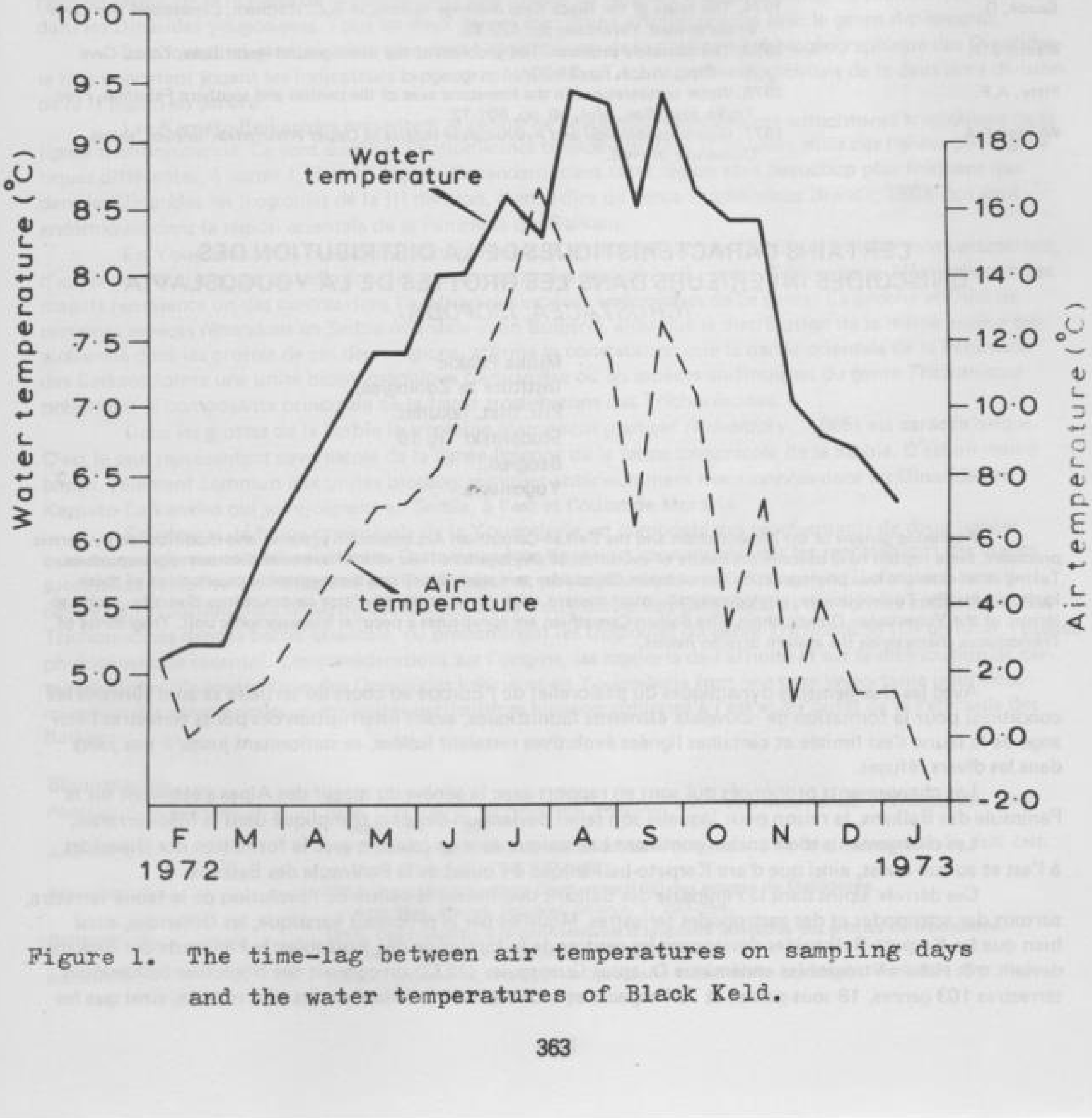


Figure 1. The time-lag between air temperatures on sampling days and the water temperatures of Black Keld.

Tim-lags between air and water temperatures

The time-lag between air temperatures and emerging groundwaters can be precisely stated and it is argued that such time-lags are an indication of rate of flow of underground water (Pitty, 1976). Lags are identified by calculating a series of correlation coefficients between water temperature observations and for a set of air temperatures means for periods at increasing intervals prior to each sampling day. Thus, it can be seen from Table 1 that the annual march of water temperatures at the Black Keld resurgence is more closely matched with air temperatures at periods prior to sampling than to air temperatures at sampling time ($r = 0.86$ for the 0 - 6 day interval). It seems that the fit is closest for the 28 - 34 day period ($r = 0.94$), and since air temperatures

Correlation coefficients between water temperatures at Black Keld and a range of antecedent air temperature means

0-2	0-6	7-13	14-20	21-27	28-34	35-41
0·87	0.86	0.83	0.86	0.93	0.94	0.88

are inevitably highly autocorrelated, a maximum effect at 28 days prior to sampling can be suggested by interpolation from the values for the adjacent 21 - 27 day and 35 - 41 day intervals. This 28-day lag is a striking characteristic of the underground course of the stream and can be attributed to slower moving water than that which runs straight through the main stream after rainfall. This lag is noticeably longer than that of 17 - 19 days observed further west in the Ingleton and Malham areas but corresponds closely with the 28 - 29 day lag observed in waters emerging from the massive limestone at Castleton in Derbyshire. Such a lag, therefore, may not be a distinctively "Yoredale Cave" feature.

The relationships in Table 1 refer to the year as a whole, but it is readily envisaged from Figure 1 that the relative importance of the immediate response (correlations for the 0 - 2 and for the 0 - 6 day periods), compared with the longer-term 28 - 34 day effect remains predominant and high ($r = 0.96$). In contrast, for the earlier March to August span, the 0 - 2, 0 - 6, and the 28 - 34 day correlations are all equally close.

References

Brook, D. 1974. The caves of the Black Keld drainage system, *in* A.C. Waltham, *Limestones and caves of north-west Yorkshire*, pp. 422-33.

Myers, J.O. 1950. The Mossdale problem. The problem of the underground water flow, *Trans. Cave Res. Grp.*, Vol. 1, pp. 21-30.

Pitty, A.F. 1976. Water temperatures in the limestone area of the central and southern Pennines, *Proc. Yorks. geol. Soc.*, Vol. 40, pp. 601-12.

Whittel, P.A. 1977. *Geomorphological and hydrological studies in Upper Wharfedale*, unpubl. thesis, University of Hull.

CERTAINS CARACTERISTIQUES DE LA DISTRIBUTION DES ONISCOIDES INFERIEURS DANS LES GROTTES DE LA YOUGOSLAVIA *(CRUSTACEA, ISOPODA)*

Milika Pljakic
Institute za Zoologica,
Prir. mat. fakultet,
Studentski Trg 16
Beograd,
Yugoslavia.

Following genesis of the Dinaric chain and the Balkan-Carpathian Arc mountain systems, and modification by karstic processes, these regions have become the centre of evolution of phylogenetic lines which have cavernicolous representatives. Taking as an example two phylogenetic lines of lower Oniscoidea this study illustrates biogeographic peculiarities of these karst faunas. The Trichoniscinae, phylogenetically most ancient, with an exceptionally large cavernicolous diversity, is characteristic of the Yugoslavian Dinaric chain. The Balkan-Carpathian arc constitutes a peculiar biogeographic unit. Troglobites of *Trichoniscus* characterise the eastern Serbian massif.

Avec les changements dynamiques du paléorelief de l'Europe au cours du tertiaire se sont formées les conditions pour la formation de nouveaux éléments faunistiques; avec l'interruption des ponts terrestres l'échange de la faune s'est limitée et certaines lignées évolutives restaient isolées, se stationnant jusqu'à nos jours dans les divers réfuges.

Les changements prononcés qui sont en rapport avec la génèse du massif des Alpes s'étendent sur la Peninsule des Balkans, la raison pour laquelle son relief devient un des plus compliqué dans la Méditérranée.

Les changements d'un ancien continent balkanique sont en relation avec la formation des Dinarides à l'est et au sud-ouest, ainsi que d'arc Karpato-balkanique à l'ouest de la Peninsule des Balkans.

Ces dérivés alpins dans la Péninsule des Balkans deviennent le centre de l'évolution de la faune terrestre, surtout des artropodes et des gastropodes terrestres. Modifiés par le processus karstique, les Dinarides, aussi bien que les Karpato-Balkanides deviennent les centres de la formation des troglobies; la Péninsule des Balkans devient très riche en troglobies endémique D. apres Gueorguiev (1973) on connait des troglobies balkaniques terrestres 103 genres, 18 sous-genres et 794 especes et sous-espèces. Les résultats les plus récents, ainsi que les

nôtres, sont en faveur de la constatation que la hétérogénité de la faune troglobie est beaucoup plus grande. Il s'agit surtout de la diversité des oniscoides inferieurs.

En Yougoslavie, les régions des Dinarides et des Karpato-Balkanides représentent les centres très importants de la radiation de la composante cavernicole de la sous-famille des *Trichoniscinae*.

A juger d'après les données sur la distribution des espèces endémiques, aussi bien que des genres et sous-genres, la zone des Dinarides (l'est et sud-est de la Yougoslavie) représente une unité particulière biogéographique. Entr'outre, certaines troglobies autochtones du deuxième division de la II légion, d'ailleurs un groupement très primitif de la lignée évolutive trichoniscienne, désignent cette particularité biogéographique de la faune cavernicole des Dinarides.

Dans les Dinarides yougoslavs le groupe de genres *Protonethes Absolon* et *Strouhal*, 1932, *Titanethes* Schiodte, 1849, est autochtone, aussi bien qu'un nouveau genre en train de la publication (Pljakic 1977). Par une analyse comparative de l'organisation des espèces, les relations phylogénétiques deviennent évidentes sur le plan générique; les étapes successives de l'évolution de ce groupe de genres troglobiens, éndémique dans les Dinarides, peuvent être suivies à partir de l'organisation du *Protonethes* monotypique, vers celle qui est aussi réalisée chez le nouveau genre monotypique, et enfin chez *Titanethes* taxonomiquement differencié (2 sous-genres et 4 espèces).

Un groupe important dans les Dinarides yougoslaves composent les genres: *Alpioniscus Racovitza*, 1908, *Macedoniscus Buturovic*, 1954, *Aegonethes Frankenberger*, 1938. Ce groupe de genres, ainsi que le précédent est caractérisé par les particularités phylogénétiques et biogéographiques. Ce groupe de genres de la lignée évolutive trichoniscienne appartient à la même division et à la même legion que le groupe précédent (II division et II légion).

La radiation la plus intensive dans les Dinarides yougoslaves est constatée chez le genre *Alpioniscus;* de trois sous-genres de la faune cavernicole de cette région, le plus divers c'est *Illyrionethes* Verhoeff, 1927 (12 espèces endemiques et 2 sous-espèces); les autre deux sous-genres, à savoir *Alpioniscus* s. str avec 4 espèces et 2 sous-espèces, ainsi que le sous-genre endémique *Macedonethes Buturovic*, 1955, tous les deux de la Macédoine occidentale, illustrent aussi la grande differentiation d'*Alpioniscus* dans les Dinarides yougoslaves.

La répartition des genres des troglobies *Macedoniscus* (2 espèces) et *Aegonethes* (2 espèces) témoignent en faveur de la richesse de la composante cavernicole de la lignée trichoniscienne. Le premier est endémique dans les Dinarides yougoslaves. Tous les deux genres sont d'une affinité proche avec le genre *Alpioniscus*.

La conclusion générale c'est que, dans l'appréciation de la particularité biogéographique des Dinarides, le rôle important jouent les indicateurs biogeographiques des Trichoniscines troglobiens de la deuxième division de la II légion en général.

Les Karpato-Balkanides présentent le centre de l'évolution des éléments autochtones troglobiens de la lignée trichoniscienne. Ce sont aussi les Trichoniscines troglobiens de la II division, mais des lignées phylogénétiques différentes, à savoir I, II et III légion. Cependant, dans cette région sont beaucoup plus fréquent que dans les Dinarides les troglobies de la III division, c'est-à-dire du genre *Trichoniscus Brandt*, 1883, qui sont endémiques dans la région orientale de la Peninsule des Balkans.

En Yougoslavie, les massifs qui font partie des Karpato-Balkanides (Serbie orientale) sont caractérisés, d'après nos résultats, par la radiation des représentants des troglobies du genre *Trichoniscus*. Même chacun des massifs représente un des centres dans l'évoltion des espèces endémiques de ce genre. La proche affinité de certaines espèces répandues en Serbie orientale et en Bulgarie, ainsi que la distribution de la même espèce troglobienne dans les grottes de ces deux régions, affirme la constatation que la partie orientale de la Peninsule des Balkans forme une unité biogéographique particulière ou les espèces endémiques du genre *Trichoniscus* présentent la composante principale de la faune troglobienne des Trichoniscines.

Dans les grottes de la Serbie la troglobie *Mesoniscus graniger (Frivaldsky*, 1865) est caractèristique. C'est le seul représentant cavernicole de la lignée ligienne de la faune cavernicole de la Serbie. C'est en même temps, l'élément commun aux unités biogeographiques antérieurement mentionnées dans les Dinarides et Karpato-Balkanides qui se rejoignent en Serbie, à l'est et l'ouest de Moravia.

En général, la faune cavernicole de la Yougoslavie est composée des représentants de deux lignées évolutives: ligienne et trichoniscienne. Cette deuxième lignée est caractérisée par les représenants des étapes successives évolutives: le complexe des Trichoniscines phylogénetiquement plus ancien (II division) avec le centre de l'évolution dans la partie occidentale de la Yougoslavie (les Dinarides) et des formes éndémiques des Trichoniscines dans la partie orientale, ou prédominent les troglobies du genre *Trichoniscus* (III division, l'étapes phylogénetique récente). Les considerations sur l'origine, les rapports de l'affinité et sur la distribution de certaines lignées phylogénétique des Oniscoides inférieurs en Yougoslavie font une base importante pour détermination des caractéristiques des unités particulières biogéographiques à l'est et à l'ouest de la Peninsule des Balkans.

Bibliographie

Absolon, K. u. Strouhal, H. 1932. *Protonethes ocellatus* nov. gen., nov. spec., eine neue Hohlen-*Trichoniscidae*. *Zool. Anz.* 101, 17-28.

Andreev, S.N. 1972. Beitrag zur Kenntnis der Landasseln Bulgariens (Isopoda, Oniscoidea). II. *Bull. Inst. Zool. Mus. Sofia*, 34, 177-188.

Buturovic, A. 1954. Isopodes nouveaux (Isop. terrestria) des grottes de Macédoine. *Acta Mus. Maced. Sci. Nat. Skopje*, 1, 233-254.

Buturovic, A. 1955. Contribution a la connaissance d'Isopodes terrestres des grottes de Macedoine. *Fragm. Balcanica. Skopje.* 1, 117-124.

Buturovic, A. 1958. O sistematici, biologiji i biogeografiji trihoniscida Jugoslavije. *God. Biol. Inst. Sarajevo*, 10, 3-67.

Gruner, H.E. u. Tabacaru, I. 1963/64. Revision der Familie *Mesoniscidae Verhoeff*, 1908 (Isopoda, Oniscoidea). *Crustaceana*, 6, 15-34.

Guéorguiev, V.B. 1973. Etapes de pénétration de la faune tertiaire terrestre dans les cavernes de la Péninsule balkanique. *C.R. Acad. bulg. Sci.*, 26, 1065-1067.

Pljakic, M.A. 1970. Nouvelles espèces des Isopodes terrestres dans les grottes de la Serbie (Yougoslavie) *Bull. Mus. Hist. Nat. Belgrade*, 25 B, 305-320.

Pljakic, M.A. 1970a. Contribution à la connaissance du genre *Macedoniscus (Trichoniscidae)* en Serbie- *Macedoniscus metohicus* sp. n. *Bull. Mus. Hist. Nat. Belgrade*, 25B, 321-328.

Pljakic, M.A. 1972. Un nouveau troglobie de la faune de Serbie dans la région de l'arc alpin karpato-balkanique — *Trichoniscus buturovici* sp. n. *Wiss. Mitt. Bosn.-herz. Landesmus. Sarajevo*, 2C, 159-165.

Pljakic, M.A. 1973. Contribution to the knowledge of the Serbian cave living fauna. *Bull. Mus. Hist. Nat. Belgrade*, 28B, 143-147.

Pljakic, M.A. 1975. Les éléments cavernicoles dans la faune de la Serbie. Des nouvelles données sur l'aire de répartition du *Mesoniscus graniger* (Frivaldsky). *Bull. Mus. Hist. Nat. Belgrade*, 30B.

Strouhal, H. 1939. *Titanethes* Schiodte (Landasseln aus Balkanhohlen . . . .). Zugleich 21' Beitrag zur Isopodenfauna des Balkans. In: *Stud. Geb. Karstforsch. Brunn, Biol. Ser.*, 5, 1-34.

Vandel, A. 1946. Isopodes terrestres récoltées par M. le Prof. Remy au cours de ses voyages dans les régions balkaniques. *Ann. Sc. Nat. Zool. Paris*, 8, 151-194.

Vandel, A. 1960. Isopodes terrestres (Première partie). In: *Fauna de France*, 64, 1-416.

Vandel, A. 1965. Les Isopodes terrestres et cavernicoles de la Bulgarie (Première partie). *Ann. Speleol.* 20, 243-270.

Vandel, A. 1967. Les Isopodes terrestres et cavernicoles de la Bulgarie (Seconde partie). *Ann. Speleol.* 22, 333-365.

Verhoeff, K.W. 1926. Ueber Isopoden der Balkanhalbinsel gesammelt von Herrn Dr. I. Buresch. Zugleich 31. IsopodenAufsatz. Mitt. Bulg. Entom. Ges. Sofia, 3, 135-158.

NEW DATA ON THE STRATIGRAPHY OF PETRALONA CAVE

Nickos A. Poulianos
Spelaeological Section of the Anthropological
Association of Greece

During the 1976 excavations a new trial section was done in the Petralona cave, which uncovered about twenty layers.

The tenth layer divides the pit into two parts very distinctly. It is a travertine layer, but very different from the top stalagmite layer. It is a flowstone, formed in a wet and damp period, as the top layer, but quite different in its crystallography. It is a sterile layer, while the top stalagmite has certain bones, tools, or other remains in it. During the formation of the tenth layer we suppose man did not enter the cave, while during the first (top) man occasionally entered.

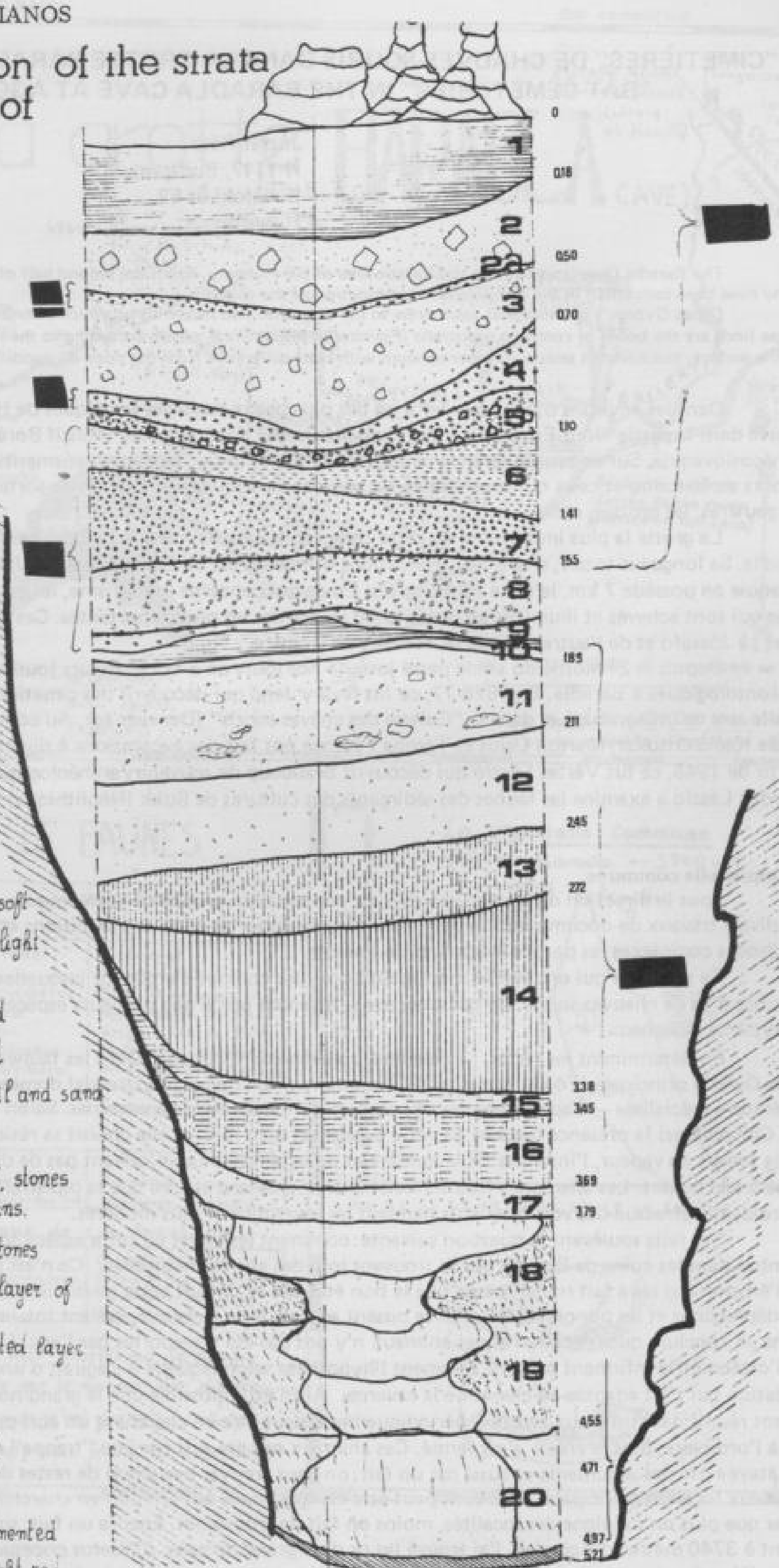
Under the top stalagmite layer the soil is very soft and full of evidence of human activity. We came to the conclusion that it was formed during a cold period, which was named the Petralonian period. Dating of the stalagmite allows an absolute date for this layer (Nos. 2 and 4) of about 400,000 years, which corresponds to the Mindel cold period of alpine terminology. Thus we think the intermediate layers, (3, 5, 7, 8, 9) including the 10th belong to an Interglacial named Thermaecian, after the gulf of Salonica, which must have been formed at that time.

Below comes layer 11, very soft soil and with the most abundant evidence of human activity, mainly stone implements. It corresponds to another cold period named Crenian, after the village Crene in the vicinity where man was mainly procuring raw material for his tools. Lower layers correspond to interglacials as well as interstadials, and the whole complex should correspond to a pre-Cromerian epoch of Europe, given that layer 11 is dated as a Matuyama boundary. The life of man in this part of Greece approaches one million years.

Reference

Ari N. Poulianos. "Stratigraphy and age of the Petralonian man", In Press, Anthropos V.4, 1977.

Cross section of the strata of the cave of Petralona



legend

1 stalagmite
2 cemented breccia
3 soft, dark red soil with irregular stones.
4 cemented breccia softer than no 2
5 dark, red, relatively soft
6 breccia-like layer light colored
7 moist, soft, dark red
8 cemented pale red
9 muddy light red soil and sand
10 stalagmite
11 red mud, grey soil, stones with crystallic grains.
12 muddy very sandy stones
13 very reddish sandy layer of terra rossa
14 argile sandy cemented layer
15 light red mud
16 dark grey mud
17 breccia-like, reddish
18 soft red soil
19 red soil slightly cemented
20 cemented argile, light-red relatively ar...

"CIMETIÈRES" DE CHAUVES-SOURIS DANS LA GROTTE BARADLA D'AGGTELEK
"BAT-CEMETERIES" IN THE BARADLA CAVE AT AGGTELEK

József Rácz
H-1117, Budapest,
Budafoki út 52.
Hungary

The Baradla Cave is situated in the Karstic area of NE-Hungary. From the second half of the 19th century onwards many have been concerned in the mapping and examination of the cave.

Dénes György's speleological team drew to my attention two mud-hills on which remnants of dead bats can be found. These finds are the bones of common pipistrelle *(Pipistrellus pipistrellus)* which, according to the literature, lives exclusively on the surface; moreover, it selects its hibernaculum with least difference from the open-air conditions.

Dans les environs d'Aggtelek il y a un des plus beaux paysages karstiques de Hongrie. Ce terrain se trouve dans la partie Nord-Est du pays qui s'appelle Északi Középhegység (Massif Boréal) et s'étend loin en Tchécoslovaquie. Sur ce terrain relativement petit on peut étudier certains évenements karstiques, p. ex. les ponors en fonction et ceux qui sont séniles, les sources karstiques, les différentes sortes de cavernes: les dolines, les gouffres, les grottes, etc.

La grotte la plus importante de cette zone est la Baradla, c'est la 25e des cavernes les plus longues du monde. Sa longueur totale, d'après les évaluations officielles est de 23. 101 mètres (Jakucs L. 1975), la Tchécoslovaquie en possède 7 km, le reste est hongrois, En ce qui concerne le tourisme, les environs des entrées naturelles qui sont achevés et illuminés en constituent les parties les plus importantes. Ces parties se trouvent à Aggtelek, à Jósvafő et de l'autre côté de la frontière: à Domica.

Depuis la 2e moitié du siècle passé jusqu'à nos jours on a fait plusieurs fouilles archéologiques et paléontologiques à Baradla. En 1876-77, ce fut Nyáry Jenő qui découvrit des cimetières préhistoriques dans la "Salle aux os" (Csontház) et dans la "Galerie des chaves-souris" (Denevér-ág), Au commencement de notre siècle Kadič Ottokár, Márton Lajos et Tompa Ference ont fait des excavations à divers point de la grotte. A partir de 1945, ce fut Vértes László qui découvrit beaucoup de souvenirs archéologiques, puis l'année dernière Kordos László a examiné les faunes des sédiments des cultures de Bukk (Néolithique) et de Hallstatt (Age de fer).

La pipistrelle commune

Sous la direction de Dénes György s'est constitué un groupe de spéléologues qui se propose de collecter les divers travaux de documentation déjà élaborés, d'y apporter certaines précisions et de découvrir avec des méthodes complexes les parties inconnues de Baradla.

Ce sont eux qui ont éveillé mon intérêt pour les collines d'argile sur lesquelles on peut trouver un grand nombre d'os de chauves-souris. Ce qui n'est pas surprenant parce que plusieurs espèces de Chiroptères peuplent ce système caverneux.

En déterminant les restes, j'ai assisté à un évènement curieux. Dans les faunes de la partie moyenne de la Galerie principale (Fő-ág) la *pipistrelle commune (Pipistrellus pipistrellus)* domine, laquelle — selon la littérature spécialisée — n'appartient pas aux espèces qui vivent dans les cavernes. Selon Topál György (spécialiste des Chiroptères) la présence massive de cette espèce est bien rare, et elle choisit sa résidence d'hiver en un lieu où la teneur en vapeur, l'intensité de la lumière et de la température n'offrent pas de différence avec un endroit situé à ciel ouvert. Les allemands Natuschke et Brehm ajoutent encore que la pipistrelle commune supporte bien le froid, elle effectue des vols fréquents pendant les jours d'hiver plus modérés.

Ces faits soulèvent la question suivante: comment les restes de cette espèce sont-ils parvenus en si grand nombre dans les coins de Baradla qui se trouvent loin des entrées naturelles? Ce n'est pas le travail de l'eau ou de l'érosion qui les a fait rouler, parce que le bon état des os détruit cette possibilité. Les échantillons, pris dans les dépressions et les ponors séniles, qui se posent au-dessus de la galerie, étaient totalement stériles. On peut donc en conclure que les cadavres des animaux n'y ont pas été transportés par l'eau. Les identités des formes et de l'ostéométrie infirment presque sûrement l'hypothèse selon laquelle il s'agirait d'une sous-espèce ou d'une variation qui s'est adaptée au climat de la caverne. Ainsi est-il possible que le grand nombre des spécimens se soient réunis dans un creux étroit — périodiquement, peut-être en cherchant un abri pendant un hiver plus froid qu'à l'ordinaire; puis le creux s'est fermé. Ces animaux ont été pris par une "trappe" naturelle. Cette hypothèse est étayée par des arguments et aussi par un fait: on peut trouver beaucoup de restes de cette espèce aux environs des deux localités principales — ce sont peut-être les spécimens qui ont péri en cherchant la sortie. On peut constater que plus on s'éloigne des localités, moins on fait de trouvailles. Encore un fait: sur la colline située exactement à 3740 mètres d'Aggtelek, j'ai trouvé les os d'un *grand hamster (Cricetus cricetus)* et d'un *campagnol roussâtre (Myodes glareolus)* et en outre une carcasse d'*escargot* qui sont tombés dans la grotte.

Aucun des restes n'est caractéristique d'un âge concret, parce qu'ils ont vécu invariablement du Pléistocène moyen justqu'à aujourd'hui. Pourtant on peut présumer qu'ils datent de l'Holocène, parce qu'ils sont restés en bon état, et que je les ai trouvés à la surface des collines d'argile.

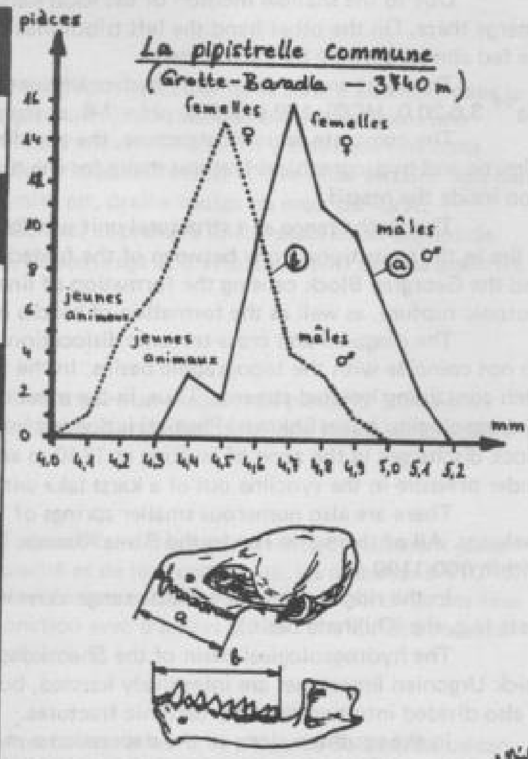
D'après les estimations ostéométriques il y a 15-28 pour cent de mâles, 55-70 pour cent de femelles et 16-25 pour cent de jeunes animaux dans chaque population.

LISTE DE FAUNES

pièces	species	espèces
Baradla – 3740 m.		
1	Gastropoda indet.	Escargot
2	Anura indet.	Grenouilles
1	Rhinolophus hipposideros	Petit Rhinolophe fer à c.
2	Myotis bechsteini	Vespertilion de Bech.
1	Myotis nattereri	Vespertilion de Natt.
≈60*	Pipistrellus pipistrellus	Pipistrelle commune
2	Miniopterus schreibersi	Minioptère de Schreib.
1	Cricetus cricetus	Grand Hamster
1	Myodes glareolus	Campagnol roussâtre
Baradla – 4400 m.		
1	Anura indet.	Grenouille
≈50*	Pipistrellus pipistrellus	Pipistrelle commune
1	phalanx cf. Leporidae ind.	phalange mastiqué
Baradla — environs de ces localités		
1	Pelobates fuscus	Pélobate
1	Rhinolophus ferrumequinum	Grand Rhinolophe fer à c.
**	Pipistrellus pipistrellus	Pipistrelle commune
1	Vulpes vulpes	Renard-roux

* Il est impossible de fixer exactement le nombre des spécimens, parce que le nombre des différentes parties anatomiques n'est pas égal, non plus.

** J'en ai vu beaucoup, mais je n'ai ni collectionné, ni compté.



Litterature

Brehm, Alfred — Az allatok vilaga, vol. VII./Tierleben, Berlin, 1876.
Felten-Helfricht-Storch — Die Bestimmung des Europaischen Fledermäuse nach der distalen Epiphyse des Humerus, Séparatum, Frankfurt, 1973.
Hanzak, Jan — Taschenatlas der Saugetiere, Praha, 1974.
Jakucs Laszlo-Denes Gyorgy — Aggteleki-karsztvidék, Guide, Budapest.
Natuschke, Gunter — Heimische Fledermause, Die neue Brehm Bücherei, Wittemberg Lutherstadt, 1960.
Topal, Gyorgy — Denevérek — Chiroptera, Faun Hungariae, XXII/2, Budapest, 1969.

THE KARST HYDROGEOLOGY OF THE SOUTHERN SLOPE OF THE GREATER CAUCASUS IN THE RACHA LIMESTONE MASSIF

K. Rakviashvili
Speleology Council,
Georgian Academy of Sciences,
Tbilisi, USSR

The limestone karst area of Western Georgia is part of the Alpine folded system. One of the largest is the Racha limestone massif (650 km^2) formed by deposits of Middle and Upper Jurassic, Cretaceous and Palaeogene-Neogene ages.

The average relief of the Racha range over the bed of the Rioni river (the base level for the northern slope of the range) is 1100 m. The surface karst forms develop at altitudes from 500 to 2400 m. The surface of this territory is covered with a rather stable layer of earth and the occurrence of denuded karst is therefore limited.

Karst waters are basically formed by atmospheric precipitation draining into numerous dolines and ponors.

Analysis of the lithology of the deposits distinguishes the following two water-bearing karst horizons:

The lower (main) water-bearing horizon is composed of Lower Neocomian dolomitized limestones, Barremian and Lower Aptian thick-bedded limestones, their thickness being 300-900 m. The underlying Middle and Upper Jurassic aquifuge deposits (thickness 1800 m) form an impermeable horizon below the entire massif.

The upper water-bearing horizon – highly jointed limestones of the upper Cretaceous-Palaeocene have a thickness being 150-300 m. This horizon is often combined with the lower water-bearing horizon. As a result of these two levels of karst waters separated by the Aptian and Albian aquifuge deposits (the middle impermeable horizon) are formed.

In the investigated territory underground basins with free, gravitational water exchange in the upper parts, as well as artesian basins under pressure can be observed. The north-eastern part of the Shaori depression with limestone submergence below the sea level serves as a pertinent illustration.

Due to the shallow incision of the local karst valleys an underbed circulation of karst waters can also emerge there. On the other hand the left tributaries of the Rioni – Kheora, Barula, Khoteura and Sharaula are fed almost entirely by karst waters.

The karst waters are mainly hydrocarbonate-calcic. The constitution of Ca^{++} is (mg/l) 32.0-100.0, Mg^{++} 3.6-20.0, HCO_3^- 152.0-335.0. pH = 7-8, at temperature 4.0 to 11.0°C.

The complete tectonic structure, the peculiarity of the jointing, the erosion of the relief, various climatic and hydrographical features make for the diversity of the hydrogeologic conditions of karst formation inside the massif.

The Racha range as a structural unit was formed on the verge of the Pliocene and the Quaternary. It lies in the transitional zone between of the folded system of the Southern slope of the Greater Caucasus and the Georgian Block causing the formation of linear asymmetrical folds and rocks displacement along the tectonic rupture, as well as the formation of blocks of horst type.

The diagonal and cross-tectonic dislocations separate underground basins, whose areas and boundaries do not coincide with the topographic basins. In the territory under investigation we distinguish four basins, each containing isolated streams. Thus, in the most uplifted south-eastern part of this territory the synclinal hydrogeological basin Shkmeri-Phutieti is divided into two blocks by a upthrust. Karst water of the uplifted block discharges in the zone of faulting at 1740 m above s.l., whereas the waters of the downcast block rise under pressure in the syncline out of a karst lake with discharge 0.4 m^3/sec.

There are also numerous smaller springs of this isolated basin in zones of local fractures and in the thalwegs. All of them give rise to the River Kheora. The interval between inflow and discharge areas differs within 600-1100 m.

In the ridge zone of the Racha range karst waters has a bipartite discharge – to the east and to the west (e.g. the Khikhata basin).

The hydrogeological basin of the Shaori depression occupies almost half of the investigated area. The thick Urgonian limestones are intensively karsted, but below 400 m the karst process is less. The Shaori basin is also divided into two parts by tectonic fractures.

In the southern slope of the depression a monoclinal karst water basin is observed, whose waters discharge out of subhorizontal caves at 1180 m. To the north, two powerful springs emerge in the horizontal caves, opening in the Barremian limestones and giving rise to the Sharaula river. Their flow-route with the underground waters of the Shaori basin is established by means of a colour test.

Almost all eight horizontal caves in this region are still active and continue their development, indicating the young age of karst.

Neotectonic movements have exerted a great influence on the karst development. In the course of these rising movements the karst waters of horizontal circulation penetrate towards the lower horizons and form two layer caves.

As stated above the direction and redistribution of the karst waters in the investigated massif is determined by disjunctive dislocations, as distinct from the other karst massifs of the Georgia, where the character of folding bears the greatest significance. The tectonic dislocations divide the underground waters into the

small isolated basins and even separate waterstreams.

It is our opinion that the Racha karst massif due to its diverse and peculiar hydrogeological conditions makes an interesting object for further detailed investigations with the major aim of establishing a pattern of karst development.

KARST DE LA HAUTE-SAUMON, ILE ANTICOSTI, QUEBEC: MODÈLE DE DÉVELOPPEMENT D'UNE KARST JEUNE

Jean Roberge
Départment de Géographie, Université McMaster,
Hamilton, Ontario, Canada

Anticosti Island is composed of very gently dipping Ordoviciah and Silurian carbonates with low relief. Karst is limited to comparatively pure members and has developed since deglaciation c 13,000 years B.P. Salmon River basin comprises 37 kms^2 of holokarst and peripheral fluviokarst, accepting a further 106 kms^2 of non-karst drainage. Karst has propagated westwards from a single resurgence for distances as great as 15.5 kms and with hydraulic gradients as low as 0.32%, aided by a remarkably continuous pattern of vertical joints bearing 110°-290°. Organisation is simple and primitive, offering an ideal laboratory for study of early karstification.

I Cadre physique

L'île Anticosti, partie émergée de la section orientale des Basses-Terres du St-Laurent, se compose de 6 formations paléoziques, de l'Ordovicien supérieur au Silurien moyen, de direction 110° avec un léger pendage S.S.W. d'environ 2°. Ce sont surtout des calcaires avec aussi des schistes argileux, des conglomérats et des grès en strates minces, le tout fracturé par un remarquable système principal de diaclases à 110° continues et persistantes et un système secondaire à 20° moins régulier. L'île est caractérisée par une topographie de cuesta. Les dépots meubles y sont peu importants. Au-dessus de 75 mètres (limite maximale de l'invasion marine post-wisconsinienne) il s'agit surtout d'un till plus ou moins continu d'épaisseur généralement inférieure à 3 mètres. La déglaciation de l'ile se serait produite vers 13,000 B.P.

II Le karst

Un karst s'est développé au centre de l'île à l'intérieur du bassin supérieur de la rivière Saumon, dans la partie inférieur des calcaires de Gun River, sous de très faibles gradients (aussi bas que 0.32%) formant une bande de plus de 15 kilomètres de longueur, il occupe une surface d'environ 37km. On y distingue une zone centrale holokarstique et une zone périférique discontinue fluviokarstique. Environ 106 km^2 de terrains non-karstiques se drainent dans le karst. Une seule résurgence, à l'extrémité est, draine toutes les eaux du karst.

Les formes de surface sont très jeunes (moins de 13,000 ans) et presque toutes établies au dépens de diaclases à 110°. On y note surtout des dolines (de dissolution, de soutirage et d'effondrement) des lits asséchés, des pavés karstiques et des diaclases élargies.

III Modele d'evolution et facteurs determinants

A) La topographie

A l'est du karst la résurgence est située à l'endroit où l'on trouve un gradient de pente (2 à 3%) bien supérieur à ceux rencontrés dans cette partie d l'île sur même substrat. Cette caractéristique locale est probablement le responsable initial du développement karstique.

B) Le réseau de diaclases

L'organisation, d'abord locale, du drainage souterrain a pu se faire très rapidement et facilement grace aux 2 ensembles de diaclases préexistants. A cause de leur régularité et de leur continuité, les diaclases à 110° ont joué un rôle primordial dans l'extension du karst progressant ainsi facilement d'est en ouest. A partir de ces axes principaux, les diaclases moins régulières à 20° ont permis la jonction avec d'autres à 110°. Au fur et à mesure de son extension, le karst a capturé les cours d'eau de surface atteints.

C) La lithologie

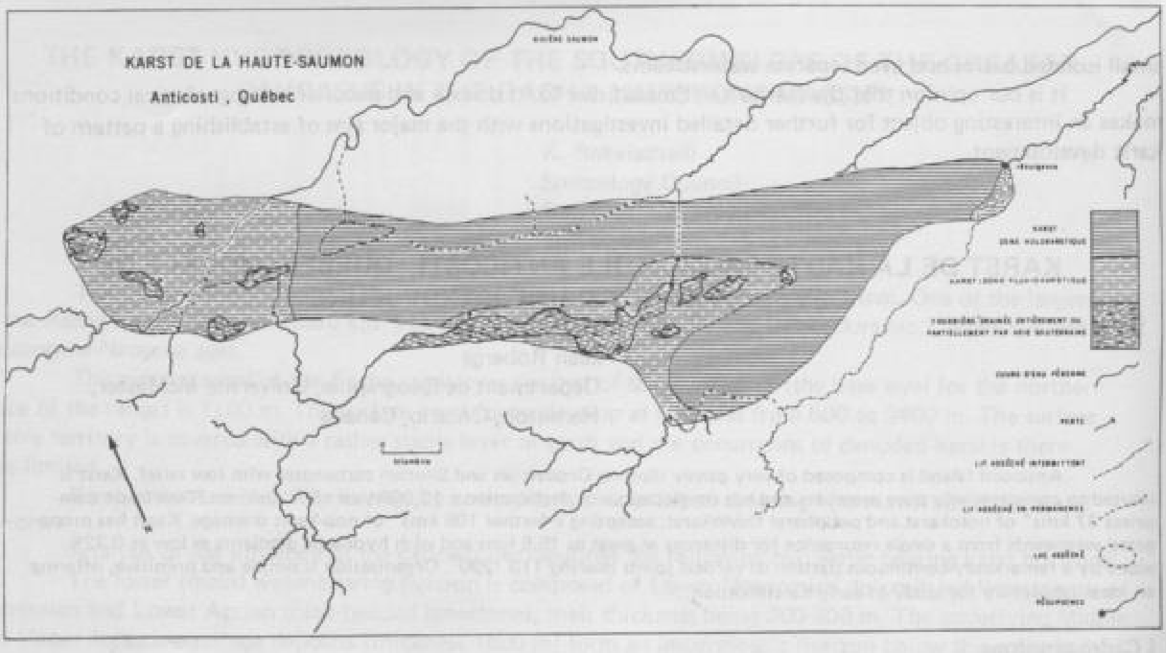
La lithologie impose des contraintes à l'extension du karst. Vers le nord, la présence de schistes calcareux au sommet de la formation de Becscie inhibe la karstification. Vers le sud, dans le Gun River supérieur, des lits de schiste argileux intercallés dans les calcaires la ralentissent.

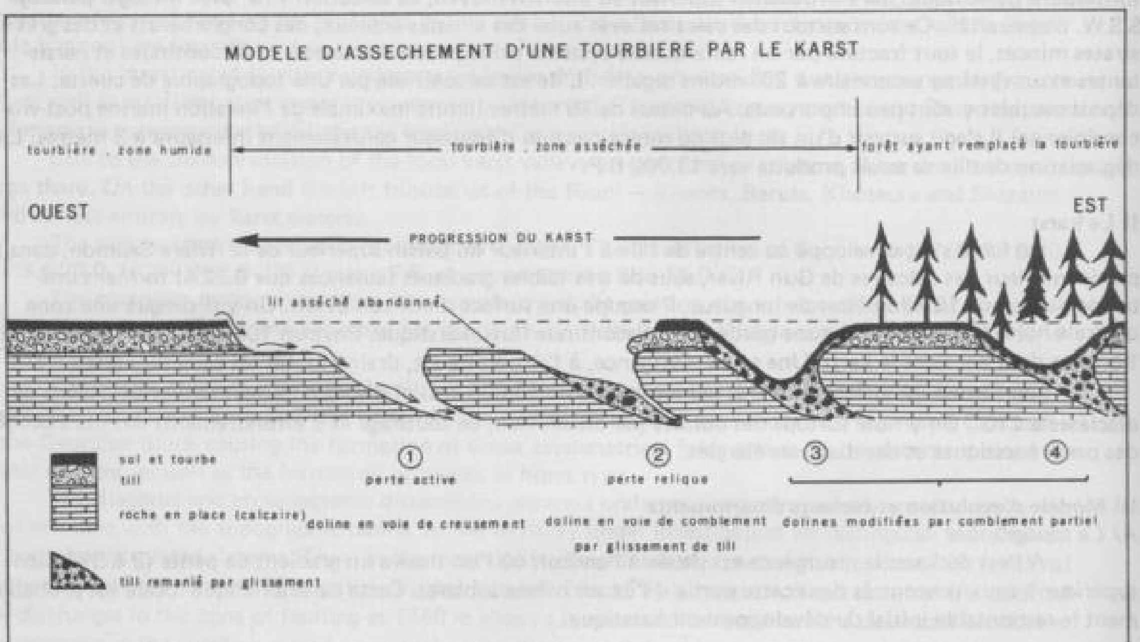
D) Autres facteurs

D'autres facteurs controlent le développement du karst. Leurs effets sont limités et locaux et ont peu d'influence sur la disposition spaciale du karst dans son ensemble. Les principaux sont la distribution du till, son épaisseur et la localisation des tourbières et autres surfaces humides.

E) L'évolution contemporaire: les zones pionnières

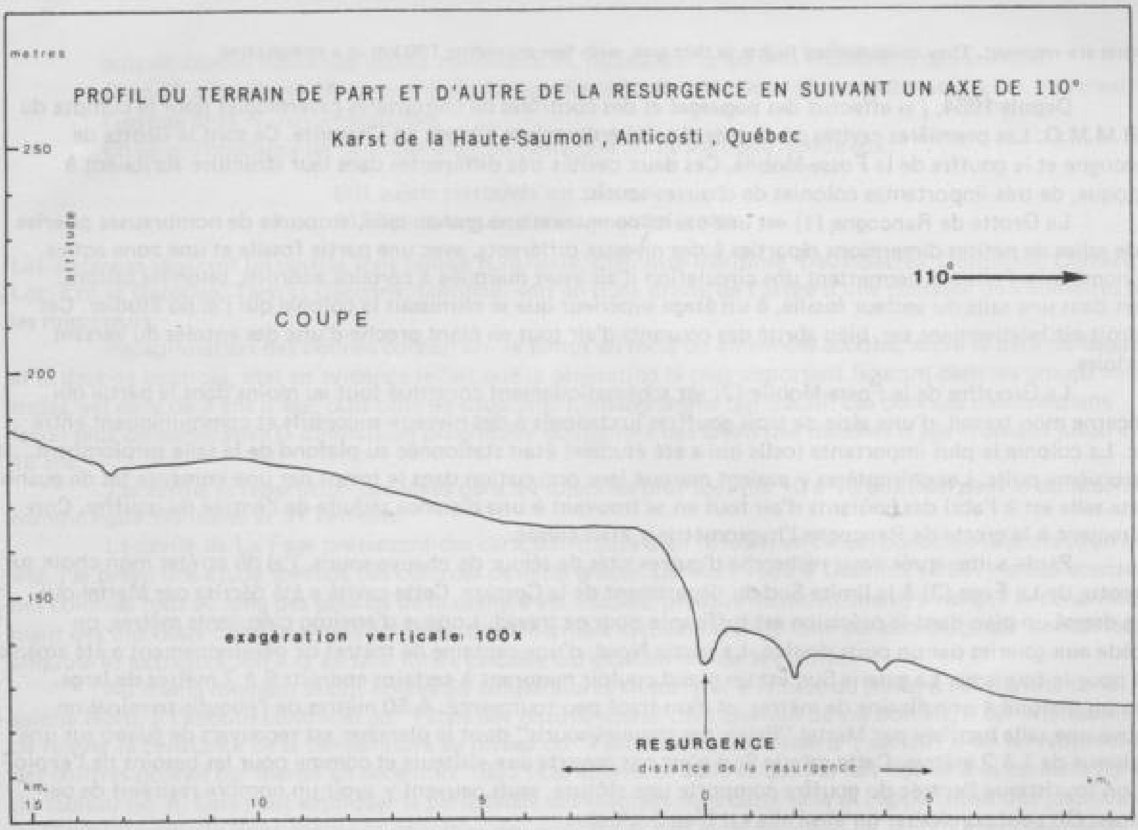
L'hypothèse d'extension des limites du karst vers l'ouest se vérifie de nos jours à son extrémité occidentale qui constitue une zone pionnière en expansion. C'est un stade de transition entre le terrain non karstique et l'holokarst. Les cours d'eau interceptés s'y perdent et les tourbières, en voie d'assèchement, se drainent sou-





terrainement. Une tourbière en particulier fournit une excellente démonstration des processus d'assèchement par karstification, preuve de la progression du karst vers l'ouest. A son extrémité est, des dolines drainent la plupart des eaux. Trois zones caracteristiques y sont visibles: à l'ouest une zone humide mal draineé; à l'est une zone s'assèchant, draineé par des dolines; finalement à l'extrème-est, dans la foret, une zone que l'on suppose avoir fait parti de la tourbière auparavant. Les dolines à proximité de la zone humide mal draineé; à l'est une d'aspect très récent drainant surtout le terrain adjacent du coté ouest. Plus vers l'est les dolines sont des pertes reliques, rendues désuètes par la formation de pertes plus jeunes en amont et se comblent partiellement par glissement du till sus-jacent suivi d'une colonisation végétale. Dans la forêt adjacente à l'est on ne retrouve que ces dolines partiellement comblées qui ont été les premières pertes à drainer la tourbière.

Au sud, des strates relativement insolubles limitent la colonisation du terrain par le karst sans l'arrêter totalement. Certaines perforations à travers ces strates, vis-à-vis diaclases importantes permettent localement à l'eau de rejoindre le système de drainage souterrain principal. De plus, le manque de régularité et de continuité



des diaclases à 20° contribue à ralentir la progression du karst vers le sud qui est donc plus lente que celle vers l'ouest mais aussi beaucoup plus irrégulière, dépendant

- de l'épaisseur, du degré de solubilité, de la résistance mécanique et de la fréquence des strates peu solubles.
- de la distribution des diaclases majeures (en particulier à 20°).
- de la localisation des apports d'eau importants.
- de la topographie.

Les formes karstiques dans la genèse desquelles l'effondrement joue un rôle important, abondent dans ce secteur.

Conclusion

Considérant la courte période de temps depuis la déglaciation wisconsinienne et la faiblesse des gradients hydrauliques, l'importance de ce développement karstique parait inattendue et peu commune. En effet, en 13,000 ans, ce karst que l'on suppose entièrement post-glaciaire aurait progressé vers l'ouest à partir de la résurgence à une vitesse moyenne minimum de 1.2 km par millénaire. On doit toutefois considérer ce taux avec réserve, gardant à l'esprit qu'il ne représente qu'une moyenne, or il est peu probable que la diffusion du karst se soit faite de façon uniforme, les conditions hydro-climatiques ayant varié depuis le tardiglaciare et les apports d'eau capturés ne se distribuant pas également d'est en ouest.

L'hypothèse selon laquelle ce karst se serait développé entièrement et si rapidement depuis la déglaciation, alliée au fait que l'on n'ait retrouvé actuellement aucun indice pouvant laisser croire à une karstification antérieure pose des problèmes. En effet cette hypothèse implique qu'il a pu en être de même aux interglaciaires précédentes et que les glaciations en aurait effacé tous les éléments, ce qui est difficile à admettre.

Ce karst en formation qu'on commence juste à connaitre a encore beaucoup à révéler et mérite beaucoup d'attention d'autant que la simplicité relative du contexte géologique, structural, physiographique et hydrographique font de celui-ci un laboratorie idéal pour l'étude du développement d'un karst jeune en milieu tempéré froid.

AU SUJET DE PLUSIEURS ANNÉES DE BAGUAGE DE CHIROPTÈRES DANS LE S.W. DE FRANCE

Pierre Saumande
18 Rue Gustav Nadaud
Limoges, 87000, France.

The results of registering the numbers of bats living in caves in the southwestern outcrops of limestone of the Massif

Central are reported. They show limited flights in that area, with few exceeding 100 km in a straight line.

Depuis 1954, j'ai effectué des baguages et des contrôles de chiroptères cavernicoles pour le compte du C.R.M.M.O. Les premières cavités où ce travail a été entrepris se situent en Charente. Ce sont la Grotte de Rancogne et le gouffre de la Fosse-Mobile. Ces deux cavités trés différentes dans leur structure abritaient à l'époque, de trés importantes colonies de chauves-souris.

La Grotte de Rancogne (1) est une cavité complexe: une grande salle, entourée de nombreuses galeries et de salles de petites dimensions réparties à des niveaux différents, avec une partie fossile et une zone active. De nombreuses entrées permettent une circulation d'air assez marquée à certains endroits, selon les saisons. C'est dans une salle du secteur fossile, à un étage supérieur que se réunissait la colonie qui j'ai pu étudier. Cet endroit est relativement sec, bien abrité des courants d'air tout en étant proche d'une des entrées du versant Tardoire.

Le Grouffre de la Fosse-Mobile (2) est schématiquement constitué tout au moins dans la partie qui concerne mon travail, d'une série de trois gouffres juxtaposés à des niveaux successifs et communiquant entre eux. La colonie la plus importante (celle qui a été étudiée) était stationnée au plafond de la salle surplombant le troisième puits. Les chiroptères y avaient marqué leur occupation dans le temps par une immense tas de guano. Cette salle est à l'abri des courants d'air tout en se trouvant à une distance réduite de l'entrée du gouffre. Contrairement à la grotte de Rancogne l'hygrométrie y était élevée.

Par la suite, aprés avoir recherche d'autres sites de séjour de chauve-souris, j'ai dû arréter mon choix sur la grotte de La Fage (3) à la limite Sud du départment de la Corrèze. Cette cavité a été décrite par Martel qui en a dressé un plan dont la précision est suffisante pour ce travail. Longue d'environ cinq cents mètres, on accède aux galeries par un puits double. La partie Nord, d'une centaine de mètres de développement a été amémagée pour le tourisme. La galerie Sud est un grand couloir mesurant à certains endroits 6 à 7 mètres de large, avec un plafond à une dizaine de mètres, et d'un tracé peu tourmenté. A 50 mètres de l'éboulis terminal on trouve une salle baptisée par Martel "Palais des chauves-souris" dont le plancher est recouvert de guano sur une épaisseur de 1 à 2 mètres. Cette galerie Sud n'est pas ouverte aux visiteurs et comme pour les besoins de l'exploitation touristique l'entrée du gouffre comporte une clôture, seuls peuvent y avoir un nombre restreint de personnes. On peut considérer qu'ainsi elle est bien protégée.

Lorsque j'ai commencé ce travail, j'avais pour but d'essayer de vérifier la véracité des dires de certains auteurs qui attribuaient aux chauves-souris des déplacements importants. La Fosse-Mobile avait été choisie en premier lieu parce que j'avais été impressionné par le volume de déjections, qui prouvait que ce gouffre était fréquenté depuis longtemps et par des groupes nombreux. Puis Rancogne a été ajouté lorsque fut trouvée la salle où stationnait la colonie et qui se présentait d'une facon trés différente. Les colonies y étaient moins fournies mais de capture trés facile. La couche de guano épaisse d'une vingtaine de centimètres était sèche. Par la suite, j'ai abandonné la cavite de la Fosse-Mobile, les chauves-souris l'ayant désertées, perturbées par de trop nombreuses visites d'un groupe peu respectueux du milieu souterrain; à cause aussi de la fermeture administrative de cette cavité située en fôret domaniale de La Braconne.

A cette époque, j'ai pensé étendre mon étude aux chauves-souris qui auraient pu élire domicile dans les cavités de la zone calcaire qui borde la partie du plateau cristallin, de la Charente à la Corrèze. Ma prospection à été vaine; les cavités visitées, toutes de dimensions relativement modestes, se sont révélées vides de chiroptères (quelques rares sujets isolés que je n'ai pas voulu déranger). Seule la grotte de La Fage est apparue comme un lieu de stationnement régulier de colonies importantes. Aprés une premiere séance de baguage qui m'avait montré les difficultés d'une telle entreprise, si on désirait l'effectuer dans de bonnes conditions, j'ai décidé de réduire les séances à une ou deux par an et de n'opérer chaque fois que sur un petit nombre de sujets avec le maximum de précautions. (J'ai toujours voulu éviter les hécatombes dont j'ai pu être témoin deux ou trois fois, dans des opérations qui se voulaient spectaculaires, de la part de personnes qui n'avaient l'air d'avoir aucun exprit scientifique).

Le total de mes interventions se décompose de la facon suivante:

2238 animaux bagués.
627 animaux controlés par moi-méme.
23 animaux controlés par des tiers.

Pour éviter de compliquer les données du problème, je me suis cantonné dans l'étude de 4 espèces:

MYOTIS MYOTIS
RHINOLOPHUS FERRUMEQUINUM
RHINOLOPHUS HIPPOSIDEROS
MINIOPTERUS SCHREIBERSI

Analyse des resultats:

L'espèce la plus importante en nombre est celle de *Myotis myotis:*

1082 sujets bagués.
528 sujets controlés.

suivie de celle de *Rhinolophus ferrumequinum:*

989 sujets bagués.
97 sujets controlés.

puis *M. myotis* beaucoup moins nombreux. *R. hipposideros* est trés faiblement représentée.

Chez *M. schreibersi, M. myotis et R. hipposideros* les femelles sont plus nombreuses, alors que c'est l'inverse chez *R. ferrumequinum.*

En ce qui concerne les déplacements on remarque qu'ils sont peu nombreux:

501 sujets retrouvés sur place.
115 sujets bagués dans une autre grotte.

Les distances séparant les cavités sont faibles (Charente, Charente-Maritime, Deux-Sèvres, Dordogne, Corrèze, Lot, Lot et Garonne, Tarn et Garonne, Gironde) soit en ligne droite de l'ordre d'une centaine de kilometres pour les migrateurs.

Recapitulation des donnés concernant le temps en mois ou en années écoulés, entre la date du baguage et la date de controle, met en evidence le fait que la génération la plus important figurant dans les groups controlés, est celle de 3 ans d'âge, puis celle de deux ans. L'histogramme qui traduit ces données montre d'une facon plus démonstrative la diminution progressive du nombre des sujets des tranches d'âge croissant jusqu'à 16 ans.

J'ai vérifié la répartition des sexes dans les sujets les plus âgés (de 10 à 16 ans). On peut la considérer comme égale: 35 mâles et 37 femelles.

La cavité de La Fage présentant des caractéristiques bien définies en ce qui concerne la protection du site, j'ai prévu une étude spéciale des colonies de cette grotte. De Mars 1965 à Decembre 1967, le déplacement des colonies tout au long des galeries de la cavité a été étudiée, presque mensuellement, ainsi que le dénombrement des individus constituantces colonies. Cette dernière estimation a été faite par comptage sur une surface aliquote et extrapolation à la surface totale calculée par planimétrie de la colonie.

Au même moment étaint notées les températures en surface, à la base du puits, à l'extrémité de la galerie Nord, à l'éboulis central et au "Palais des chauve-souris". A l'examen de ces donnés, il est intéressant de relever la constance de la température au niveau du "Palais des chauves-souris", surtout si on les rapproche des chiffres donnés par Martel en décembre 1892 (Les abimes p. 364) et que j'ai fait figurer à la dernière ligne du tableau no. 6. Cela peut expliquer la persistance des colonies dans cette salle et l'appellation trés justifiées de Martel. La galerie Nord accuse au contraire des différences trés sensibles selon les saisons et on peut se demander si la désobstruction faite à l'extrémité de cette galerie, lors des fouilles paléontologiques, n'a pas modifié les conditions climatiques de cette parte de la grotte.

En ce qui concerne les chiroptères, il y a une trés nette prédominance des *M. schreibersi*. Les *R. ferrumequinum* suivent assez loin en arrière dans le classement par dénombrement des individus. *R. hipposideros et M. myotis* ne sont jamais représentés que par quelques spécimens. On remarque aussi que, d'avril à Septembre la galerie Nord est désertée par les chauves-souris. Cette période correspond à la saison touristique et nous avons ici la preuve flagrante du rôle perturbateur de l'homme. Il est aussi curieux de constater le déplacement des colonies, du "Palais des Chauves-souris" vers la zone de l'éboulis central à la fin de l'automne.

Enfin je voudrais transcrire une dernière remarque. Lors d'une séance de baguage dans une des grotte où j'opérais, j'avais découvert un ou deux squelette de chiroptère sur le guano de la salle. Une recherche systématique dans ce guano qui est trés sec a permis de retrouver ce jour-là 33 bagues sur des ossements, ou dispersées.

Le controle sur les registres du C.R.M.M.O. m'a amené à constater que 3 de ces bagues appartenaient à des animaux bagués le jour, 5 autres faisaient partie du même lot de bagues utilisées la même journée, l'année suivante, et enfin 18 autres bagues avaient été mises en place le même jour et une autre année. Cette mortalité importante et massive laisse présumer des techniques de baguage singulièrement nocives, et permet de conclure que dans de telles conditions, cette méthode d'investigation n'est d'aucune utilité pour l'étude scientifique des chiroptères . . . bien au contraire.

Bibliographie

1. Martel — Les abimes p. 384 et France Ignorée p. 36.
2. Martel — Les abimes p. 380/381 et France Ignorée p. 37.
3. Martel — Les abimes p. 361/362 et France Ignorée p. 63.

KARST DRAINAGE PATTERNS IN THE LONG MOUNTAINS OF THE EASTERN UNITED STATES

J.W. Saunders, D.M. Medville W.F. Koerschner
1037, Cross Keys Road, 4B, Lexington, Ky, 40504 U.S.A.

Karst development in the Appalachian Mountains of the eastern U.S. is found primarily in the folded and faulted rocks of Cambrian to lower Carboniferous Age. The long mountains under consideration are linear clastic-capped mountains with carbonate units cropping out in continuous strips along one side of the mountainside, parallel to both the strike and the mountainside. Relief is 300-600 m. Beds dip into the mountains, with dips from 5 to 40°. The fairly uniform relationship between stratigraphy, structure and topography along each mountain allows one to generalize about cave development and subsurface drainage based on a number of examples that arose under seemingly similar circumstances. Investigated in this study were 730 km of selected

long mountains in West Virginia, Virginia, Kentucky and Tennessee. Pine Mountain, the longest examined, extends for 200 km in Kentucky and Tennessee, 130 km of it uncrossed by any surface stream.

Surface drainage follows definite patterns. Small streams heading near the mountaintop flow perpendicular to the strike down to the uppermost limestone exposures, and generally sink. Springs returning drainage to the surface are found at the contact of the carbonate rocks with underlying shales or where the carbonates encounter major surface streams at the foot of the mountain. Water exiting from springs at the lowermost carbonate exposures continues down the mountainside perpendicular to the strike until entering major creeks or rivers paralleling the mountain and the strike. In places these major surface streams have cut through the mountains, at water gaps. In the 730 km of long mountains examined, there are nine such water gaps interrupting the continuity of the carbonate outcrop.

Recharge for springs in the limestone and dolomite consists of sinking streams, infiltration of precipitation falling on the carbonate, and inputs from shafts, with known depths up to 70 m. Little water tracing has been done, so what is known of flow paths comes largely from cave maps. Over 80% of cave passage is orientated parallel or subparallel to the strike. Cassell Cave (10 km surveyed under 1.5 km of mountainside) on Back Allegheny Mountain and Linefork Cave (2 km surveyed under 1.6 km of mountainside) on Pine Mountain are examples of this trend for lengthy passages. The drainage basins for the long mountain springs appear to be up to about 5 km long with widths of 300-2100 m. Although both cave drainage and nearby major surface streams flow subparallel to the strike, they commonly flow in opposite directions; thus there appears to be no influence of the surface stream on the direction of cave stream flow.

The strike-subparallel orientation of cave drainage that is the pattern in limestone may be understood from a consideration of joints and bedding. Joint influence is strong in many long mountain caves. Joint orientation was found to be generally parallel to the strike in a study in Cassell Cave, the only such joint study available. The ideal bedding passage can be geometrically visualized as the line produced by the intersection of two planes, one the bed or bedding plane dipping into the mountain and the other the piezometric surface inclined generally parallel to the mountain. For the ideal bedding unit paralleling the strike, the deviation of passage orientation from true strike-parallel will increase with greater stream gradient and decrease with greater strata dip.

For any watershed draining a linear carbonate outcrop and overlying clastics, two end member drainage basin shapes are possible: the spring located (a) at the end or (b) in the middle of the lower edge of the carbonate exposure. Only one limestone spring was found that clearly drained from both directions along the mountain. Major flow in the limestone caves studied cannot be followed directly into the mountain, but instead along and under the mountainside. Tributaries carried down dip in steep bedding passages or against the dip in joint-controlled passages are known. Based on maps of the few short (less than 150 m) dolomitic spring caves known, and in the absence of sufficient water tracing, dolomitic springs appear more likely than limestone springs to drain from two opposite directions. Available evidence indicates that flow in the dolomitic systems is more commonly independent of strike and from within rather than along the mountain. The presence of very high gradient trans-stratal major streams in some of the dolomitic spring caves (contrasted with nearly flat gradients in limestone caves) and of major dolomitic springs 30-50 m higher than the lowest available outcrops in the absence of recognizable stratigraphic barriers to solution (contrasted with limestone springs at the lowest available exposure) suggest that limited solubility and/or limited parting abundance may be restricting underground water in the dolomitic systems from finding the lowest level as quickly as in the limestone systems. Significantly, there are almost no major known caves in limestone overlying the dolomite on two mountains (totalling 100 km) where drainage is through dolomitic springs, although adjacent limestone springs on the same mountain are associated with large caves. The presence of several major limestone caves on a third mountain drained by dolomitic springs (26 km) presently remains an exception to this pattern, although the much lower dip in this case may be influential.

Major springs fall into six categories: (1) dolomitic springs found well above the lowest exposure, (2) springs spilling over major shale units in the limestone, (3) spillover springs at the lowest carbonate exposure, underlain by older shales or in some cases by overridden younger clastics along a thrust fault, (4) tap springs, where a major surface stream has breached a favourable carbonate unit with a meander at the foot of the mountain, (5) other springs at the foot of the mountain and graded to major surface streams, and (6) gap springs, graded to surface streams at water gaps.

Due to the dip into the mountain, caves and drainage behind spillover springs are graded to the spillover point. Those spillover springs located at the more incised locations will discharge at lower elevations. The importance of elevational differences in competition between adjacent springs has not been clearly observed. There are no recognized examples of flow reversals, stream captures, abandoned discharge sites, multiple exsurgences, or other signs of drainage shifts in the study area, except for a few abandoned or intermittent outlets at some gaps.

Gap springs and caves are considerably smaller, where present, than mountainside counterparts. The significance of this finding can be understood by considering that for most of these springs drainage is potentially derived from the identical type of mountainside drained by mountainside spillover springs farther down the mountain at some distance from the gap. The gap springs are often more than 100 m lower in elevation than these spillover springs, a situation expected to result in greater competitive ability to capture drainage, as well as to permit larger cave development deeper inside the mountain. The best example of this lack of competitive edge at a gap is found at Jellico Gap in Pine Mountain. A limestone cave stream seen two km from the gap and the same size as the gap spring flows away from the gap, despite being 100 m higher in elevation. No convincing explanation for the small size of gap springs and caves in the long mountain water gaps has been offered. In other related geological settings in the Appalachians water gaps are favourable locations for sizable springs and caves.

AUFZEICHNUNGEN LANGFRISTIGER, TEKTONISCHER WELLENBEWEGUNGEN IN DEN WACHSTUMSACHSEN VON TROPFSTEINEN
CONSERVATION OF TECTONIC WAVES IN THE AXES OF STALAGMITES OVER LONG PERIODS

Bodo Schillat
Lupinenacker 6,
2104 Hamburg 92

The variations concerning the axes of stalagmites and stalactites were measured and can be explained as being generated by tectonic movements.

The reason for the movements is supposed to be mass transport between the mantle and the crust of the earth, which is followed by waves in the crust. The origin of the waves is not known. They might be compensating processes, it seems also conceivable, that convective movements like seafloorspreading are the proposed waves.

Bei der Bearbeitung von erdbebengefällten Stalagmiten (Bodentropfsteinen) aus unterschiedlich alten Sinterphasen und verschiedenen Höhlengebieten zeigte sich ein bemerkenswert unregelmäßiger Verlauf der Wachstumsachsen. Keiner der längsgeschnittenen Stalagmiten weist eine gerade oder annähernd gerade Wachstumsachse auf, auch dann nicht, wenn er äusserlich scheinbar regelmäßig gewachsen ist.

Im Achsenbild werden Kurven und sprunghafte Verstellungen sichtbar, die in den verschiedenen Stalagmiten einer Sinterphase auch in kleinen Exemplaren häufig einen vergleichbaren Verlauf haben.

Grob gesehen zeigt sich folgendes Bild: Nach Phasen starker, sprunghafter Verstellungen der Achse folgen lange Kurven, die als annähernde Einpendelung auf die vor dem Sprung bestehende Lage angesehen werden können.

Die Kontinuität dieser Erscheinung in den fossilen bis relativ jungen Sintergenerationen ist so auffällig, daß sich die Frage nach der Ursache zwangsläufig stellt. Die Möglichkeit der willkürlichen Wanderung der Tropfwasserzufuhr an der Höhlendecke oder an Stalaktiten (Deckentropfstein) ist individuell, wäre also nur für den zugehörigen Stalagmiten zutreffend.

Eine weitere und in der Literatur genannte Ursache für die Krümmung von Tropfsteinen soll und ist wohl in manchen Fällen der Höhlenwind.

Eine andere Möglichkeit besteht darin, die Veränderungen der Wachstumsachse in Zusammenhang mit tektonischen Geschehnissen, wie Schollenkippungen, zu sehen.

Die Achsenkrümmungen und Sprünge in den Stalagmiten als lotrechte Aufzeichnungen langfristiger Schollenbewegungen zu sehen, lag daher nahe. Leider ist dies hier nicht so unmittelbar möglich wie bei der Nachzeichnung ehemaliger Wasseroberflächen z.b. bei Sinterbecken. Zum besseren Verständnis mag folgendes auch in den Abb. 1 und 2 dargestellte Beispiel dienen.

In einem waagerecht stehenden Raum wird das Lot von einem festgelegten Punkt der Decke auf bestimmten Punkt des Bodens gefällt. Bringe ich diesen Raum in eine Schräglage, so stehen sich zwar Decken-und Bodenpunkt im Raum gegenüber, das Lot ist jedoch in Richtung des tiefsten Punktes der Raumneigung gewandert und hat sich damit vom Bodenpunkt entfernt. Je höher der Raum ist, desto größer wird naturgemäß die Abweichung des Lotes zum Bodenpunkt. Übertragen wir das auf einen Höhlenraum, so wird die Deckentropfstelle oder der Stalktit zu einem Punkt, von dem aus der Wassertropfen über Jahrtausende das Lot fällt. Der von ihm aufgebaute Stalagmit wächst so lange in der senkrechten, wie der Raum in der waagerechten steht. Erfährt die Scholle, in der die Höhle beheimatet ist, eine Kippung und der Höhlenraum damit eine Schräglage, so verändert sich die Wachstumsachse des Stalaktiten direkt in Form einer Kurve. Die Wachstumsachse des Stalagmiten erfährt dabei immer eine stärkere Krümmung, die vom Höhenabstand der Tropfstelle vorgeschrieben wird.

Gleichzeitig ist die im Stalagmiten vergrößerte Abweichung der Krümmung ein Indiz für die echte Aufzeichnung einer Schollenkippung. Würde z.B. die Wanderung der Tropfstelle am Stalaktiten verantwortlich sein so käme es nur zur Ausbildung spiegelbildlicher Kurven, wenn die Wachstumsgeschwindigkeit beider Teile gleich ist. Erfolgt die Bewegung der Scholle so rasch, daß die Wachstumsachse des Stalagmiten nicht folgen kann, kommt es zu einer sprunghaften Verstellung derselben.

Bei unterschiedlichen Wachstumsgeschwindigkeiten von Stalaktit zu Stalagmit muß nur das Höhenabstandsverhältnis berücksichtigt werden, da nicht die Länge und Neigung der Kurven, sondern nur ihr Abstand von der vormaligen Lotrechten für die Rekonstruktion der Schollenneigung nötig ist.

Nach der 1969 erfolgten Entdeckung der Riesenberg Höhle im Weserbergland mit ihrem ungestörten, reichen Tropfsteinbestand, bot sich die Möglichkeit zu einer Überprüfung am jungen bis recenten Tropfsteinmaterial. Vorstudien an Stalaktiten ergaben eine Krümmung, die vorwiegend in Richtung 154° orientiert ist.

Nach diesen Vorstudien wurden 3 Doppelobjekte (Stalaktit mit dazugehörigem Stalagmit) entnommen.

Vor der Entnahme der Proben wurden die Abstände von Stalaktit zu Stalagmit gemessen und die Orientierung der gewählten Schnittrichtung 154° zu 332° auf dem Objekt mittels Kompaß und Widiareißnadel aufgezeichnet.

Die Tropfsteine wurden in der angezeichneten Richtung geschnitten. Die in allen Objekten übereinstimmende Schichtung und Zonierung, bestätigte die Erwartung, daß es sich um eine Altersgruppe (Generation) handelt. Die Wachstumsachsen in den 3 Stalagmiten zeigten große Ähnlichkeiten miteinander.

Die Auswertung der gefundenen Kurven im unteren Abschnitt des Objektes 3 wird in Abb. 3 gezeigt.

Bei der Frage nach der Ursache dieer in den Achsenkurven aufgezeichneten Schollenkippungen konnte man an Ausgleichsbewegungen der Erdkruste nach eiszeitlichen Belastungen denken. Diese Annahme steht je-

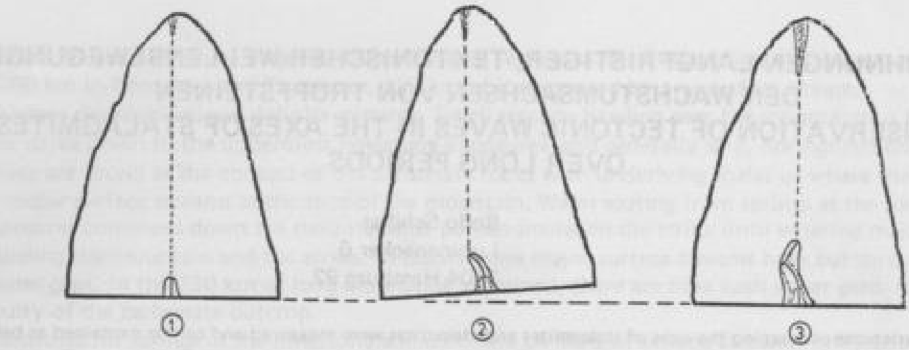


Fig. 1. (1) Höhlenraum in Ruhelage. Stalaktit (Deckenzapfen) und Stalagmit (Bodenzapfen) wachsen senkrecht (0 Lage).
(2) Zeigt den Raum während einer von rechts ansetzenden Hebung. Das Wachstum zeichnet diese Hebung im Stalagmiten mit einer entsprechend verstärkten Kurve nach. Der Längenabstand zwischen Stalaktit und Stalagmit, sowie der Seitenabstand von der 0 Lage zeigen den Grad der Kippung.
(3) Die Bewegung ist rückläufig geworden und hat die Ausgangslage, 0 Lage, erreicht.

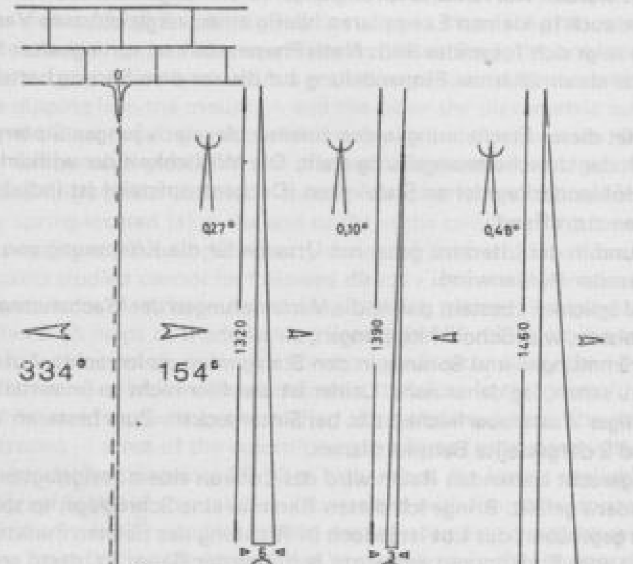


Fig. 2. Objekt 3, Messung der Abweichungen 2, 3, 4.
Die grosseren Pfeile zeigen die Orientierung der Kompassrichtung.
Die kleineren Pfeile zeigen die Richtung der Ablenkung.

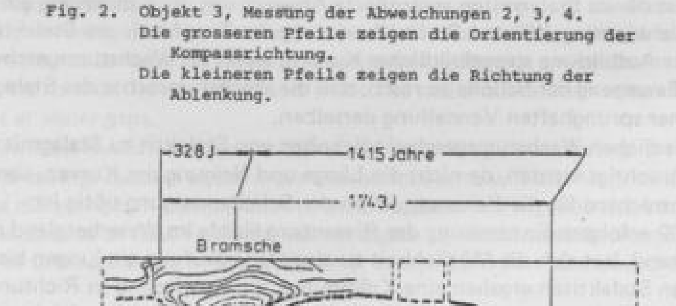


Fig. 3. Wachstumsachse des Stalagmiten Objekt 3 in horizontaler Lage. Für das Wachstum des Stalagmiten wurde eine Modellkonstante von 7 mm pro Jahrhundert angenommen. Die obere Masslinie zeigt die gestrekte (gerade) Länge der einzelnen Abschnitte mit den auf das angenommene Wachstum bezogenen Alterswerten. Der Schnitt durch das Tektogen nach Stadler und Teichmuller wurde eingezeichnet.
Bei 3 befindet sich die Scholle wieder in Normallage.
Bei 4 beginnt eine erneute Hebung, die ihr Maximum erreicht.
5 - 6 Spring.

doch in Widerspruch zu den bisherigen Befunden im geschnittenen Tropfsteinmaterial. So zeigen sich die in den Wachstumsachsen aufgezeichneten Kippungen bei den meisten und auch fossilen Sinterperioden, häufig inmitten langer Wachstumsperioden. Wenn man voraussetzt, daß Sinterwachstum in unseren Breiten nur nach Eiszeiten oder Zwischeneiszeiten möglich war, müßten diese Achsenveränderungen in der Nähe der Basis liegen. Dieses trifft zwar bei den untersuchten Objekten zu, ist aber wohl nicht als Regel zu betrachten, denn es sind auch Anzeichen für Veränderungen während reiner Sedimentationsperioden vorhanden. Betrachten wir die bisher in den Wachstumsachsen sichtbaren Veranderungen, so zeigen sich in längeren und kürzeren Abständen Kippungen verschiedener Intensität, deren Periodik noch nicht erkennbar ist. Für die Deutung dieser Kippungen wird vom Verfasser der Durchgang von Wellen zwischen Erdkruste und - Mantel angenommen. Untersuchungen im Rahmen des Unternehmens Erdmantel ergeben auch in Teilen Deutschlands junge Niveauveränderungen der Kruste (1). Es erscheint jedoch schwierig trotz größter Präzision und modernster Geräte, langsame Bewegungen zu erfassen, da immer nur eine Art Momentaufnahme erfolgt, während die Wachstumsachse von Tropfsteinen über sehr lange Zeiträume registriert und Informationen gespeichert hat.

Die auffällige Form der Kurven ließ vermuten, daß am nördlichen Schollenrand eine entsprechend tiefreichende Schwelle oder ähnliches vorhanden sein könnte, die indirekt durch die Lotabweichungen im Hohlenraum nachgezeichnet wurde. Man muß sich dazu die vertikale Wachstumsachse des Stalagmiten um 90° in die Bewegungsrichtung gekippt vorstellen.

Wie jüngere umfassende Untersuchungen (2) zeigen, existiert tatsächlich ein ausgedehnter Pluton in der Bewegungsrichtung der Wellenfront. Dieser unter dem Namen "Niedersächsisches Tektogen" eingegliederte Tiefenkörper erstreckt sich in W – E Richtung etwa 160 km und N -S Richtung 50 – 60 km. In seinem südöstlichen Grenzbereich liegt der Gebirgszug des "Süntels" mit der Riesenberg Höhle.

Die nach der Arbeit von G. Stadler und R. Teichmüller nachgezeichnete Skizze Abb. 5 zeigt einen Schnitt durch den Pluton. Die Schnittform dieses Plutons zeigt eine überraschende Ähnlichkeit mit der Achsenkurve des Stalagmiten und kann auch der Bewegungsrichtung der Wellenfront entsprechend als die vermutete tiefreichende Schwelle angesehen werden.

Die Achsenkurve wurde um 90° gekippt und dem Schnitt unterlegt Abb. 5 und 6. Für das Stalagmitenwachstum wurde eine Modellkonstante von 7 mm pro Jahrundert angenommen.

Literatur

D.F.G. 1972. Forschungsbericht; Das Unternehmen Erdmantel Franz Steiner Verlag GmbH Wiesbaden S. 156, 158, 166, 220-225, 328-330.

Franke, H.W. 1956. Wilnis unter der Erde F.A. Brockhaus Wiesbaden, S. 143-144.

Stadler, G. und Teichmüller, R. 1971. Zusammenfassender Überblick über die Entwicklung des Bramscher Massivs und des Niedersächsischen Tektogens. Fortschr. Geol. Rheinld. und Westf. Bd. 18, Krefeld, S. 547-564.

Schillat, B. 1976. Aufzeichnungen langfristiger, tektonischer Wellenbewegungen in den Wachstumsachsen von Tropfsteinen. Abhandlungen zur Karst – und Höhlenkunde, Reihe A, Heft 14, Fr. Mangold'sche Buchhandlung Blaubeuren.

HYDROCHEMICAL ZONALITY AND THE VELOCITY OF KARST PROCESSES

Y.I. Shutov
Institute of Mineral Resources,
Simferopol, USSR.

As detected by numerous authors investigating karst problems, there is a certain coincidence of hydro-dynamical and hydrochemical zones in karst regions. It is characterised by a clear-cut difference in velocities of groundwater movement and in volumes of groundwater flow in different hydrodynamical zones. It is established that the mountainous Crimea a correlation between groundwater flow volumes in zones of active, restricted and impeded exchange is expressed by ratio of 1:0. 1:0.001. For this region the zones of hydrocarbonate, sulphate and chloride waters (change of mineralization from 0.4 to 7 g/l) are distinguished according to their macrocomponent composition. The microcomponent composition also emphasises this zonality. Both the variety of microcomponent composition and the concentration of separate elements are increased with depth. An increase of mercury content from 2.10^{-8} to 1.10^{-6} g/l takes place; concentrations of manganese, titanium, chromium, vanadium, nickel, molybdenum and other elements are also increased. Their content in deep zones is usually 1-2 times higher than those typical of upper parts of the karst zone. One should also notice the increased "set" of elements in deeper horizons in comparison with 4-7 microcomponents typical for upper zones.

Earlier (Shutov, 1973) three hydrochemical zones were revealed within mountainous Crimea. In the first zone down from the surface, corrosion is the leading hydrochemical process. It is supported by a considerable quantity of carbon dioxide in the air of karst cavities (its phonocontent in the caves of the Crimea is 01-0.5%, maximum content – 1.1-7.5%). Below, waters are in equilibrium in respect to calcium carbonate or they are partially saturated. This is hydrochemical zone II; processes of accumulation and mixed corrosion prevail here. In the lower, (third from the surface) hydrochemical zone, the processes of sulphide oxidation prevail and here sulphate waters of different cation conposition are formed.

Deficit of saturation, calculated according to different formula (Roques, 1967, Thrailkill, 1968)

for the first zone fluctuates within (-173 mg/l) – (0), for the second zone – (+6 mg/l)–(+100 mg/l), for the third – more than (+100 mg/l). For all these atmospheric precipitation normally exhibits the greatest aggressivity. Deficit of saturation for atmospheric precipitation is equal to (0173 mg/l). Aggressivity of infiltration waters (slowing infiltrating through small caverns and joints) depends to a great extent on depth. Thus, at a depth of 80m. aggressivity is equal to (-90 mg/l), but at a depth of 250m it is zero. Waters of subterranean streams are less oversaturated with respect to calcite, as is explained by great velocity of transfer through different natural situations, possessing different thermodynamic parameters. This question has been considered in detail by Thrailkill (1968).

The facts, obtained for different hydrochemical zones, are well coordinated with calculations of potential aggressivity. V.N. Dublyansky (1971), according to analyses of waters, collected at different depths, made calculations of gradients horizontal and vertical leaching (mineral change during 100 m path of filtration) for mountainous Crimea and the Western Caucasus. For the upper zone the vertical leaching gradient changes from 167 to 18 mg/l/1.00 m, varying normally with depth. In the second zone, where movement of underground waters is directed mainly in a horizontal direction, the horizontal leaching gradient forms (+3.5)–(+0.5 mg/l) (solution) to (-0.1)–(17.4 mg/l) (carbonate deposits).

The first hydrochemical zone from the surface coincides with the vadose zone and zone of karst seasonal fluctuation. The majority of karst voids occur within this zone. In the mountain Crimea 57% of all karst cavities are formed up to 100m below surface; 10% – at a depth from 100 to 300m (vadose zone); 33% – at a depth of 300-400m (zone of seasonal fluctuation in karst water levels). In the last zone the processes of erosion play the significant part in formation of karst voids. The comparatively high percentage of karst voids at such depths is explained by above-mentioned processes of erosion.

A similar situation may be observed in sulphate karst. Investigations, carried out on flat territory in the Western Ukraine, showed that surface waters entering a karst massif, possess a great deficit of saturation (calculations carried out by a method of Zverev, 1967), which is equal to (-1920)– (-1810 mg/l). In the zone of active exchange between different waters this value is sharply reduced and fluctuated from (-180) to (-40 mg/l), depending on length of seepage path. Below this zone, where drainage conditions are rather difficult, the zone of restricted exchange between waters is situated. Here water is either in condition of equilibrium with gypsum or slightly supersatuated (+20 mg/l).

These investigations, carried out in the karst regions differ due to their natural conditions. Both geosyncline and platform karst, however, showed that karsting processes as a result of corrosion were possible only within the upper geodynamic zones, namely, in vadose zone and zone of seasonal fluctuations karst water levels. Aggressive properties of surface waters going underground are directly connected with depth. Anomalous increase of voids in the zone of seasonal fluctuations of karst water levels is connected with processes of erosion by large karst streams having been formed within these two zones.

References

Dublyansky, V.N. 1971. Genesis and hydrogeochemical significance of the great Ukrainian karst slopes. Doctoral thesis, Geol. Min. Nauk, Perm, USSR (in Russian).

Roques, H. 1967. Chime des carbonates et hydrogeologie karstique. Memoires et documents. Centre de recherches et documentation cartographiques et geographiques, vol. 4.

Shutov, Y.I. 1973. Geochemical zonality of karst waters in the high ridge of the mountainous Crimea. Abstracts of papers of the 6th International Congress of Speleology. Olomouc.

Thrailkill, J. 1968. Chemical and hydrological factors in the excavation of limestone caves. Geological society of America Bulletin, vol. 79.

Zverev, V.P. 1967. Hydrogeochemical investigations of gypsum groundwaters. Izd-Vo. Nauk.

THE UTILIZATION AND DEVELOPMENT OF CAVE RESCUE RESOURCES

Daniel I. Smith
US National Cave Rescue Co-ordinator
834 Louise Drive, Petaluma
California, 94952, U.S.A.

For the past several years the National Cave Rescue Commission, a member of the UIS Rescue Commission, has been researching ways to develop ways of rapidly locating cave rescue teams and resources, for both cavers and legal or rather local authorities. What was needed was a simple system by which sufficient numbers or special skill areas could be quickly obtained in time of an emergency. All too many times a rescue resource would list only the fact that they were an available source of help. They would not expand on what special skills or the like they could offer; what kind of time frame it would take to obtain their assistance. When a caver breaks his leg in a maze type cave the task of removing him is very much straight forward, requiring no special or exotic methods. However, take that same caver and break his back beyond a sump and his friends and or the local authorities will need to call the closest competent specialists. The problems remain: where do the special skills exist; how can they be called; what can they provide?

To solve these problems the NCRC is developing a uniform way to list not only cave rescue teams but sources which could assist cave rescue operations, such as the fire service or local military organisations. . . the list could be endless. Additionally, what about the isolated caver who has very special knowledge of a specific cave or area yet is not associated with a cave rescue team or organisation, how can he be incorporated? What

is needed is an inventory of, or rather a directory organised region by region with ALL resources listed, who they are; what they can provide; what areas they are limited in; what areas or area they can offer their best service to; how can they be contacted. In the United States the U.S. Air Forces operates an around the clock computer center called the "Inland Rescue Command". The sole function of this center is to locate special emergency resources for any requesting agency, team or organisation and if need be provide free emergency air transport of the special resource directly to the scene. What this means is that a local cave rescue unit can in effect summon any cave rescue resources which will precisely complement the needs of the situation.

However, to avoid wordy or lengthy descriptions of ability the NCRC proposes a numerical system which would act as a measure of overall technical or the gross ability of a rescue service. In the U.S.A. hospitals airports, fire depts., all have established numerical codes which describe the gross potential ability of the specific agency. Since each code is a product of a compilation numerous relative factors, the organisation can very easily determine what areas could best be improved in order to improve their overall efficiency. Amid organisations which are staffed by volunteers it could be most beneficial to study the components which are given the highest relative value; perhaps even promote friendly competition in the spirit of improvement. In order to make an honest estimate of the skill level which a cave rescue resource possesses the NCRC studied cave rescues of the past 10 years to determine what were the major factors for the success or failure of a wide number of cave rescue incidents. The results were tabulated and analyzed to see what skills or abilities are most important and then those items assigned a comparative value. An ideal score of 500 points was decided upon as the 100% mark or rather to define an organisation which could approach almost any cave rescue problem without assistance of any sort. No bottom limits were set as it was felt that any skill was better than none. The points system was further developed as a guide to the formation of new teams or resources, those just starting out and looking for what to do first with their limited resources or funds.

The following is a listing of the component point value and areas of specialisation. It should be remembered that this system is designed primarily as a means for getting the best and most qualified resources of a given area; It is not intended for use as a means for exclusion or snob appeal. Those with limited resources must know where to look for assistance . . . .

I Manpower Credit in this section may not exceed 60% of the gross score.

A. *Emergency Medical Skill (per man)*

+ 50 Doctor° as part of the team with both caving and E.R. exper.
+ 30 RN° or 1500 hr paramedic (LA. Co. std.) w/ caving & E.R. exper.
+ 18 EMT II with caving and E.R. experience (460 hr)
+ 10 EMT I (180 hr)
+ 5 Advanced first aid, or Dunlap course
+ 2 cardio-pulmonary resuscitation
+ 1 std. first aid

B. *Training*

+ 10 Monthly training sessions with critique published
+ 5 Quarterly training sessions with critique published
+ 1 Semi annual training sessions with critique published

C. *Team Size (response force of men, list gross size separately)*

+ 17 16+ men, in two teams, 8 man with leader
+ 15 12-15, in two teams, 6 man with leader plus reserve.
+ 13 8-11, in one team, 8 man with leader plus reserve
+ 10 6-7, in one team with leader

D. *Special Skills (per person)*

+ 6 vertical skill and rigging
+ 10 divers, cave (must be in pairs for credit and possess *full* equipment)
+ 3 explosives technology (state lic. req.)
+ 5 search & rescue school (nationally recognized)
+ 2 past cave rescue operational experience
+ 5 leadership training (nationally recognized)
+ 2 active cavers over 5 years

°Note: MD's and RN's must have EMS speciality training to be given credit.

II Medical/Life Support

A. Supplies shall sufficient to care for a minimum of two victims and shall be appropriate to the highest skill level as stated under Section 1-A.

+ 15 wound dressing
+ 15 airway management (simple)
+ 25 airway management (advanced); i.e. esophageal
+ 25 fracture immobilization
+ 25 I.V. fluid replacement/augmentation (licensed)
+ 25 drug injection (licensed)
+ 25 shock/hypothermia
+ 15 *special equipment, such as oxygen, suction device, etc. Credit upon application only.

III Organisation (20 points minimum)

+ 10 formal operating procedures, written and chain of command
- 20 None
+ 5 recognized by a legally responsible rescue agency*
+ 10 formal and active incorporation with a legal rescue agency*
+ 5 quarterly revision of call down/manpower rosters
+ 5 liability coverage min. $30,000 per man
+ 15 active pre-plan program with file

B. *Mobilization*

+ 20 24 hour manned phone year round
+ 15 24 hour manned phone Friday to Sunday
+ 15 local authority as answering service

C. *Response (to a staging area, local, and with all equipment)*

+ 35 100% of team in 45 min. or less
+ 20 100% of team in 60 min. or less
+ 10 100% of team in 75 min. or less
+ 3 100% of team in 90 min. or less
+ 1 100% of team in over 91 min.

*Credit given for only one category.

IV A. Communications Equipment (5 point minimum)

+ 5 field telephone with switchboard and 1 mi. wire
+ 5 two way radios in pairs (5 watt min.)
+ 5 two way radio/telephone multi channel, with emergency agency crystal, (subject to local conditions)

B. *Vertical Equipment (10 points min.)*

+ 2 *layed* nylon rope 600'+ 7/16" min. diam.
+ 5 masdam rope winch (es)
+ 2 carabiners, pitons, slings
+ 2 bolt kit with manual or electric battery drill
+ 2 ascenders and brake bars
+ 2 block and tackle, pulleys (bearing style only)

C. *Extrication Equipment* (10 point min).

+ 5 chisel/drill set with hammer. 10 lb. hand or power hammer.
+ 5 porta power 10 ton set
+ 5 cable come-along
+ 5 trenching tools, 3 shovels, mattocks, canvas buckets

D. *Transportation (12 points min.)*

+ 25 Niel/Robertson stretcher with frame (add 10 pts. if sump style)
+ 10 green splint stretcher frame
+ 5 ABS style stokes, *undivided*
+ 2 stokes — *steel, undivided.* Aluminium not acceptable.
+ 10 backboard, long and short with ties and cervical supports
+ 5 carring sheet
+ 25 exposure bag, neoprene, CRC standard style
+ 20 thermal sarong with pump, MRO style, (mountaineers)

NATIONAL CAVE RESCUE COMMISSION
RESOURCE EVALUATION — SPECIMEN QUESTIONNAIRE

Name, (individual if RA, group if team)

Address:

Phone(S)

Date of organisation:

Operational base:

Affiliations:

I. Manpower; outline each individual, use separate sheets if required

A. Emergency medical skill
B. in service training
C. Team size, gross and response force
D. Special skills, for each person

II. Life support, list what areas you can be effective in and have legal authority to perform. be complete and list ALL equipment.

III Organisation:

A. Operating procedures
B. Chain of command
C. liability coverage
D. legal recognition/authority

E. mobilization time, average, at operational base.
F. how are you mobilised, by what system, by who

IV Equipment:

A. Communications
B. Vertical/rigging
C. Extraction tools
D. Patient transportation

Rescue Advisor;
Please outline your complete skill, experience and training list what agencies view you as competent, List what areas you consider yourself expert in (geographical)

THE CONCENTRATION OF SOME HEAVY METALS IN SEDIMENTS IN SOME MENDIP CAVES, AND AN ASSESSMENT OF THE SIGNIFICANCE OF UN-NATURAL CONTAMINATION

Roger Dunning Stenner
Department of Inorganic Chemistry, Univ. of Bristol

Three streams enter St. Cuthbert's Swallet, Priddy, Somerset (ST 543 505) after flowing through disturbed land where lead smelting was carried out from pre-Roman times until the early 20th century (Gough, 1967; Irwin, Stenner and Tilly, 1968). The water resurges at Wookey Hole Cave as the River Axe (Atkinson, Drew with High, 1967; Stenner, 1968). The extent of the contamination caused by the lead industry in St. Cuthbert's Swallet, in Wookey Hole Cave, and in the River Axe was not known. Neither was the magnitude of natural contamination by the leeching of metals from mineral veins and from naturally enriched soils.

Experimental

Samples were collected from an archaeological dig in the 4th chamber of Wookey in August 1973, 1974 and 1975, when the stream level in the cave was lowered by opening the weir at the cave entrance. Samples were collected from the first five chambers and the passage from Wookey 9 to the surface (now closed). Samples were also collected from St. Cuthbert's Swallet and three other Mendip caves. Further surface sites provided 150 samples to provide more comparative data, analysed using the same analytical procedures.

The three sets of results from the Wookey 4 dig were compatible with one another, and a summary of these results is presented in Table 1. It is intended to publish the results in more detail separately.

Samples were dried, screened, digested with nitric acid and analysed for Cu, Pb, and Zn by atomic absorption spectrophotometry. Full practical details (essential when attempting to compare the figures with those obtained by other workers) will be presented in the future publication. In 90 samples analysed in duplicate, the mean of each metal had a Standard Error of approximately 5.5%. Maximum enhancement of lead by calcium was 50 p.p.m.

TABLE 1

Thickness of sample analysed cm. (approx)	*Thickness of deposit, cm.*	*Description of deposits surface*	*Metal concentration, p.p.m.* Cu	Pb	Zn
1	8 (approx)	soft, unstratified	18	7200	1100
2	7 (approx)		25	11000	1600
0.9	17.5	hard; stratified, many strata containing charcoal or bone fragments	71	26000	1600
0.8			38	24000	2100
1.6			29	5200	1800
0.5			38	5100	1700
0.9			37	4800	780
0.6			31	3600	860
0.5			34	5100	1500
5			53	4700	680
4			50	3000	820
2	15	compact, unstratified	36	480	760
2	15		75	750	1050
2	16	muddy gravel	28	1100	810

The concentration of copper, lead and zinc in sections through a mud bank in Wookey 4 containing archaeological material, given by samples collected in August 1973, 1974 and 1975. Not drawn to scale. Deposits found within the 17.5 cm. stratified layer have been provisionally dated 240-280 A.D.

Discussion

1. Table 1 shows conclusively that high levels of lead in Wookey Hole sediments are unnatural, a consequence of the lead industry. The contamination pre-dated artefacts which have been provisionally dated 240-280 A.D. (Tratman, 1976, personal communication). It would therefore be quite easy to determine whether a Wookey Hole sediment pre-dates the lead industry, or has been carried by a stream which is not a part of the St. Cuthbert's Swallet to River Axe system.

2. The analysis of 9 samples from the river bed in Wookey Hole chamber 1 - 5 gives figures similar to the surface deposits in Table 1. The mean of Pb was 8500 (S.D. 2400) p.p.m. Eight samples from stream passages in St. Cuthbert's Swallet had a mean for Pb of 31000 (S.D. 15000) p.p.m. while 8 samples from the 3 feeder streams gave a mean for Pb of 44000 (S.D. 8000) p.p.m. Further down the Axe, at Loxton, four samples from the river bed contained a mean of 90 p.p.m. Pb. The pattern of the distribution of Pb between Wookey Hole and Loxton is not known, neither are the biological consequences of the contamination. However, in the Axe at Wookey Hole and in the streams sinking into St. Cuthbert's Swallet, concentrations of Pb are considerably higher than normal in aquatic plants, invertebrate animals and fish.

3. A sample of stream sediment was collected 3m. above the present stream level in St. Cuthbert's Swallet. Concentrations of Pb and Zn were 890 and 160 p.p.m. respectively, similar in range to three other ancient deposits in this cave, and to the lower (pre-mining) deposits in Wookey Hole. This result gives further support to the conclusions of Paragraph 1, above.

4. The analysis of 16 samples from 3 caves with no known association with contaminated streams gave figures for Cu, Pb and Zn of 22(9), 140(90) and 170(120) p.p.m. respectively (mean with S.D. in parenthesis). These figures suggest that sediments in St. Cuthbert's Swallet and Wookey Hole which pre - date the lead smelting industry are indeed higher than usual, particularly Pb. The natural variability is much higher for Cu and Zn than for Pb. The natural enhancement of Pb is nevertheless very small in comparison with the man-made pollution.

5. In the upper parts of St. Cuthbert's Swallet, deposits were found which were clay-like in appearance, unlike other stream deposits. They contained high concentrations of Pb as cerrusite, which had not been transported by streams, and the possibility that elsewhere stream-borne deposits may be enriched in heavy metals after their deposition must be considered. Metals removed from solution by limestone (Stenner, 1977) must go somewhere! The nature of the anomalous clay-like deposits was shown by X-ray diffraction analysis (Badham, 1974, personal communication).

6. Of 120 soil samples analysed, 61 contained less than 500 p.p.m. Pb, and only 6 contained more than 5000 p.p.m. Pb. The samples included very many from intensively mined land, and this serves to emphasise the unusual magnitude of the levels found in the sediments in the streams which sink into St. Cuthbert's Swallet.

7. A similar situation exists in the Charterhouse-on-Mendip to Cheddar system. The results presented here suggest that Cheddar deposits will show a pattern similar to those at Wookey Hole, with high contamination of post-lead smelting sediments, and low levels in sediments which either pre-date the lead industry, or which have not been carried by the stream which carries water from Charterhouse.

8. While these results are of archaeological and spelaeological interest, they have no commercial interest, since this work clearly shows the impossibility of utilising the deposits without causing intolerable environmental havoc.

References

Atkinson, T.C., Drew, D.P. with High, C.	1967. Mendip Karst Hydrology Research Project, Phases I and II. *Wessex Cave Club Occ. Pub. Ser. 2* (1).
Badham, N.	1974. Personal Communication.
Gough, J.W.	1967. The Mines of Mendip (2nd. Ed.). David and Charles.
Irwin, D.J., Stenner R.D. & Tilly, G.	1968. St. Cuthbert's Report, Part A., discovery and exploration. *British Exploration Club Cav. Rep.* 13, Part A, 36pp.
Stenner, R.D.	1968. Water tracing in St. Cuthbert's Swallet, Priddy, Somerset. *Trans. C.R.G., 10,* (2), p. 49-60.
	1977. The natural removal of some heavy metals from streams by limestone. In prep.
Tratman, E.K.	1976. Personal communication.

THE NATURAL REMOVAL OF SOME HEAVY METALS FROM STREAMS BY LIMESTONE

R.D. Stenner

Department of Inorganic Chemistry, Univ. of Bristol.

The treatment of industrial waste water with lime to reduce the concentration of heavy metals is a well known and widely used process. It has been shown that when samples of natural waters are shaken with finely powdered calcite, concentrations of low levels of many heavy metals are reduced (Stenner, 1970 and 1971). This was confirmed in the laboratory, using synthetic solutions and chelating ion exchange resin to concentrate the solutions prior to analysis by atomic-absorption spectrophotometry (Burkitt, 1974, personal communication).

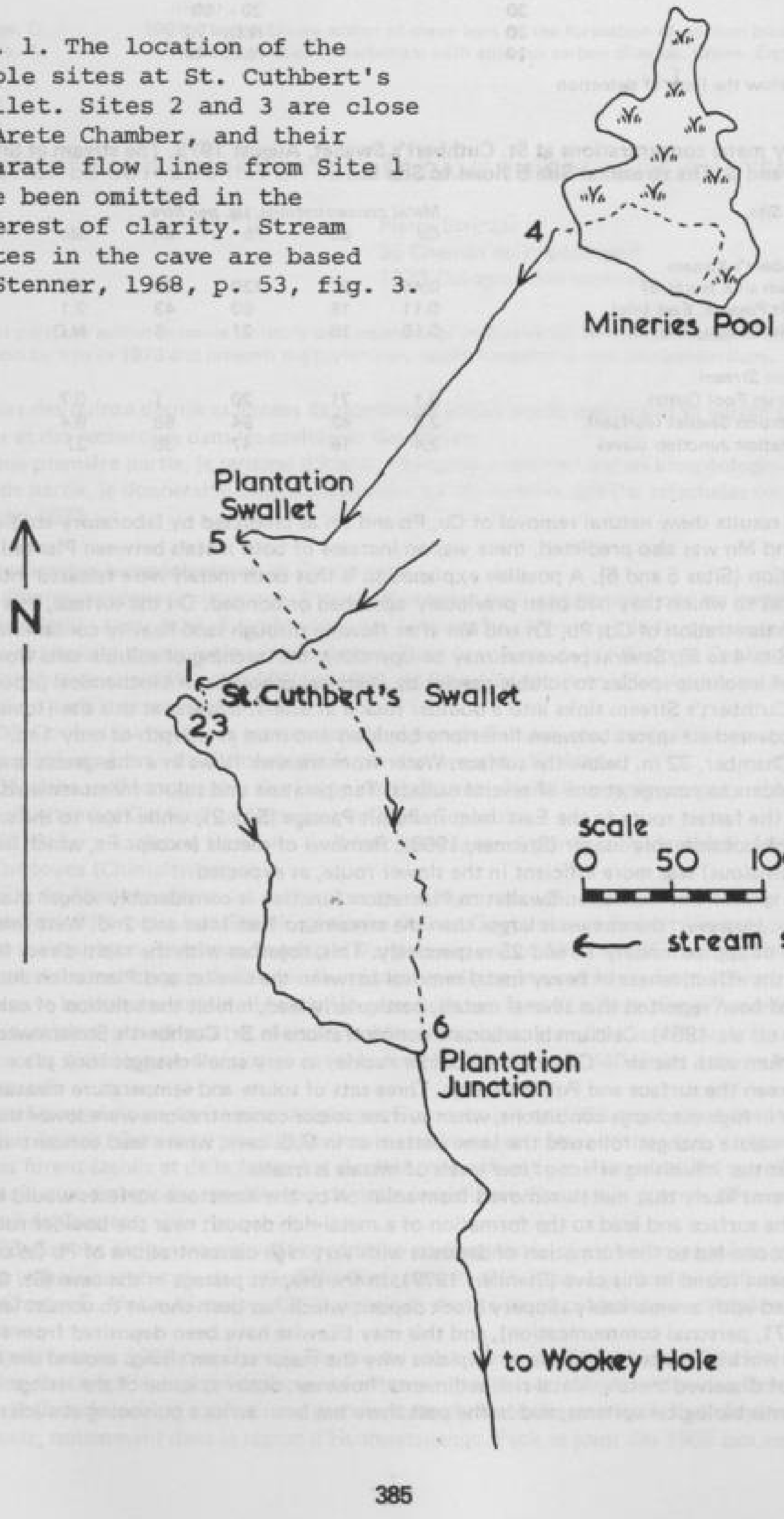
It was not known whether limestone could act in a similar way in nature. Surface phenomena, the possibility that active sites on the limestone could become exhausted, and the dynamics of the removal of the

metals were considerations which could affect the process in nature. Earlier results, which showed low levels of heavy metals in resurgences, and results from G.B. cave in 1968 (Table 1) indicated that it was likely that limestone naturally removed heavy metals from streams, and it was decided to examine the process directly by analysing water samples from two streams which enter St. Cuthbert's Swallet, Priddy, Somerset. The hydrology of the cave system has been described previously (Stenner 1968). Figure 1 shows the location of the sites.

Experimental

Water samples were collected in August 1973 from St. Cuthbert's Stream close to the sink beside Entrance Shaft of the cave, and from the East Inlet and the 2nd. West Inlet, which are both in Pulpit Passage, sites 1, 2 and 3 respectively in Figure 1 and Table 2. Water samples were also collected from Plantation Stream at its source near the Mineries Pool, at Plantation Swallet, and at Plantation Junction in the cave, sites 4, 5 and 6 respectively. Samples were collected in 2½ litre containers, acidified with 5 cm^3 AnalaR HNO_3 to minimise metal loss, and filtered through a 0.45 μ millipore filter. Metals were then concentrated using the procedure

Fig. 1. The location of the sample sites at St. Cuthbert's Swallet. Sites 2 and 3 are close to Arete Chamber, and their separate flow lines from Site 1 have been omitted in the interest of clarity. Stream routes in the cave are based on Stenner, 1968, p. 53, fig. 3.



described by Riley and Taylor (1968). After adjusting the pH to 5 with AnalaR reagents dissolved in double-distilled water the samples were immediately syphoned through 10 cm x 1 cm^3 columns of Chelex 100 chelating ion exchange resin. The metals were eluted with 2M HNO_3 (AnalaR grade in double-distilled water) and diluted to 25 cm^3. This procedure concentrated the metals by a factor of 100, also removing alkali and alkaline earth interference. The metal concentrations were determined by atomic-absorption spectrophotometry using a Varian Techtron AA 5 instrument. The results are presented in Table 2.

TABLE 1. Heavy metal concentrations in the Main Stream of G.B. Cave, Charterhouse-on-Mendip, 1968 (µg per litre).

Metal	*Main Stream Mean*	*Surface Range*	*Main Stream, the Gorge. (1 result only)*
Zn	60	40 - 110	15
Cu	30	20 - 50	N.D.
Fe	30	N.D. - 70	N.D.
Pb	10	N.D. - 40	N.D.

N.D.: Below the limit of detection

TABLE 2. Heavy metal concentrations at St. Cuthbert's Swallet, August 1973. The stream at Site 1 flows to Sites 2 and 3. The stream at Site 5 flows to Site 6.

Stream, Site.	*Metal concentrations, µg. per litre.*					
	Cd	*Cu*	*Pb*	*Zn*	*Mn*	*Fe*
St. Cuthbert's Stream						
1. Stream sink (surface)	0.40	27	120	69	5.2	1280
2. Pulpit Passage, East Inlet	0.11	18	60	43	2.1	460
3. Pulpit Passage, 2nd. W. Inlet	0.16	16	21	5	N.D.	1050
Plantation Stream						
4. Mineries Pool Outlet	0.1	71	20	1	0.7	1240
5. Plantation Swallet (surface)	2.3	42	94	68	9.4	310
6. Plantation Junction (cave)	2.4	18	47	36	37	620

Discussion

1. The results show natural removal of Cu, Pb and Zn as predicted by laboratory studies. Although the removal of Fe and Mn was also predicted, there was an increase of both metals between Plantation Swallet and Plantation Junction (Sites 5 and 6). A possible explanation is that both metals were released into solution from organic substances to which they had been previously adsorbed or bonded. On the surface, this stream showed an increase in concentration of Cd, Pb, Zn and Mn after flowing through land heavily contaminated by lead smelting (from Site 4 to 5). Several processes may be operating; the leeching of soluble salts from smelter waste, the conversion of insoluble species to soluble species by chemical processes or biochemical processes.

2. St. Cuthbert's Stream sinks into a boulder ruckle at Site 1. Digging at this site (Irwin, Stenner and Tilly, 1968) uncovered air spaces between limestone boulders and mud at a depth of only 1 m. The ruckle extends to Arete Chamber, 32 m. below the surface. Water from the sink flows in a changeable and diffuse pattern through the boulders to emerge at one of several outlets. Temperature and solute measurements have shown that water flowed in the fastest route to the East Inlet in Pulpit Passage (Site 2), while flow to the smaller 2nd West Inlet (Site 3) took considerably longer (Stenner, 1968). Removal of metals (except Fe, which has already been shown to be anomalous) was more efficient in the slower route, as expected.

3. The route from Plantation Swallet to Plantation Junction is considerably longer than the two routes to Pulpit Passage. However, the stream is larger than the streams to East Inlet and 2nd. West Inlet by the considerable factors of approximately 15 and 25 respectively. This, together with the rapid direct flow of this stream, reduces the effectiveness of heavy metal removal between the swallet and Plantation Junction.

4. It has been reported that several metals, particularly lead, inhibit the solution of calcite by solutions of CO_2 (Terjsen et. al., 1961). Calcium bicarbonate concentrations in St. Cuthbert's Stream were close to those in equilibrium with the air $- CO_2$ of the boulder ruckle, so very small changes took place in solute concentrations between the surface and Pulpit Passage. Three sets of solute and temperature measurements were made previously in high discharge conditions, when surface solute concentrations were lower than usual. On all three occasions, solute changes followed the same pattern as in G.B. cave, where lead concentrations are low. This suggests that the inhibiting effect of low levels of metals is small.

5. It seems likely that metals removed from solution by the limestone surfaces would be mechanically removed from the surface and lead to the formation of a metal-rich deposit near the boulder ruckle. It is possible that this process led to the formation of deposits with very high concentrations of Pb (as cerussite) and Zn which have been found in this cave (Stenner, 1977). In the deepest passage in the cave (St. Cuthbert's 2), pebbles are coated with a remarkably slippery black deposit which has been shown to consist largely of Pb and Mn (Priddle, 1971, personal communication), and this may likewise have been deposited from solution.

6. The work presented in this paper explains why the major stream risings around the Mendip Hills have low levels of dissolved metals. Metal-rich sediments, however, occur at some of the risings. Metals may be remobilised into biological systems, and in the past there has been serious poisoning at such risings (Gough, 1967).

References

Burkitt, A. 1974. University of Bristol, Personal communication.

Irwin, D.J., Stenner, R.D. & Tilly, G.D. 1968. St. Cuthbert's Report. Part A, the discovery and exploration. *Bristol Exploration Club Cave Rep.* 13 Pt. A, 36pp.

Gough, J.W. 1967. The Mines of Mendip (2nd Ed.). David and Charles.

Priddle, C. 1971. Personal communication.

Riley, J.P. & Taylor, D. 1968. The use of chelating resins for concentration of trace elements from seawater in conjunction with atomic-absorption spectrophotometry. *Anal. chim. acta 40*, p. 479-485.

Stenner, R.D. 1968. Water tracing in St. Cuthbert's Swallet, Priddy, Somerset. *Trans. C.R.G. 10*(2), p.49-60.

1970. The measurement of the aggressiveness of water towards calcium carbonate. M.Sc. Thesis. (unpublished), University of Wales.

1971. The measurement of the aggressiveness of water to calcium carbonate Pts. II. Trans. C.R.G. *13*(4), p. 283-289.

1973. A study of the hydrology of G.B. Cave, Charterhouse-on-Mendip, Somerset, Proc. Univ. Bristol Spelaeol. Soc. *13*(2), p. 171-226.

1977. The concentration of some heavy metals in sediments in some Mendip caves. In preparation.

Terjesen, S.G., Erga, O., Thorsen, G. and Ve, A. 1961. The inhibitory action of metal ions on the formation of calcium bicarbonate by the reaction of calcium carbonate with aqueous carbon dioxide. *Chem. Eng. Sci. 44*, p. 277-288.

RECHERCHES SUR LES INVERTEBRÉS CAVERNICOLES DE GUATEMALA

Pierre Strinati
35 Chemin du Pre-Langard
1223 Cologny, Switzerland

In a first part, the author presents a history of biospeleology in Guatemala. In a second part, he describes the caves of Guatemala visited by him in 1973 and presents the preliminary results concerning cave fauna collections.

Au cours des quinze dernières années de nombreux spéléologues américains et européens ont effectué des explorations et des recherches dans les cavités du Guatemala.

Dans une première partie, je tenterai d'établir l'historique des recherches biospéologiques dans ce pays. Dans une seconde partie, je donnerai quelques indications sur les récoltes que j'ai effectuées dans deux grottes guatémaltèques en 1973.

Historique des recherches biospéologiques an Guatemala

Avant d'entreprendre cet historique, il me faut préciser qu'il ne concerne que les invertébrés.

Cette restriction étant faite, il semble bien que la première référence à la faune cavernicole du Guatemala soit due au naturaliste genevois Henri de Saussure. Dans le volume de la "Biologia Centrali-Americana" consacré aux Orthoptères et publié entre 1893 et 1899, de Saussure décrit en effet *Arachnomimus cavicola* récolté par Champion dans la grotte de Lanquin.

En 1906, Cook visite quelques grottes dans la région de Senahú, récolte de la faune et publie en 1913 une note sur des pièges en forme de filaments tissés par des larves de diptères.

En 1936, dans sa "Monographie des Catopidae", Jeannel décrit *Ptomaphagus giaquintoi;* cette nouvelle espèce avait été récoltée par Gianquinto Mira dans la Cueva Sepacuite.

En 1950, Sailer mentionne la récolte de *Primicimex cavernis* par R.L. Wenzel et R. Mitchell dans une grotte près de Chocoyos (Chimaltenango).

Le mérite du développement des recherches spéléologiques au Guatemala revient en grande partie à deux personnages fort différents: Jose Storek, géologue fixé au Guatemala et Robert Vergnes, aventurier français, spéléologue mais surtout chercheur de trésors. Vergnes a visité en 1956 et 1957 un certain nombre de grottes du Guatemala en compagnie de Storek. Il a récolté quelques invertébrés qui ont été remis au Laboratoire de Moulis. On trouve le récit des explorations de Vergnes dans son livre "Le Pays Vierge" publié en 1957. Vergnes a, en fait, exploré peu de grottes, mais ses publications, bien que non-scientifiques, eurent le mérite d' attirer l'attention des spéléologues américains et européens sur le pays qu'il définissait comme le "Paradis Inconnu des Spéléologues".

La première expédition américaine dirigée par Gurnee suivit en 1959 assez exactement les traces de Vergnes. Aidés par Storek, Gurnee et ses collaborateurs visitèrent les mêmes grottes que Vergnes. Des plans détaillés des grottes furent établis et de la faune fut récoltée, notamment par Varnedoe. Un travail de Causey (1960) est consacré aux diplopodes récoltés lors de cette expédition. Quant aux grottes, elles ont fait l'objet, en 1962, d'un travail de Gurnee.

En 1968, Gurnee dirige une nouvelle expédition au Guatemala. Il est accompagné de spéléologues, de chercheurs et de techniciens chargés de réaliser des films pour la télévision. Les récoltes de faune sont effectuées par Nicholas et Charles E. Mohr. Nicholas (1968) signale la récolte d'une cinquantaine d'espèces dans douze différentes grottes.

C'est également en 1968 que Dreux effectue ses premières expéditions dans l'Alta Verapaz.

Au point de vue spéléologique également les équipes de l'Association for Mexican Cave Studies (Texas) et celles venues du Canada qui ont exploré une grande partie du territoire mexicain font de plus en plus d'incursions au Guatemala, notamment dans la région d'Huehuetenango. Peck se joint dès 1969 aux expéditions cana-

diennes et effectue de très importantes récoltes d'invertébrés cavernicoles (Peck, 1974).

En 1971, les zoologistes italiens Sbordoni, Argano et Zullini visitent quelques grottes dans le nord du Guatemala, à proximité immédiate de la frontière mexicaine.

En 1971 également, débute une expédition dirigée par Dreux. Les recherches s'échelonnent sur 12 mois et permettent une prospection intensive de l'Alta Verapaz.

En 1973, lors d'un court séjour au Guatemala, j'ai l'occasion de récolter de la faune dans deux cavités de l'Alta Verapaz.

En 1974 et 1975 se déroule l'importante expédition nationale française. Deux zoologistes participent à l'expédition: Delamare Deboutteville et Juberthie; ils effectuent d'importantes récoltes dans quatre grottes de l'Alta Verapaz. Les résultats zoologiques ont fait l'objet de deux travaux préliminaires publiés en 1975 et 1976.

D'autres expéditions spéléologiques our archéologiques ont lieu en 1975 et 1976; les Canadiens de la McMaster University continuent leurs prospections dans l'Huehuetenango; Michel Siffre de son côté effectue des recherches dans le Petén.

Description des grottes visitées

1) Grutas de Lanquin

Situation: Près du village de Lanquin (Alta Verapaz). Altitude: 380 m.

Date: 7 Avril 1973.

Description: Les Grutas de Lanquin sont partiellement aménagées; un éclairage électrique a été installe dans la zone proche de l'entrée.

La cavité se compose d'un réseau fossile formé par une série de grandes salles et d'un réseau inférieur actif. Divers plans de cette grotte ont été établis; le plus récent est celui publié dans Spelunca Spécial No. 1 (Guatemala) à la page 36.

Les récoltes de faune ont été effectuées uniquement dans le réseau fossile. Sur les parois ont été récoltés des diptères et des araignées. Les autres invertebrés récoltés se trouvaient sous des cailloux ou parmi des débris ligneux. Ils appartenaient aux groupes suivants: amblypyges, Schizomides, diplopodes, isopodes, collemboles, hémiptères, hyménoptères, lépidoptères, coléoptères, gastéropodes.

La température de l'air était de 25°.

2) Cueva Chirrepeck

Situation: A proximité de la route menant de Coban à Santa Cruz Verapaz; à 14 km. de route au sud de Coban. (Alta Verapaz). Il s'agit peut-être de la grotte mentionnée par Vergnes à la page 81 de son livre "Le Pays Vierge".

Altitude: 1.400 m.

Dates: 6 et 8 Avril 1973.

Description: Le couloir d'entrée mène tout d'abord dans une petite chambre, puis se divise. A droite, une étroiture donne dans une galerie inférieure où se trouve une petite colonie de chauves-souris; le sol est couvert d'amas de guano récent. A gauche, on rencontre tout d'abord une petite chambre utilisée par les Indiens; on y trouve en effet quelques petits autels et des bougies. Un couloir descendent fait suite à cette chambre; il aboutit à un puits terminal peu profond.

Dans la chambre utilisée par les Indiens j'ai récolté sous des cailloux des Schizomides, des acariens, des pseudoscorpions appartenant à deux espèces: *Ideobisium simile* Balzan et *Paraliochthonius strinatii* Beier (Beier, 1974), des isopodes et des collemboles. Dans la chambre la plus éloignée de l'entrée j'ai récolté de nombreuses araignées et le premier Campodéidé cavernicole du Guatemala: *Juxtlacampa hauseri* Condé (Condé, 1975). Sous les cailloux se trouvaient de nombreux diplopodes et notamment *Lophodesmus petrinus* Hoffman (1976a) et *Chirrepeckia lyncilecta* (Hoffman 1976b). Dans la galerie inférieure, sur le guano, j'ai surtout récolté des *Lophodesmus petrinus*. Enfin, en divers points de la grotte, j'ai récolté quelques exemplaires appartenant aux groupes suivants: chilopodes, hémiptères, diptères, gastéropodes.

Bibliographie

Beier, M. 1974. Ein neuer *Paraliochthonius* aus Guatemala. *Revue suisse Zool.* 81 (1): 101-102.

Causey, N.B. 1960. Millipeds collected in guatemalan caves, including *Calymmodesmus inquinatus* n. sp. (Stylodesmidae: Polydesmida). *Proc. Biol. Soc. Wash.*, 73: 275-280.

Cook, O.F. 1913. Web-spinning fly larvae in guatemalan caves. *Journ. Wash. Acad. Sci.* 3 (1): 190-193.

Conde, B. 1975. Description du premier Campodéidé cavernicole du Guatemala. *Revue suisse Zool.* 82 (2): 421-424.

Delamare Deboutteville, C & Juberthie, C. 1975. Mission en République de Saint-Domingue et au Guatemala. *Ann. speleol.* 30 (4): 767-771.

Delamare Deboutteville, C. & Juberthie, C. 1976. Recherches biospéléologiques. *Spelunca Special* 1: 18-24.

Gurnee, R.H. 1962. The caves of Guatemala. *Bull. Nat. speleol. Soc.* 24 (1): 25-30.

Hoffman, R.L. 1976a. A new lophodesmid milliped from a guatemalan cave, with notes on related forms (Polydesmida: Pyrgodesmidae). *Revue suisse Zool.* 83 (2): 307-316.

Hoffman, R.L. 1976b. A new genus and species of cave-dwelling milliped from Guatemala (Diplopoda: Polydesmida). *Revue suisse Zool.* 83 (3): 743-746.

Jeannel, R. 1936. Monographie des Catopidae. *Mém. Mus. Hist. nat. Paris* N.S. 1: 1-438.

Nicholas, G. 1968. Fauna in "Mayan Cave Discoveries". *Explorers J.* 46 (3): 168-171.

Peck, S.B. 1974. Recent studies on the invertebrate fauna and ecology of sub-tropical and tropical american caves. *AMCS News* 5 (1): 30-38.

Sailer, R.I. 1950. The second record for *Primicimex cavernis* Barber (Heteroptera, Cimidae). *Proc. entomol. Soc. Wash*, 52 (6): 308.
Saussure, H. de 1899. Gryllidae in "F.D. Godman & O. Salvin: Biologia Centrali-American". Insecta Orthoptera 1: 198-284, pl. 11-13 London.
Sbordoni, V., Argano, R. & Zullini, A. 1973. Biological investigations on the caves of Chiapas (Mexico) and adjacent countries: introduction. In "Subterranean Fauna of Mexico", part II, *Quaderni Acc. naz. Lincei* 171: 5-45, pl. 1-6.
Vergnes, R. 1957. Le pays vierge. Pierre Amiot, Paris, 221 p.

PALEOKARST OF THE PLAIN TERRITORIES AND SPECIFIC FEATURES OF ITS MORPHOLOGY

A.V. Stupishin
Kazan, USSR.

Paleokarst or ancient karst constitutes a problem in the modern doctrine of karst. Due to complexity of geological substrates, tectonic mobility and fragmentation in mountains, paleokarst is difficult to identify. More favourable conditions for preservation of paleokarst exist within the bounds of the platform structures with low relief. The sedimentary cover of platforms is formed with strata having nearly horizontal bedding. The thickness of sedimentary covers is often some thousands of metres. The age range of the rocks starts from the Cambrian period. Many areas of the vast plains (e.g. the Volga-Ural area) are 70-80% formed with soluble rocks, namely, limestone, dolomite, gypsum, anhydrite, chalk and rock-salt.

Subaerial conditions combined with corresponding climatic-landscape conditions were necessary to form generations of paleokarst. Such favourable conditions were formed by positive tectonic epeirogenetic movements. It was an epoch of breaks in the order of sedimentation, with weathering, soluble rocks being leached and karsted.

Up to seven karst epochs of Paleozoic and Mesozoic were identified in studying numerous geological sections in the South of the Russian platform (Stupishin, 1960, 1967, 1973). The karst epochs took place in the following times: Pre-Famenian (Devonian) Pre-Tournaisian, Early Visean, Pre-Bashkirian, Pre-Vereian and Kungarian (Carboniferous-Permian) as well as in the Lower Mesozoic (Pre-Bathonian time).

Ancient epochs of karst formation were also in the Kainozoic, but they should be called a neokarst, because their main features of the landscape and relief were much like the present, and also due to the fact that karst developed mostly in present river valleys. Morphological levels of karst in different geological sections of the sedimentary cover developed in ancient karst epochs. The levels of paleokarst alternated with rocks having thicknesses of some hundred meters. The uppermost level of the paleokarst can be studied in the natural exposures and in mines and quarries (the Lower Mesozoic karst).

The structure of the paleokarst is analogous that of recent karst. It consists of two morphological complexes, surface and underground. The surface complex of karst forms consists of sinks, sink holes and cauldrons of various sizes. The underground complex of karst forms is represented by a complex system of diverse karst cavities. The surface and underground karst forms are filled with the products of inwash and collapse of the overlying rocks – clays, sands, carbonate breccia. Mineral deposits of bauxite, bentonite, etc, are related to paleokarst forms. Unlike the present karst, the paleokarst developed under different climatic and landscape conditions. The paleokarst of continental epochs of the Paleozoic and Lower Mesozoic was similar to the present karst of warm and humid climate, rather compared with the present karst of moderate zone. This paleokarst developed in the islands of Paleozoic and Lower Mesozoic eras. In the Paleozoic the karst was developed in the Lower Permian carbonate-sulphate layers with a thickness up to 150 meters.

According to paleogeographic studies, the Lower Mesozoic karst landscape was a peculiar analogue of the present karst landscapes of the Cuban and Jamaican plains. Under conditions of humid and warm maritime climate of the Lower Mesozoic the limestones and dolomites were undermined by intensive leaching from the surface as well as from below. The surface was pocked with many sink-holes produced by leaching and collapse, and with well-like sinks and caves. All these karst forms are filled with clay, sand and the products of collapse (carbonate breccia). A spore-and-pollen analysis of the clay fill from a core sample revealed that it was under conditions of warm and humid climate that the intensive karsting of the Lower Permian limestones and dolomites took place. Analysis of the ancient soil, taken from an ancient karst sink, revealed that in a Lower Mesozoic soil the humus content reached 19.7%.

Study of the paleokarst is carried on by various methods. So far the main method is a method of boring, which permits us to take a core sample and to verify the presence of karsted rocks. Analysis of the lithologic content of the karsted stratigraphic horizons is carried on not only through study of the core, but also by investigation of natural exposures and mine openings. Application of a spore-and-pollen analysis for study of the fill from karst cavities is of great interest. Reconstruction of the buried karst paleolandscape, e.g. of the Lower Mesozoic time is possible on the basis of the collected data.

Definition of the karst age along with definition of the space parameters and the karst level has a specific scientific interest and is one of the important problems in study of paleokarst. Two methods exist for defining the time of the karst levels forming. First method is a definition of the age of the karst cavity fill with a spore-and-pollen analysis. The second method is a definition of the karst age with the methods used in geomorphology.

Paleokarst represents an ancient karst developed in a specific area. That is why it is not advisable to study only present karst. Definition of the particular succession and tendencies in the development of karst is possible after revelation of the epochs of karst development. The definition of specific trends in karst development is important for prediction of the future karst processes.

References

Stupishin, A.V. 1960. The problems of the karst paleogeography on the example of the Middle Volga area. *Earth Science. Collections of the Moscow Society of the Nature researches.* vol. Y (XIV), New series, Moscow State Univ. Publish House.

Stupishin, A.V. 1967. *Plain karst and the basic laws of its development on the example of the Middle Volga area.* Kazan Univ. Publish House.

Stupishin, A.V. 1973. Plain karst and the basic laws of its development. *Symposium on karst-morphogenesis Papers.* Hungary.

HYDROGEOLOGY OF A GYPSUM KARST IN NEWFOUNDLAND

Geraldine A. Sweet
Department of Geography, McMaster University,
Hamilton, Ontario, Canada.

Newfoundland lies within the Appalachian Mountain system. As a result of successive folding the geology is extremely complex, especially in the Carboniferous rocks of the South West. These are mainly limestones and sandstones, with local outcrops of gypsum.

It is with the gypsum, particularly at Codroy, that this paper is concerned. The gypsum is massively contorted and effectively masked by a glacial till mantle varying 2-40 m, deposited >13,000 B.P. This represents the maximum age of karst development which is characterized by frequent sinkholes, several dry valleys, an excellent example of river capture, small caves and considerable underground drainage.

The karst area is some 4 km^2, extending from the base of the Anguille Mountains to the Atlantic Coast, where the gypsum outcrops form rapidly receding sea cliffs about 20-30 m high. Because of complex folding the beds are upended, and layers of mudstone and shale form recessions between. Two springs ≈0.7ℓ/sec issue from conduits in bluffs and in several places, small semi-permanent trickles flow from the junction between the bedrock and till. Small karren features are abundant, particularly on breakdown boulders and the underside of the wave-cut notch which is well developed at the base of the cliffs.

The minimum hydraulic gradient of the karst to the sea is 1:174 and a regional water table is not readily defined. Drainage from some of the water filled sinks appears to be totally independent, while the main permanent stream is supplied from a sink. Both surface channel flow and underground springs appear at random heights and above a certain water-holding threshold some sinks drain into surface streams with a flushing action.

Initial tracing for a flow pattern was carried out with Rhodamine W.T. Results indicate regional diffusion with groundwater (after rain) flowing at at least 3.2m/sec, but the system is obviously not totally diffuse because principal known springs along the coast and in the stream valley are conduit type. From standard chemical analysis, waters divide into three categories; surface standing water, surface flowing water, underground flow. The most important discriminating variables were temperature and total hardness. (Waters from adjacent non-gypsum areas ranged 54-120 ppm $CaCO_3$). It would appear that water-filled sinks regardless of size, were not in contact with gypsum because their range is similar (110-190 ppm $CaCO_3$). Surface streams increment from 70-90 to 550-1,300 ppm $CaCO_3$ over a run of 2.5 km, crossing the karst belt. Conduit Springs maintained an almost constant temperature of 7°-8°C, and almost constant discharge throughout the sampling season, despite onset of drought conditions punctuated by a violent storm depositing 16 mm of precipitation. Hardness ranged from 1440-1800 ppm $CaCO_3$ mainly as sulphate anion. Although they were flowing out of gypsum conduits it is difficult to assess how far the waters travelled through the rock, or for how long. In one of these springs erosion seems to be so rapid that the water is constantly cloudy with suspended particles.

Within the 4 km^2 area there are 260+ sinkholes ranging in size from 100 x 200 x 25 m to 1 x 1 x 1 m. Some of these are obviously old, but catastrophic collapse produced new individuals as recently as Spring 1976.

There appears to be no regular spatial pattern to the sinks but they can be divided into several types; in scale there are three sizes, the largest (100 x 200 x 25m) all being water-filled, deep, and close to the inland or upslope limit of the gypsum. Medium size sinks are generally circular or almost circular in shape, 35-45 m in diameter and 10-15 m deep. Some are water-filled, but there is apparently no real pattern to divide them from those that are not. Several are inland, some along the coast and others in the stream valley. Very small sinks are clustered in random array around the medium sized sinks.

A second classification can be applied (Drake and Ford 1972). Most large and medium sinks have subsidiary or daughter sinks which may be aligned (possibly along geologic control) or clustered around them.

Thirdly they can be classified by shape; a large number of sinks display characteristically straight steep sides, circular openings and very narrow bottoms, i.e. funnel-shaped. Others have sides shelving steeply at first, but then flattening out into a bowl shape in the base. These are almost all water-filled, and have accumulated fines at the base which prevents fast flushing. It is suggested that there are the older sinks while the funnel-shaped ones are more recent. The youngest sink (<10 years) exhibit typical collapse form in the unconsolidated

mantle. There is very little exposure of gypsum in any of the sinkholes, they are expressed in the till. Suffosion processes play a part in their expansion.

At Romaines Brook, approximately 100 km northwest an area of intensive sinkhole denisty has developed in a crumbly gypsum, under a 2 m till mantle. The area is bounded on one side by the sea and on another by the deeply entrenched stream from which steep gypsum cliffs rise to the sinkhole plain. The hydraulic gradient is steep and karst development is rapid. Sinks ranging from 1 m to 6 m diam., with a local relief of 2-10 m, are so close together that the resulting landscape is a miniature facsimile of the more usually tropical mogote or cockpit karst.

Successful dye tracing tests, with indicators at several points, plus the thermal and chemical characteristics of coastal springs, suggest that ideal diffuse flow conditions prevail in the complex structure and lithology underlying the till mantle (Shuster & White 1971). Nonetheless the nature of spring resurgences and the abundance of point collapse features indicate elements of conduit and chamber development. Hydrologic and hydrochemical elements of diffuse systems, need not exclude the possibility of rapid development of karst surface features, therefore it would be difficult to assign the Codroy Karst to one of the two conditions.

It appears that under the appropriate conditions small scale mogote karst can be generated very rapidly in gypsum, even in temperate latitudes.

References cited

Drake, J.J., Ford, D.C. 1972. The Analysis of Growth Patterns of Two-Generation Populations: The Example of Karst Sinkholes. *Can. Geog.* Vol. XVI, 4.

Shuster, E.T., White, W.B. 1971. Seasonal Fluctuations in the Chemistry of Limestone Springs; A Possible Means for Characterising Carbonate Aquifers, *Jnl. of Hydrology*, 14.

INFILLED DOLINES IN NORTHERN PART OF THE POLISH JURA REGION

Adam Szynkiewicz
ul. Bacciarellego 39/1
51-649 Wroclaw
Poland

In the region of Dzialoszyn on the Warta River infilled dolines are uncovered as a result of limestone exploration. These are near tectonic zones on an upland of Oxfordian and Kimeridgian limestones (Upper Jurassic) which dip monoclinally at a small gradient toward the northeast.

The upland is cut by faults along the Warta valley and bordered on the north by the Kleszczow rift.

The paleokarstic relief of the Malm (Lower Jurassic) surface of this upland was deeply eroded and was covered in the Pleistocene. Small eroded mogotes project through the cover of outwash sands while on the uplands fragments of infilled karst depressions are preserved and uncovered in quarries.

Infilled dolines

Type 1 are of Holocene age. Small dolines 0.5 m in diameter, to 1.5 m in depth, appear in the Wurm periglacial debris. In the contact zone with the limestone there is a brown clay product of karst weathering. The small dolines are filled with fine gray quartzic sands.

Type 2 are of Lower or Middle Pleistocene age. These are karst pits 2 m in diameter and about 40 m deep. The walls are covered with brown karst clays similar to those filling the lower horizontal fissures. The pits are filled with grey sands and fluvioglacial gravel. Sometimes the pits are filled with varved clays.

Type 3 are of Pliocene — Lower Pleistocene age. The dolines 5 m in diameter and over 10 m deep are filled with limestone and igneous boulders strongly weathered with red quartzitic sands, red bone breccia, terra rossa and calcite.

Type 4 are of Tertiary age. They are large karst forms often over 100 m in diameter and about 50 m deep. In the contact zone with the dolines the limestones are strongly weathered. The filling of the dolines consists of white quartzitic grain sands. In some marginal sands blue clay aggregations have been observed. The sands are similar to those found under the brown coal in the Kleszczow rift (where infilled dolines were also found) and identical to quartzitic sands deposited under the brown coal in dolines near Sulejow on the Pilica River. Because brown coal in Central Poland comes from the Upper Oligocene and Miocene, therefore it has been assumed that the infilled dolines of Type 4 could have developed before the Miocene.

Influence of infilled dolines on exploitation

The infilled dolines uncovered in quarries are the cause of considerable difficulties in exploiting limestone. The poor cohesion of the infill sediments results in differential stability of the quarry levels and faces. Undercutting the fossil dolines results in earth slides interrupting exploitation in many working areas. The fossil karst reduces the quality of the deposits and affects the economics of cement or lime production. It is necessary to carry out detailed studies not only on the distribution of karst forms, but also on determination of the paleogeographic conditions when the dolines were developed.

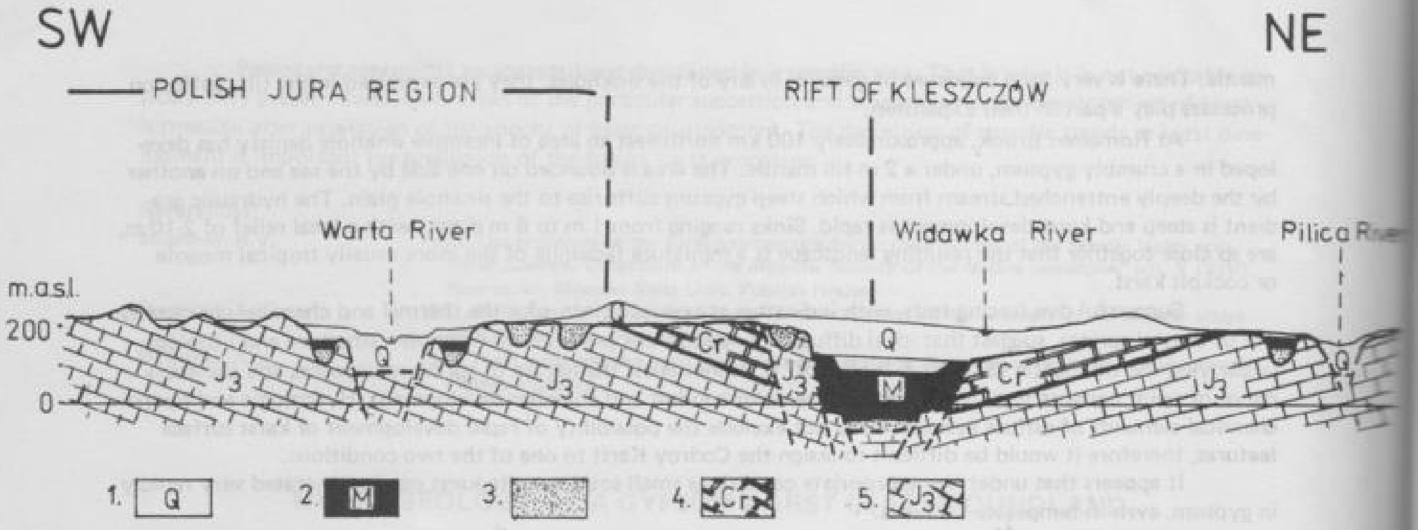


Fig. 1. Cross-section of the northern part of the Polish Jurassic region to the Pilica river. 1. Quaternary deposits. 2. Miocene brown coal. 3. Tertiary sands. 4. Cretaceous. 5. Upper Jurassic limestones.

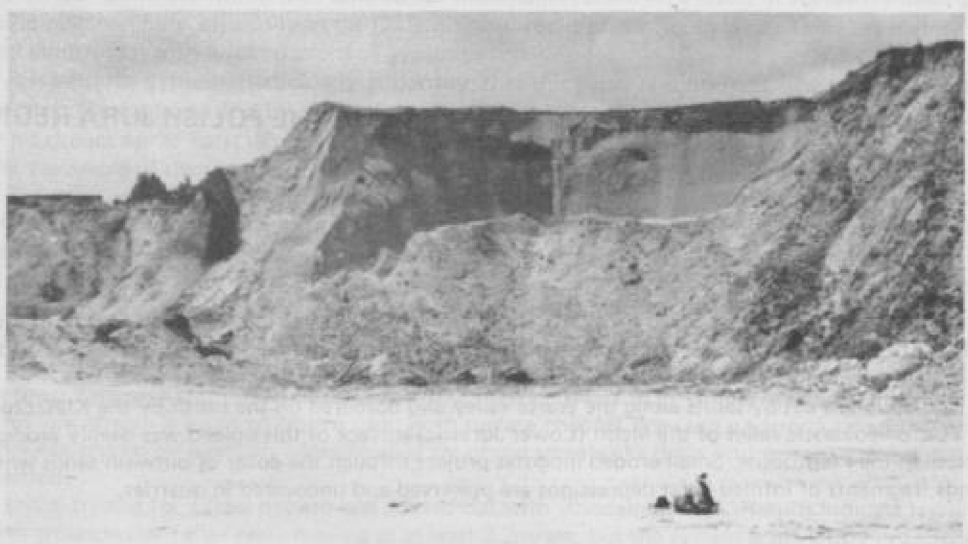


Fig. 2. Dzialoszyn - doline filled with Tertiary sands.

Fig. 3. Sulejow - doline filled with brown coal.

CAVE DEVELOPMENT IN CON-CALCAREOUS ARCHEAN IGNEOUS ROCKS

Leander Tell
Archives of Swedish Speleology, Norrkoping,
Sweden

Generally speaking it is almost considered an axiom that cave development occurs by corrosive erosion in calcareous rocks. One example is the commonly expressed old opinion that Scotland, in contrast to other parts of Great Britain, is almost void of known caves, a belief that for instance Tony Oldham absolutely rejects as unworthy after having registered more than 400 caves in his work "Caves in Scotland" (1975), where an outstanding example of non-calcareous caves is the famous Fingal's Cave, developed in basalt. Therewith we enter quite another field of speleology.

It is therefore not true that caves only occur in soluble carbonate rocks. Several researchers like M. Gortani and O. Lehmann have found similar phenomena in non-carbonatic rocks. After publications by F. Anelli, the Subcommission of UIS for terminology has proposed a third group of karstic features besides (1) real Karst and (2) Parakarst, namely Pseudokarst, a term for "a landscape with forms similar to a karst, but developed in non-karstifiable, non-soluble rocks". Such rocks are found all over the world but are of course more easy identifiable in countries where carbonatic rocks are rare, but where instead there is a multitude of crystalline archean non-calcareous, non-soluble igneous rocks, for instance Sweden. This country is almost void of sedimentary Devon-, Carbon- and Permian formations and presents only some small relicts from Trias and Jurassic.

Under such circumstances the development of caves in non-calcareous, non-soluble rocks can be studied by means of many different phenomena, and it has been possible to establish a special typology. At the 3rd International Congress of Speleology in 1961 I proposed the following specification:

1. Diaclases and Paraclases — still open or moraine-covered fissures, clefts and crevices forming caves, originating from tectonic movements in the earth's crust.
2. Frostwedging and Corrasion caves, principally formed by frost and weathering in coarse-grained granites and gneisses. Here it must be pointed out that any effects of hydration of silicates are hard to prove.
3. Glacial phenomena, e.g. owing to the formidable pressure of the Inland Ice and to the following uplift of the depressed landseape. This third group represents most of the goals of Swedish speleology, owing to their multitude and diversity of forms. These caves show different actions of the different Inland Ice glaciers, and the group can be subdivided in many sections, e.g. crushing of rock and accumulating blocks at the foot of hills and mountains or dispersing them as erratic blocks all over the country, creating many interstitial caves. Further abrading or hollowing of rocks by ice or melt water, creates natural tunnels and thousands of witches' cauldrons etc.,

Some earlier papers by the author, treating the same subject are:

1. *Die Höhlentypen Schwedens,* Proceedings of the 3rd Intern. Congr. of Speleology, Vienna 1961.
2. Die Höhlentypen Schwedens, *Archives of Swedish Speleology* nr 2, Norrköping 1962
3. Speleological Studies of Swedish Nature, *Arch. Swed. Spel.* nr. 4, Norrköping 1964
5. *Verschiedes Verhalten gewisser Grundgesteine,* Proc. 4th Int. Congr. Speleol. Ljubljana 1965
6. *Höhlenphönomene in Granit und anderen kristallinen Urgesteine,* Proc. 5th Int. Congr. Spel. Stuggart 1969
7. Karstic occurrences in Sweden, *Arch. Swed. Spel.* nr 12, Norrköping 1973
8. *About Karst in general and Swedish Karst in particular,* Proc. 6th Int. Congr. Spel. Olomouc 1973
9. Fifty typical Swedish caves, *Arch. Swed. Spel.* nr. 14, Norrköping

RELATIONSHIPS BETWEEN SIZE, BIOMASS, WATER AND FAT CONTENT IN TWO SPECIES OF COLLEMBOLA ACCORDING TO THEIR DISTRIBUTION IN THE CAVE OF SAINTE-CATHERINE, DISTRICT OF ARIEGE, SOUTH OF FRANCE

J. — M. Thibaud
Museum National D'Histoire Naturelle
Ecologie Generale
4 Avenue Du Petit Chateau — 91800 Brunoy
France

In this paper, we propose to compare two species of Collembola (Insecta) belonging to the same genus and living in the same cave (South of France, Pyrenean Mountains). *Tomocerus problematicus* is a true cave-dwelling species, while *Tomocerus minor* normally occurs in the top litter layer of deciduous forest, but may also be found inside a cave, but only near the cave opening.

Six populations of about 20 individuals were collected at different levels inside the cave, from the entrance to the terminal room at depth of 80 m.

Fresh body weights (Y), dry body weights (X), unfatted body weights (Z), body water contents, fat contents and sizes (L) were successively measured on each sampled individual in order to establish mathematical equations which express the relationships between the different parameters which are in fact proportional. The formulae set out between weights and sizes meet this requirement, and we have been able to use them to compare the populations from the point of view of their gain in weight in adult instars.

In particular, when comparing two populations of the species, living together at the same place, the

fact content of individuals belonging to the cave-dwelling species is always greater than the fat content of the epigean species, while the inverse is true when calculating their water content.

Of interest in this study is the exceptional bulk of lipids found in cave-dwelling forms. It may be possible to consider these results as a general phenomenon concerning all terrestrial arthropods living inside a cave-ecosystem, and could be interpreted as an adaption of animal species which live in an extreme and hostile medium where foods are hardly sufficient and fasting periods are often frequent.

CAVES, A MOTIVATIONAL FOCUS IN GEOLOGICAL EDUCATION

Glen H. Thompson, Jr.
Elizabethtown College,
Pennsylvania, U.S.A.

In the United States of America and, I suspect in most other countries too, college studies leading toward a bachelor's degree include a variety of subjects outside one's major discipline presumably for the purpose of intellectual broadening. Instruction in these so called "core courses" is frequently hampered due to lack of student interest.

Somewhat coincidental to the problem just stated is the fact that spelunking as a sport finds its greatest participation from college students. For whatever reasons conjectured, caves are items of interest to this age group. They are also phenomena in the discipline of geology, a subject widely elected to satisfy the core science required for the undergraduate degree.

Thus to me it seemed only logical that in a particular geology course in which I as an instructor experimenting with instructional techniques did choose caves as a focus around which introductory geology could be learned. The course, offered only in summer session, is field oriented and includes a one week camp experience near the famous Germany Valley of West Virginia. Here caves are abundant, accessible and varied and have the distinction of engendering classic papers on certains aspects of speleogenesis. Though the results have not been analyzed in a rigorous manner, they have been nonetheless gratifying to me. These results have been in the form of student attitudes, completed projects and subsequent activities of participants even years after they had finished the course.

The balance of this paper will describe how speleology is incorporated as a focal point in geological instruction and will describe some of the specific projects undertaken by these non-science majors in their first geology course.

Since a cave is defined as a void this leads easily to the conclusion that relatively little about the cave itself can be studied. Other than its morphological aspects one is constrained to consider speleothems, sediment fillings, water and the rock surrounding the cave. This is geology, pure and simple.

Studies in the field camp begin with a spelunking trip into one of the local undeveloped caves. Somewhere at an appropriate place inside the cave I present an elementary lesson describing the process by which a solution cave forms. This specifically includes aspects of geochemistry, hydrology, mineralogy, stratigraphy and structural geology, all of which are introduced as topics within the realm of geology. Exploration is resumed and frequent stops are made to explain cave related features as they are encountered. Many of these mini-lectures are spontaneous and are in answer to questions raised by the students. This trip concludes any overt and contrived attempt to capture student interest regarding the subject of caves.

Approximately half the course is devoted to student designed projects, and this introduction to cave geology has proven sufficient in each of the six years the course has been offered to induce some project work in the area of speleology. Additional projects in other phases of geology were sometimes seeded as cave related geology was being considered. One project, for instance, where strengths of various rocks were tested and compared was born in a student's mind when I mentioned their underground safety depended largely upon the strength of limestone and the patterns of joints and bedding planes in the cave roof.

Synopses of some of the more successful speleological projects are given as follows:

1. A study was made of the sediment in the entrance area of Breathing Cave, Virginia not only inferring changing water flow regimes, but also concluding on a basis of cementation that two distinct periods of sedimentation had occurred.
2. A study of the Bullpasture River partially charged by waters from several cave systems including Butler and Breathing Caves was instructive in elementary geochemistry. In this work an appropriate portion of the river was mappedin terms of temperature, pH and hardness and then related to regional geology and cavern development.
3. Three caves have been mapped as partial projects. The maps were accompanied by reports analyzing geologic controls on passage trends and morphology.
4. Under the guidance of Harold Hamilton of the Carnegie Museum in Pittsburg, Pennsylvania the entrance area of Root Cave, West Virginia was examined for its potential of bearing bones deposited by feeding raptors. Though the object was to gain knowledge of climatic changes as deduced from indigenous fauna, unfortunately the site did not prove to be productive.
5. A project to discover new caves involved the study of geological and topographic maps and caves related literature. An area of discovery potential was delineated. A brief search on foot verified the prediction of Mississippian Greenbrier limestone and several large sinkholes and a strong flowing spring

were located. That project is now being continued by the college Geology Club.

6. Several projects have involved ground water tracing with fluorescein dye.

In conclusion, I have observed more than 120 students who were not majoring in science learn considerable geology and maintain positive enthusiastic attitudes about their studies. This was accomplished bv providing the opportunity to first incorporate the natural curiosity about caves and then to relate their presence and morphological features to geological principles. From this introduction students were then able to demonstrate a working knowledge as they completed projects devoted to speleological problems. For those not electing to work on speleological problems knowledge and attitudes gained in the introduction to cave science quickly transferred to other applications of basic geology. Thus caves have served successfully as a motivational focus or point of departure in an educational effort.

PRESIDENTIAL ADDRESS
THEN AND NOW

E.K. Tratman

It is my pleasant duty to welcome you all to Britain to this 7th International Speleological Congress. You have come from many countries and we are all linked together by our common interest in caves and all that concerns them. The Congress is an opportuntiy to exchange views and ideas, for co-operation in projects concerned with caves and with the advancement of knowledge about caves.

Now it has been my good fortune to have been associated with caving for well over half a century. Most of my experience has been limited to the British Isles though I have had opportunities to visit many other countries notably in connection with the International Congresses. Within that period I have seen many changes and developments in the study of caves. So in this address I am seeking to show what caving was like and what it is now. Perhaps a short film made in 1937 will demonstrate better than anything else the conditions of caving at that time. In a sense it is an historical document. It should be viewed light-heartedly and some of the comical peculiarities are due to two facts, poor lighting and having to run the cameras at half-speed with the actors also trying to move at half normal speed. You will have ample opportunities to see modern films at this conference so that you can form your own views as to how much progress has been made.

The film shows the types of equipment that were standard in 1937 and remained standard till after the end of the Second World War. We all know the sort of equipment that is in use today. New materials and new techniques have been developed. Ladders are now light-weight ones of steel wire and aluminium alloy rungs. It is worth recording that the now almost universal use of swaged or crimped tubes on the wires to space the rungs was introduced from the U.S.A. I recall reading about this method in a N.S.S. Newsletter and persuaded my own society (U.B.S.S.) to give the method a try. We use the method still and so do many other groups of cavers.

Natural fibre ropes have been replaced with man-made fibre ones. A great advance but not without its hazards and the need for variations in techniques dependent on the type of rope used. This has in turn led to the development of S.R.T. (Single Rope Techniques), again not without its hazards. Many pieces of personal equipment have been developed. All this makes for safer caving while at the same time lightening the load that must be carried in for deep explorations.

Even more revolutionary has been the change in clothing used in cave explorations. The 'Neoprene' wet suit arrived quite a long way back and will continue to be the mainstay for cavers' garments.

Theories of cave formation have been based for many years on the fundamental paper of Davies and Bretz and the terms 'Phreatic' and 'Vadose' are in world-wide use. Their general principles still hold good. Naturally they have had to be elaborated and changed in detail and the term paraphreatic has been coined to cover caves that may be intermittently phreatic while most of the time vadose. Another change in view point from the original theories is that water in caves can move very swiftly under phreatic conditions.

From the basic concepts of Davies and Bretz has arisen the study of solution of limestone by water to form the caves. A notable contribution to this study was the theory of 'Mischungkorrosion' of Bögli. Beyond this the chemistry of the solution processes has been very widely studied. The more it was studied the more it was realised that the process was very complex but for long the basic concept of solution by waters carrying CO_2 held the field. More recently attention has begun to be paid to the part played in the solution of limestone by the complex humic acids, something that I have long advocated. Arising from the work on solution arose investigations into the micro-crystalline structure of limestones and how variations in this affect rates of solution. All the techniques used gave no absolute measurements of rates of development of caves. In 1966 Dr. Hanna produced the first 'Micro-erosion Meter'. This has undergone much development and provided the strict specifications he gave of the material to be used in the construction of the machines and proper care in use, the rates of solution can be determined for local areas within caves, or for that matter on surface karst sites.

Even with all these methods available dating of caves still presented major difficulties. Now from the research work of Dr. Ford a new tool has been produced, the method of dating stalagmites by Uranium/Thorium Disequilibrium Method. Papers on this will be given at this conference. Beyond this it may be possible, in the not too distant future, to use fission tracks in crystals to date caves.

The tracing of underground water routes is an important piece of cave research. It is not necessary

for me to elaborate on this. The use of fluorescent dyes has been the mainstay of this work for a long time. Then from Austria came the development of dyed spores for such traces. This was a major development advance, which in turn has been largely superceded by a return to dyes of different categories including optical brighteners each with different ranges of fluorescence. They can be identified, by using a fluorimeter, in very low concentration and to ease the labour of collecting samples at regular intervals the automatic water sampling apparatus has been developed.

In cave biology there is still much to be done. In Britain the initial stages of collecting specimens is largely complete in the simple matter of determining the fauna that one can expect to find. This is not true of many other areas where very little is known, if anything, about the fauna in the caves. There is a trend to move forward and examine the food chains. Laboratories have been set up, notably at Moulis, for the study of cave organisms. Under rare conditions one may find caves which have been completely sealed for a long time and to have been isolated from the active streamway. In such sites one may find that the only living organisms are bacteria on the cave walls. These may only grow in the laboratory at cave temperature. Their food chain is not obvious and I support Trevor Ford's tentative suggestion that they may derive their food from the actual limestone.

Cave archaeology is a specialised branch of cave studies. In the past 50-60 years major advances in techniques have been made. Some, but not all derived from techniques used on surface sites. One major handicap is the lack of light. Even the best artificial light is not as good as daylight. The focus has also changed. It is no longer a matter of finding objects but of finding out everything that one can about the conditions under which the archaeological deposits were formed: if man is represented, how did he live? It must also be remembered that excavation effectively destroys the evidence and therefore it is imperative that every scrap of information should be retrieved. Cave archaeology is a time-consuming occupation carried out under adverse physical conditions. Because excavation means destruction then at every cave site one should try to leave untouched deposits for future generations. Such deposits should be adequately protected. No archaeological site is completed until a full report has been published.

Transport has changed enormously especially in the period since 1950. The changes have been, on the whole, beneficial to speleology but it does bring in the matter of conservation of caves in a crowded country such as Britain. On the other hand modern transport has made it possible to do what was formerly considered impossible. Expeditions can be mounted to go to out of the way places. Little time is used up in getting to the areas. Air travel cuts the time down to a matter of days for even the remotest areas. Helicopters can be used to ferry in gear and supplies from the nearest airfield. It costs rather more but that is balanced by the time saved.

To conclude, this conference is primarily directed to the scientific study of caves and all that pertains to them. There is always the lure of new discoveries of all kinds and one may think that every new discovery reduces the chances of further ones. But every discovery brings forward its own problems, which in turn will have to be solved. This is the spur to further research into caves.

THE WESTBURY-SUB-MENDIP CAVE AND THE EARLIEST EVIDENCE FOR MAN IN BRITAIN

E.K. Tratman
Penrose Cottage
Burrington
Bristol, England

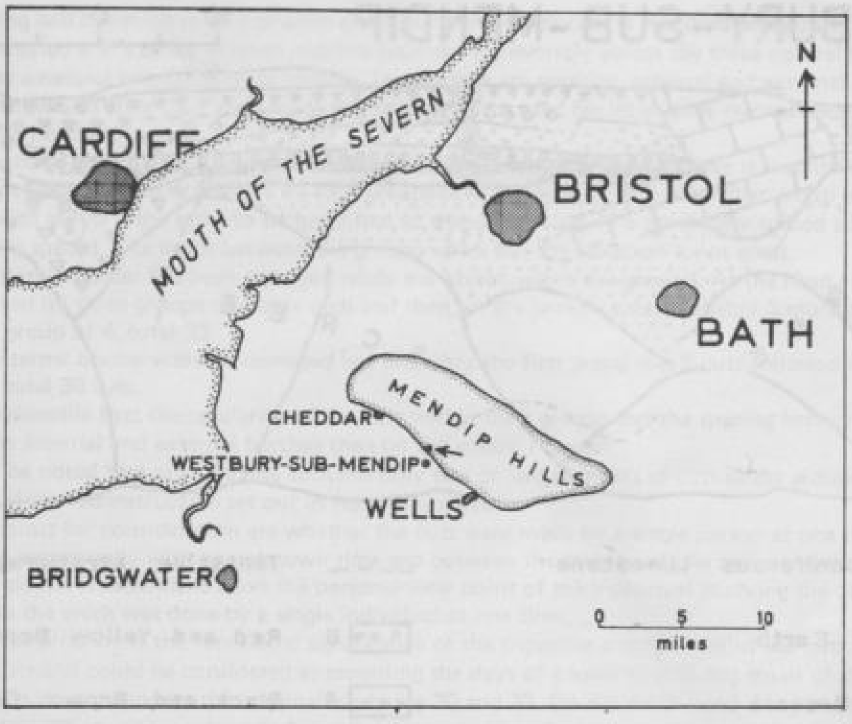
The cave consists of a large single chamber. It was exposed by quarrying. It runs west-east with a length of over 100m, width 12m and height 20m. The cave was formed under phreatic conditions and was subsequently invaded by a river. Its location is at the very edge of the southern Mendip escarpment. Here the Carboniferous Limestone has a steep southerly dip. There is a major thrust fault associated with the cave.

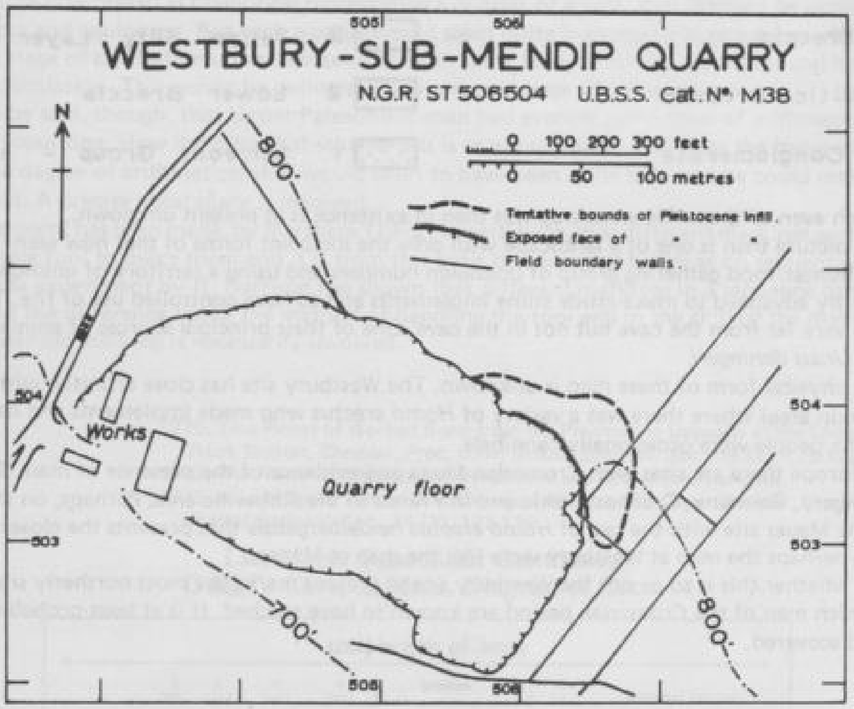
When the cave was first exposed it was filled to the roof with deposits and the roof was only about 1.5m under the surface of the limestone and in places ran right up to the surface. The deposits fall into two major groups, lower and upper.

The lower group consists of yellow clays, sands and gravels with evidence of current bedding. Their attitude and nature indicates a surface river running nearly at grade with limited turbulance within the cave. This group is siliceous in nature and the chert mixed in with the gravels is derived from the Greensand deposits, which now do not exist at all in the area. In this siliceous group there are scanty mammalian remains: mostly small fragments and very much rolled. The commonest animal is *Bison sp*, a small variety. Other beasts are *Hyaena brevirostris, Dicerorhinus sp.* and *Caster fiber* (Beaver).

The phase of gravel infilling ended with a period of collapse of the roof but for a short while gravels were still being deposited because they are found between the boulders from the roof fall. Upwards the gravels merge fairly rapidly into the upper group of deposits.

The upper group are throughout calcareous in nature. They are divisible into a series of beds some of which are sharply demarcated and some are seen as presenting gradual change from one layer to another. All the layers contain mammalian bones and teeth. Some birds are represented. Most of the remains are fragmentary but some at least of the fragmentation is due to the effects of blasting in the quarry. By far the commonest animal is *Ursus deningeri*, the ancestral form of both *Ursus speleus* and *Ursus arctos*. The presence of *Castor*





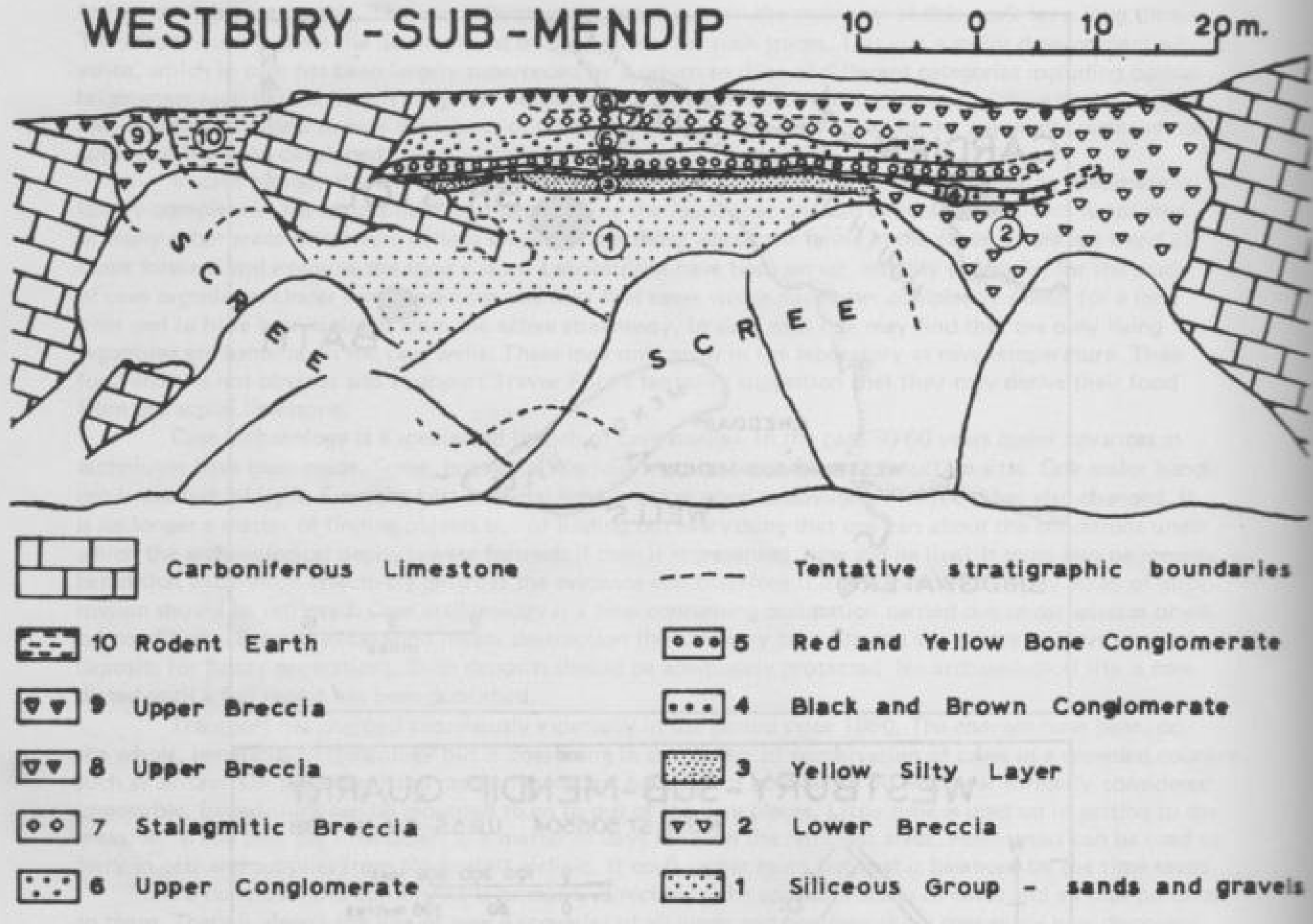
fiber is evidence of a riverine environment. The total of animals represented is 49 species. They include amongst the carnivores *Crocuta crocuta, Homotherium latidens* (Owen), *F. gombaszoegensis, Xenocyon lycaonoides, Canis lupus mosbachensis,* and amonst the *Perisodactlya* there is *Dicerorhinus etruscus.*

The evidence for the presence of man *(Homo. sp.)* is found within the calcareous deposits. First the accumulation of animal bones within the deposits can be partly attributed to man. Second are the few crude flint implements, which can be attributed to the earliest Acheulian and the flint from which they were made came from the Upper Chalk. The nearest outcrop of chalk is now some 30km away. Third there is the presence of charcoal, sometimes in such quantity as to darken the whole layer. This can only be attributed to man, who had learnt to control fire.

The fauna of the calcareous deposits places it within the Middle Pleistocene and the Cromerian sub-division. The siliceous gravels are older but on the scanty faunal evidence also fall within the Cromerian.

The palynological evidence confirms that the climate was temperate and the surrounding country was open type with a fair degree of tree cover. The date would be about 400,000 years ago.

At this time the landscape was very different from that now existing. The main gorges now seen such as Cheddar Gorge, Burrington Combe, and the gorges of the Bristol Avon had not been formed. It was before the Severn changed its course from easterly to southwest via the Iron Bridge fluvio-glacial gorge to the Bristol Chan-



nel. How much even of that wide waterway was then in existence is at present unknown.

The picture then is one of a landscape with only the incipient forms of that now seen. A landscape inhabited by a hunter/food gathering group of unknown numbers and using a territory of unknown extent. They were sufficiently advanced to make crude stone implements and to have controlled use of fire. They lived beside a river not so very far from the cave but not in the cave. One of their principal sources of animal protein seems to have been *Ursus deningeri*.

The physical form of these men is unknown. The Westbury site has close affinities with that at Chou Kuo Tien (Pekin area) where there was a variety of *Homo erectus* who made implements and had the controlled use of fire. The people were occasionally cannibals.

In Europe there are sites with Cromerian fauna and evidence of the presence of man. Sites are known in Spain, Hungary, Germany, Czechoslovakia and in France in the Abbeville area. Perhaps, on the faunal evidence, it is the Mauer site with the jaw of *Homo erectus heidelbergensis* that presents the closest parallel to Westbury, so perhaps the men at Westbury were like the man at Mauer.

But whether this is so or not the Westbury site at present marks the most northerly site in western Europe to which men of the Cromerian period are known to have reached. It is at least probable that further sites will be discovered.

References

Bishop, M.J. 1974. A Preliminary Report on the Middle Pleistocene Mammal Bearing Deposits of Westbury-Sub-Mendip, Somerset, *Proc. Univ. Bristol Spelaeol. Soc.*, 13 (3), 301-318.

A LATE UPPER PALAEOLITHIC CALCULATOR(?) FROM GOUGH'S CAVE, CHEDDAR, MENDIP

E.K. Tratman
Penrose Cottage
Burrington
Bristol, England

The problem of how Late Upper Palaeolithic man could and did count and for what purposes in unsolved. Engraved marks in various forms on bone and antler are commonly found at Late Upper Palaeolithic sites in Europe and North Africa. A few have been badly recorded in the past from sites of similar age in Britain. This paper deals with an example of special interest from a cave in Britain.

The object is the tibia of a hare which bone was first made into a point by cutting off the distal end

and then grinding and polishing it till a smooth small point was produced. It was used as a point for some time and then was selected and a series of small notches were cut transversely across the three natural borders of the bone, which has a natural triangular cross section. The borders are anterior, internal and external. The notches are all quite shallow and after they were made the point was not used for its original purpose any more as there is no wear on the notches.

The notches were made in groups of 4, 5 and 6. On the anterior border there is, counting from the head of the bone, a group of six followed by four groups of 4 and finally there is another group of 6, total 28. The length of each group is the same to within 1 mm so that the groups of 6 are closely spaced and the groups of 4 more widely spaced. The space between the groups varies but the variation is not great.

The internal border has been damaged while the object was in the ground. At the head end is a group of 5 cuts followed by three groups of 4 cuts each and then, in the broken area, probably 3 more groups of 4 and finally another group of 4, total 33.

The external border was also damaged but probably the first group was 5 cuts followed by five groups each of 5 cuts, total 30 cuts.

It is noticeable that the regularity of the cuts within their groups and the spacing between the groups is less exact on the internal and external borders than on the anterior border.

It will be noted that any one line contains only one or two numbers of cuts in the groups and never all three numbers, if the reconstruction set out in figure 1 is correct.

Two points for consideration are whether the cuts were made by a single person at one time or whether they were made sequentially with an unknown time gap between the making of one series and the next one. The answer to both points is dependent upon the personal view point of the individual studying the object. The author considers the work was done by a single individual at one time.

The next problem is the functional significance of the tripartite arrangement of the cuts. The anterior border has 28 cuts and could be considered as recording the days of a lunar month but totals of the cuts on the other two borders do not support this supposition being 30 and 33. On the other hand the grand total comes to 91, which could be interpreted as calendrical representing a quarter of a year, that is could be possibly connected with the solstices and equinoxes. But such a usage would seem quite inappropriate to a people in the hunting/food gathering stage of civilisation unless it was to do with some form of religious concept and here we enter a vast realm of speculation. This would be pointless at our present stage of knowledge.

It can be said, though, that Upper Palaeolithic man had evolved some form of arithmetical scheme associated with counting. How intricate that scheme was is as yet unknown but from the items studied from various sites the degree of arithmetical skill would seem to have been quite high and he could make fairly complex calculations. A precise vocabulary is involved.

A final point has been made, by Marshack (1972) in particular, that different markings within a sequence demand a separate tool to make them and it is from this basis that some of his ideas on sequential marking are derived. A simple experiment by R. Harrison has shown that different markings in a sequence can be made with a single tool and the difference lies in the method of handling the tool and in the skill of the maker. No change of tool nor sequential marking is necessarily involved.

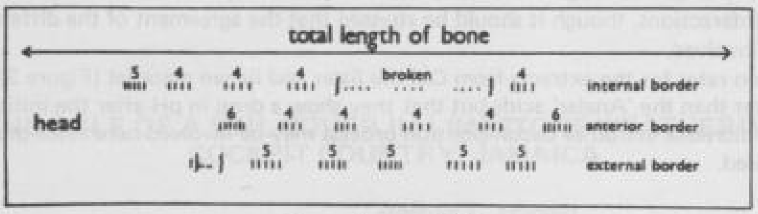
References

Harrison, R.A. 1976. Two Pieces of Worked Bone from the Pleistocene Deposits at the Chelm's Combe Rock Shelter, Cheddar, *Proc. Univ. Bristol Spelaeol. Soc.*, 14 (2), 115-122.

Marshack, A. 1972. *The Roots of Civilisation*, Weidenfeld and Nicholson, London.

Tratman, E.K. 1976. A Late Upper Palaeolithic Calculator(?) Gough's Cave, Cheddar, Somerset, *Proc. Univ. Bristol Spelaeol. Soc.*, 14 (2), 123-129.

Late Upper Palaeolithic Calculator, Gough's Cave, Cheddar. Diagram of Cuts.



REACTION RATES AND EQUILIBRIUM LEVELS IN THE DISSOLUTION OF LIMESTONES IN ORGANIC ACIDS

Stephen T. Trudgill
Department of Geography
University of Sheffield, S10 2TN, U.K.

Introduction

In laboratory experiments it is relatively easy to control the variables involved, but they may not

necessarily be representative of natural conditions. The use of naturally occurring substances is more realistic but the variables are more difficult to control and the results may be more difficult to interpret. Accordingly a Carboniferous Limestone has been dissolved in known 'Analar' organic acids and also in extracts from naturally occurring organic materials.

Solubility levels

Limestone tablets (2.5 cm diameter, 0.5 cm high) of Carboniferous Limestone (Avon Gorge, Somerset, England; sparite; 98% $CaCO_3$, 1% $MgCO_3$) were dissolved in 100 ml of 0.025M organic acids. The acid was titrated with EDTA for Ca in solution after 7 days. The results are shown in Table 1. The acids which showed the highest apparent solubilities were tartaric, citric and salicylic. These are strongly complexing acids (Huang and Kiang, 1972).

TABLE 1. **mg/l $CaCO_3$ in solution after immersion of Carboniferous Limestone tables for one week in organic acids**

Acid	*mg/l*
Tartaric acid	19,8000
Citric acid	9,200
Salicylic acid	8,400
Lactic acid	1,800
Acetic acid	1,000
Oxalic acid	200
Distilled water (open to laboratory atmosphere)	300

TABLE 2. **Equilibrium rates, powdered Carboniferous Limestone**

Acid	*Chart length to stable pH reading (mm)*	*Hours*	*Stable pH*
a Oxalic	56.0	2.8	7.8
b Citric	34.0	1.7	7.6
c Tartaric	19.0	0.9	7.6
d Salicylic	10.5	0.5	7.6
e Lactic	4.5	0.2	7.5
f Acetic	2.0	0.1	7.8

Dissolution rates

In a second experiment 1g samples of the limestone were dissolved in powder form in 100 ml of the organic acids, with gentle stirring during the experiment. pH was recorded using a Polymetron continuous recording pH meter. The results are shown in Figure 1. They are summarised in Table 2, using the measured length of chart paper to indicate the dissolution rate (chart speed being 1 hour = 20mm), and measurement being to the point of flattening of the curve. It can be seen that the results do not necessarily agree with the results for the solubility level. It can be suggested that the acids with the highest apparent solubilities may have a lower reaction rate than the ones with a lower apparent solubility, though this is not necessarily the case.

It is interesting to note that if the reaction rates are superimposed (Figure 2) that the differences appear most marked in the initial stages of reaction. This may have implications for water residence time/chemical diffusion interactions, though it should be stressed that the agreement of the different complexing ability of the acids involved.

The reaction rates for the extracts from *Calluna* litter and lichen material (Figure 3) are of interest in that they are faster than the 'Analar' acids but that they show a drop in pH after the initial reaction. It is possible that some microbial action or decomposition process may be involved here since the extracts were fresh and not sterilised.

Discussion

These experiments are still in progress and a fuller report at a more sophisticated level should be available in due course. The primary problems are the high solution to solid ratio and the effect stirring may have upon the pH (streaming potential). Further work should include a more extensive use of material occurring naturally under more controlled conditions. The natural extracts are difficult to analyse because they are highly coloured and often particulate. The experiments indicate that there is, however, some potential in this technique. This is important since organic acids and water contact time/chemical reaction rates are significant considerations in natural systems.

Reference

Huang, W.H. & W.C. Kiang 1972. Laboratory dissolution of plagioclase feldspars in water and organic acids at room temperature. *Amer. Mineralogist*, 57, 1849-1859.

Fig 1 DISSOLUTION RATE OF CARBONIFEROUS LIMESTONES IN ORGANIC ACIDS

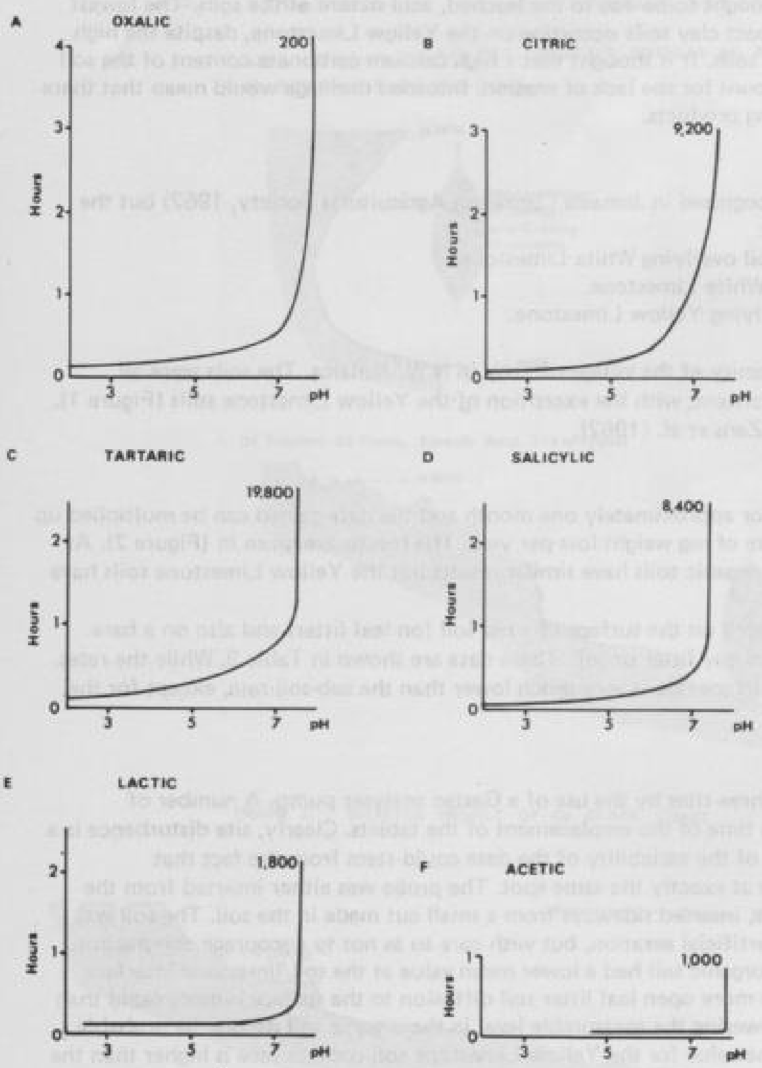
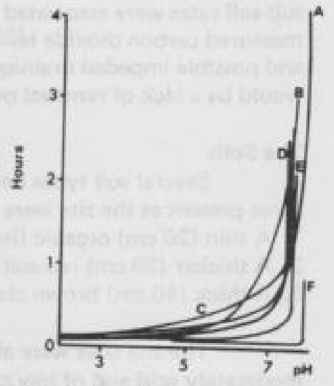
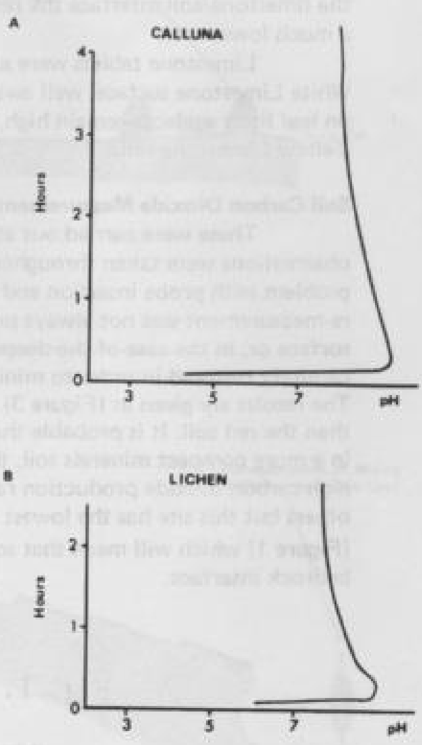


Fig 2 LIMESTONE DISSOLUTION IN ORGANIC ACIDS



Superimposed Profiles

Fig 3 LIMESTONE DISSOLUTION IN ORGANIC EXTRACTS



THE ROLE OF A SOIL COVER IN LIMESTONE WEATHERING, COCKPIT COUNTRY, JAMAICA

Stephen T. Trudgill
Department of Geography
University of Sheffield, S10 2TN, U.K.

The aim of the fieldwork undertaken in Jamaica in May and June, 1975 was to assess whether the presence of a soil cover influenced the nature of limestone erosion in a tropical limestone environment. In a temperate Carboniferous Limestone environment it has been suggested that erosion under organic and acid drift soils is greater than that on bare limestone surfaces while that under calcareous soils is less (Trudgill, 1972, 1976a,b). In the present study erosion rates were assessed by placing pre-weighed tablets of Jamaica White Limestone in soil profiles and at the soil/bedrock interface. Weight losses measurable after an emplacement period are taken as an indication of erosion rate. The method is described by Trudgill (1975). Supporting data on soil pH, calcium carbonate content and carbon dioxide levels were also obtained.

The data presented are in no way statistically representative, but three sites were studied in order to

provide examples of contrasting soil types. Comparisons of weight loss of tablets placed on bare limestone surfaces suggested that erosion rates under all soil types were at least equal to and usually greater than those where a soil cover was absent. This is thought to be due to the leached, acid nature of the soils. The lowest sub-soil rates were associated with compact clay soils occurring on the Yellow Limestone, despite the high measured carbon dioxide levels of these soils. It is thought that a high calcium carbonate content of the soil and possible impeded drainage may account for the lack of erosion. Impeded drainage would mean that there would be a lack of removal of weathering products.

The Soils

Several soil types have been recognised in Jamaica (Jamaican Agricultural Society, 1962) but the three present at the site were as follows:

1. A thin (20 cm) organic (leaf litter) soil overlying White Limestone.
2. A thicker (30 cm) red soil overlying White Limestone.
3. A thick (40 cm) brown clay soil overlying Yellow Limestone.

The soil sites were all in the vicinity of the village of Troy in N.W. Jamaica. The soils were all moderately acid and of low carbonate content, with the exception of the Yellow Limestone soils (Figure 1). The geology of the area is described by Zans *et al.* (1962).

The Erosion Rates

The emplacement period was for approximately one month and the data gained can be multiplied up in order to give a rate equivalent to a rate of mg weight loss per year. The results are given in (Figure 2). At the limestone/soil interface the red and organic soils have similar results but the Yellow Limestone soils have a much lower rate.

Limestone tablets were also placed on the surface of a red soil (on leaf litter) and also on a bare White Limestone surface, well away from any litter or soil. These data are shown in Table 3. While the rates on leaf litter surfaces remain high, the surface rate is very much lower than the sub-soil rate, except for the Yellow Limestone soils.

Soil Carbon Dioxide Measurements

These were carried out at the three sites by the use of a Gastec analyser pump. A number of observations were taken throughout the time of the emplacement of the tablets. Clearly, site disturbance is a problem with probe insertion and some of the variability of the data could stem from the fact that re-measurement was not always possible at exactly the same spot. The probe was either inserted from the surface or, in the case of the deeper soils, inserted sideways from a small cut made in the soil. The soil was carefully restored in order to minimise artificial aeration, but with care so as not to encourage compaction. The results are given in (Figure 3). The organic soil had a lower mean value at the soil/limestone interface than the red soil. It is probable that in a more open leaf litter soil diffusion to the surface is more rapid than in a more compact minerals soil, thus lowering the measurable level in the organic soil despite its probable high carbon dioxide production rate. The value for the Yellow Limestone soil contact face is higher than the others but this site has the lowest erosion rate. These soils do, however, have the highest carbonate content (Figure 1) which will mean that solutional activity will tend to be taking place in the soil and not at the soil/bedrock interface.

Fig. 1. **SOIL CHARACTERISTICS**

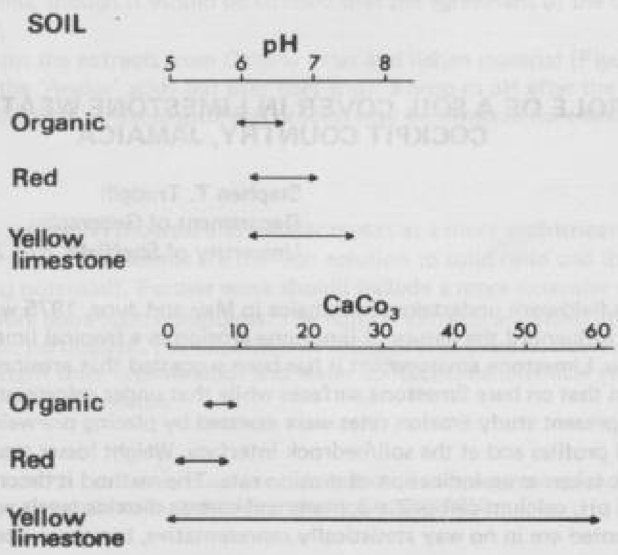


FIGURE 1 SELECTED PROFILES OF ALDABRA COAST

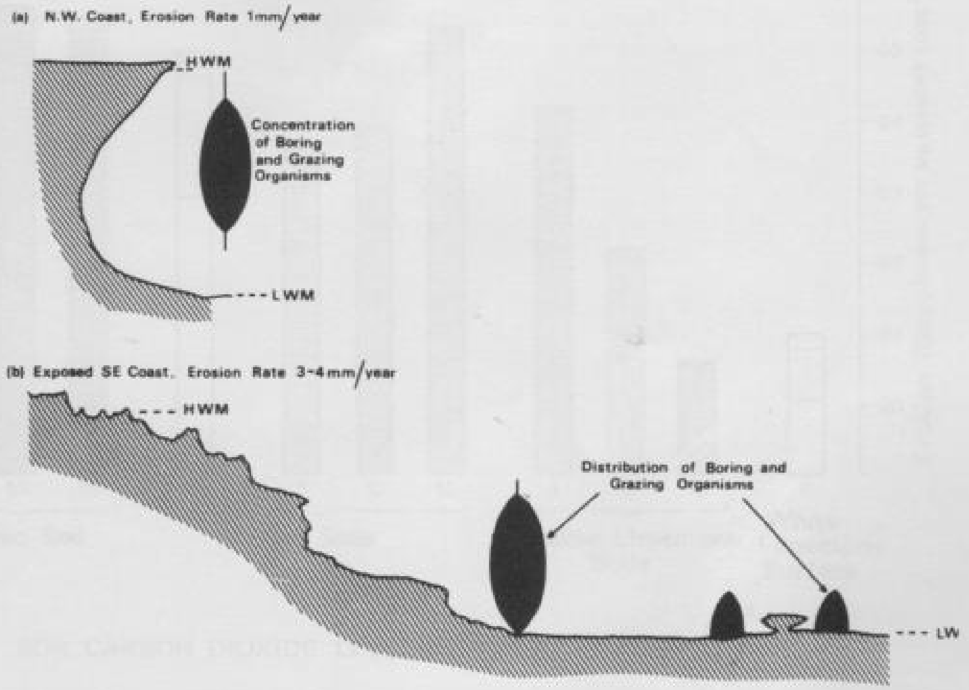


FIGURE 2 SELECTED PROFILE OF Co CLARE COAST

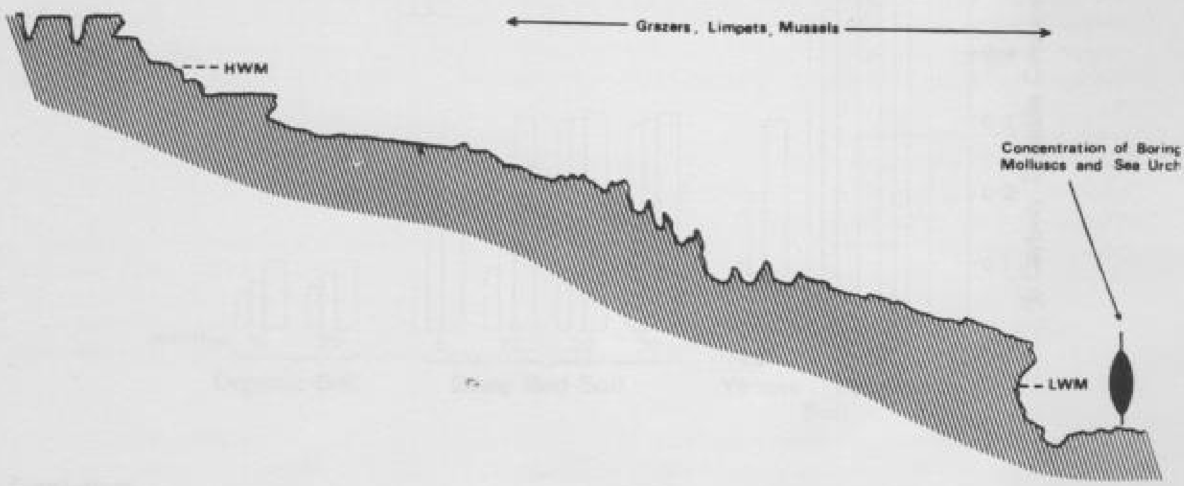


Fig. 2. **EROSION RATES**

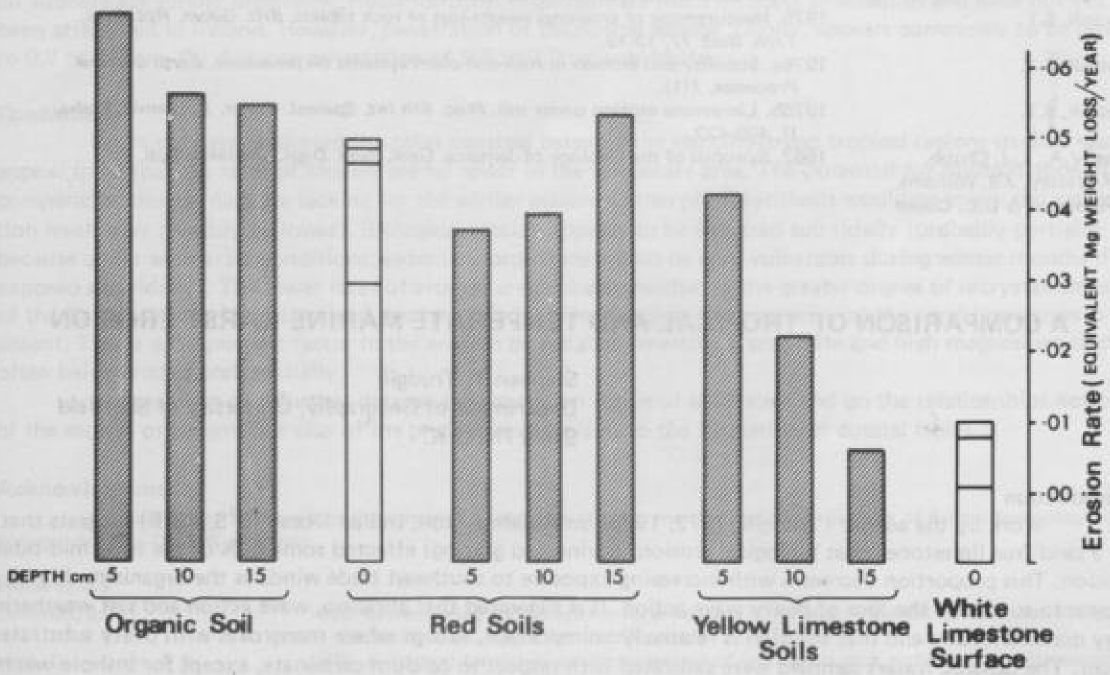
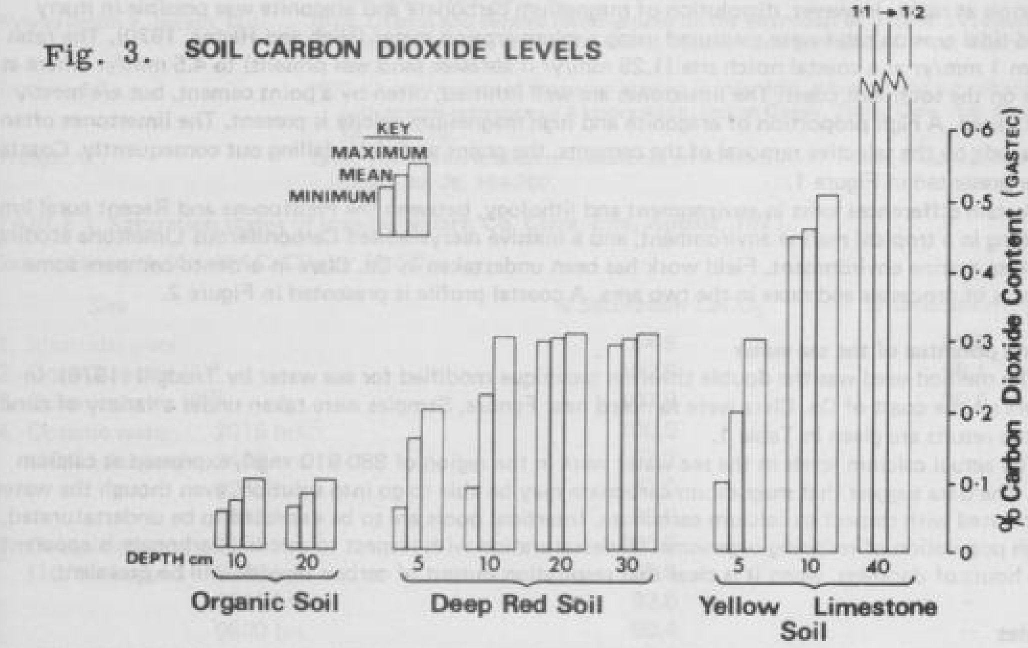


Fig. 3. **SOIL CARBON DIOXIDE LEVELS**



Conclusions

The presence of a soil cover appears to increase the rate of bedrock erosion except in the case of the Yellow Limestone soil. Erosion rate is not necessarily related to soil carbon dioxide content but more to high leaching in a rainfall of about 60-100" (1778-2540 mm) per annum and a consequent acidity of the soils, in conjunction with free drainage. The presence of soil carbonates must be evidence of poor drainage, otherwise the soluble carbonates would have been leached out of the soil. Accordingly, erosion rates will be low under the Yellow Limestone soils, but only of the same order of the subaerial rates, not lower than them. It appears that the presence of a soil cover could markedly affect the development of a dissected topography, erosion being greatest where pockets of organic and red soils occur. These conclusions are based on pilot examples, not on statistical samples. More work is needed in order to consolidate the evidence for this potentially significant conclusion.

Acknowledgements

The author would like to thank the NERC and the Carnegie Institute for research grants; the Jamaican Caving Club for hospitality and the other members of the Cockpit Country Expedition for assistance and support.

References

Jamaica Agricultural Society, 1962. *The Farmer's Guide*, University Press, Glasgow.

Trudgill, S.T. 1972. The influence of drifts and soils on limestone weathering in N.W. Clare, Ireland, *Proc. Univ. Bristol Speleol. Soc.*, 13(1), 113-118.

Trudgill, S.T. 1975. Measurement of erosional weight-loss of rock tablets, *Brit. Geom. Res. Grp., Tech. Bull. 17*, 13-19.

Trudgill, S.T. 1976a. Stability and erosion in rock-soil-plant systems on limestone, *Earth Surface Processes, 1*(1).

Trudgill, S.T. 1976b. Limestone erosion under soil. *Proc. 6th Int. Speleol. Congr.* Academia, Praha. II, 409-422.

Zans, V.A., L.J. Chubb, H.R. Versey, J.B. Williams, E. Robinson & D.L. Cooke 1962. Synopsis of the Geology of Jamaica. *Geol. Surv. Dept., Jamaica*, Bull. 4.

A COMPARISON OF TROPICAL AND TEMPERATE MARINE KARST EROSION

Stephen T. Trudgill
Department of Geography, University of Sheffield
S10 2TN. U.K.

Introduction

Work by the author (Trudgill, 1972; 1976) on Aldabra Atoll, Indian Ocean (9°S, 46°E) suggests that on a sand-free limestone coast biological erosion (boring and grazing) effected some 60% of the total mid-tidal erosion. This proportion decreases with increasing exposure to southeast trade winds as the organisms do not appear to survive in the face of heavy wave action. It is suggested that abrasion, wave action and salt weathering play dominant roles and that solution is relatively unimportant, except where mangroves with peaty substrates occur. The oceanic waters sampled were saturated with respect to calcium carbonate, except for inshore waters and tidal pools at night. However, dissolution of magnesium carbonate and aragonite was possible in many waters. Mid-tidal erosion rates were measured using a micro-erosion meter (High and Hanna, 1970). The rates ranged from 1 mm/yr at a coastal notch site (1.25 mm/yr if abrasive sand was present) to 4.5 mm/yr where at a ramp site on the southeast coast. The limestones are well lithified, often by a point cement, but are mostly not recrystallised. A high proportion of aragonite and high magnesium calcite is present. The limestones often appear to erode by the selective removal of the cements, the grains and clasts falling out consequently. Coastal profiles are presented in Figure 1.

Certain differences exist in environment and lithology, between the Pleistocene and Recent coral limestones eroding in a tropical marine environment, and a massive recrystallised Carboniferous Limestone eroding in a temperate marine environment. Field work has been undertaken in Co. Clare in order to compare some of the aspects of processes and rates in the two area. A coastal profile is presented in Figure 2.

The solution potential of the sea water

The method used was the double titration technique modified for sea water by Trudgill (1976). Inshore waters on the coast of Co. Clare were sampled near Fanore. Samples were taken under a variety of conditions and the results are given in Table 1.

The actual calcium levels in the sea water were in the region of 880-910 mg/l, expressed as calcium carbonate. The data suggest that magnesium carbonate may be able to go into solution, even though the water may be saturated with respect to calcium carbonate. Intertidal pools are to be expected to be undersaturated, given a high population of respiring organisms. Undersaturation with respect to calcium carbonate is apparent during the hours of darkness, when it is clear that respiration output of carbon dioxide will be prevalent.

Erosion rates

An intertidal erosion measurement site, using micro-erosion meters, has been established in a mid- to upper intertidal position at Murroogh, a site described by Coleman (1969). The site does not necessarily represent the most rapid rate of erosion since this may be occurring slightly further down the intertidal zone. Here, however, the site is too dissected for the emplacement of a micro-erosion meter site. The mean value for erosion is 0.198 mm/yr for 14 measurement points within a 12 cm triangle. This value is of the order of five to twenty times less than the Aldabra value. It is felt that this reflects the more recrystallised nature of the Carboniferous Limestone, rather than any overall climatic contrasts.

Biological erosion

Organisms which are capable of erosion and which frequently occur on the Irish shores are listed in Table 2. Other organisms, namely algal grazers, may also be present but their effect on the rock beneath the algae is only very slight. Evidence of the observations of the author and of Ryland-Smith and Nelson (1975) suggests that most of the erosive organisms are concentrated in the lower to sub-tidal zones. Morphological observations tend to confirm this, in that at very low spring tides a notch, of some 1 m amplitude and 0.2 to 0.5 m indentation can commonly be seen (e.g. Black Head). This notch supports a dense population of boring molluscs and sea urchins.

Rates of biological erosion can be estimated for the boring molluscs by measuring the depth of the bored hole (by means of a resin cast) and by counting the number of growth rings on the mollusc occupying the hole and assuming the rings to be annual (Trudgill, 1976). Estimates for *Gastrochaena* ranged from 0.2 to

0.3 cm/yr. The boring rates are of the order of five to three times less than those of around 1 cm/yr obtained on Aldabra for similar organisms. Rates for other organisms are more difficult to establish and have not yet been attempted in Ireland. However, penetration of the boring sponge, *Cliona*, appears commonly to be limited to 0.2 to 0.7 cm. On Aldabra penetration of 0.5 to 2.0 cm was found.

Conclusions

From the data presented the chief contrast between the temperate and tropical regions studied would appear to be that the rates of erosion are far lower in the temperate area. The potential for solution appears comparable, though data are lacking for the winter seasons (when photosynthesis would be lower and saturation levels may possibly be lower). Biological erosion appears to be focussed sub-tidally (probably partially because under temperate conditions, sedentary organisms would be very vulnerable during winter months if exposed sub-tidally). The lower rates of erosion are probably related to the greater degree of recrystallisation of the Carboniferous Limestone and the fact that the mineralogical heterogeneity of the coral limestones is absent. This is an important factor in the erosion of Aldabra limestones, aragonite and high magnesium calcite often being eroded preferentially.

It remains to gain further data on the saturation status of sea waters and on the relationships not only of the erosive organisms but also of the protective organisms to the formation of coastal lapies.

Acknowledgements

I would like to acknowledge the continued assistance of other members of the University of Bristol Speleological Society, notably Dr. E.K. Tratman.

References

Coleman, J.C. 1969. Some marine and lacustrine karst features in Ireland. *Abhandlungen, V. Int. Kong. Spelaologie, Stuttgart. Bd. 1. München.*

High, C.J. Hanna, F.K. 1970. A method for the direct measurement of erosion on rock surfaces. *Brit. Geomorph. Res. Grp., Tech. Bull.,* 5.

Ryland-Smith F. Nelson, G.J. 1975. Littoral and benthic investigations on the west coast of Ireland: IV. Faunistic and ecological studies on some shores in County Clare and Galway. *Proc. Roy. Irish. Acad.* 75, B., 11, 245-266.

Trudgill, S.T. 1972. Quantification of limestone erosion in intertidal, subaerial and subsoil environments, with special reference to Aldabra Atoll, Indian Ocean. *Trans. Cave. Res. Grp. Gt. Brit. 14,* 176-179.

Trudgill, S.T. 1976. The marine erosion of limestones on Aldabra Atoll, Indian Ocean. *Z. Geomorph., Suppl. Bd. 26,* 164-200.

TABLE 1. Saturation status of inshore waters, Co. Clare, Eire, August, 1971.
Saturation with 'Analar' $CaCO_3$ or $MgCO_3$

Site		*% Saturation $CaCO_3$*	*% Saturation $MgCO_3$*
1. Intertidal pool		94.8	92.5
2. Oceanic water (1)[a]		109.6	98.4
3. Oceanic water (2)[b]		107.9	99.6
4. Oceanic water,	2015 hrs.[c]	100.0	–
(10/11 August)	2400 hrs.	97.2	–
	0245 hrs.	87.0	–
	0545 hrs.	93.0	–
5. Oceanic water,	2130 hrs.[d]	106.6	–
(16/17 August)	0030 hrs.	95.6	–
	0315 hrs.	93.8	–
	0600 hrs.	99.4	–
	1030 hrs.	104.9	–
	1200 hrs.	102.8	–
	1400 hrs.	103.7	–
6. Oceanic water (3)[e]		107.9	101

\- = not measured
a = cool, cloudy
b = hot, sunny
c = cool, dull, windy
d = hot, sunny
e = saturated with Carboniferous Limestone; $CaCO_3$: $MgCO_3$ – 98:1

TABLE 2. Erosive organisms on limestone, Co. Clare

Organism	*Intertidal Zone*	*Erosive Mechanism*
Limpet, *Patella vulgata*	mid-tidal	'home scar', grazing
Sea Urchin, *Heterocentrotus lividus*	mid-lower tidal	boring and grazing
Boring Mollusc, *Hiatella arctica*	lower-sub-tidal	boring
Boring Mollusc, *Gastrochaena spengleri*	lower-sub-tidal	boring
Boring Sponge, *Cliona* sp.	lower-sub-tidal	boring

ENERGY FLOW AND FAUNISTICAL DISTRIBUTION INSIDE KARST: THE INFLUENCE OF MODULES OF OPENNESS.

M.J. Turquin and Y. Bouvet
Lab de Biologie souterraine, Universite Claude Bernard
Lyon, France

The cave entrance is conventionally regarded as the first accessible part of the cave interior. This paper presents the cave entrance in biological terms, as a measure of access to the karst by epigean life ("module of openness").

On the basis of collections of invertebrates from the Tunnel de Drom, an artificial tunnel, closed at one end and comparable in fauna, climate and biotopes with a cave, three faunal groups were distinguished (Bouvet, Turquin, Michalon, 1972): a threshold community of mainly epigean species, a deep community of troglobitic animals, and a transitional community forming an ecotone between epigean and hypogean biotopes. An entrance community of this type, a functional grouping of animals in a well defined biotope, may not exist in all horizontal or subhorizontal entrances.

Climatic conditions in horizontal and subhorizontal passages (Bouvet, Turquin, Michalon, 1972; Turquin, Bouvet, Renault, Pattee 1975) are substantially different from those in pot-holes. Temperature changes penetrate further in pot-holes and light penetrates deeper and for a longer period during the day. Pot-holes are cold traps (Gèze 1965), often closed by ice and snow for most of the year at high altitudes. Pot-holes generally lack the assemblage of hibernating animals found in horizontal tunnels in winter, although aestivating invertebrates migrate in the shafts in summer.

Observations have been made on the Gouffre d'Antona in French Jura. The 3m x 4m opening lies above a nearly vertical pit 30m deep giving access by a debris slope to a shaft 20m deep. This cavity is penetrable to -120m. While the shaft walls have very few invertebrates the debris slope is inhabited by several trogloxene organisms, specimens of which have fallen from the surface (Bouvet, Turquin, 1976). These trogloxenes do not move away from the debris; further down they are superseded by *Royerella, Pseudosinella, Onychiurus, Sciara, Phora, Rhymosia, Trichocera* and nymphs of *Speolepta*.

To quantify the animal input, baited traps were collected every month in 1971 and 1972. It was assumed that invertebrates would survive the fall from the cave mouth onto the deposits beneath. At least 58 systematic units of organisms were collected in traps on the platform (-30m) and at the bottom of shaft P20, (-20m), of which 33 species were found in less than 25% of the traps.

Epigean beetles, trapped in high numbers in summer and autumn but completely absent in winter, make up a large part of the trogloxene imported biomass. Acari, which also inhabit the soil outside, are present throughout the year, decreasing in abundance down the slope. Although a trogloxene, the collembolan *Tomocerus minor* usually inhabits the platform and slope; it has a summer peak of abundance. The troglophile staphylinid predator *Quedius mesomelinus* is remarkably abundant in all seasons and moves about even in January and February. The troglobite collembolan, *Pseudosinella vandeli* is present in small numbers in the debris through the year while the troglobite bathysciine *Royerella villardi* is absent in winter but moves towards the entrance in summer. The dipteran *Trichocera regelationis* is abundant in winter while the detritivorous dipterans *Sciara* sp. and *Phora aptina*, regular cave-dwellers, are abundant throughout the year. *Phora* reaches a summer peak (145 per trap). The total faunal community reaches maximum abundance in summer due to input of trogloxenes, multiplication of trogloxenes, multiplication of troglophiles like *Phora, Sciara* and *T. minor*, and upward movement of troglobites such as *R. villardi, P. vandeli* and *Trichoniscoides mixtus*.

Gravity transports trogloxenes and litter into pot-holes but not into horizontal passages. Avens can be regarded as ecological traps, a role reflected in the ratio of trogloxene to troglophile + troglobite species of 1.43 for the P30 of Gouffre d'Antona to 0.84 for the Tunnel de Drom. The faunal community at the bottom of the vertical pit has a relatively high index of diversity ($\alpha = 9.25$) reflecting a heterogeneous fauna partly derived from the surface, carried in by gravity. In contrast, a nearby shaft, joined to the surface by breccia with a network of narrow spaces lined mainly with soil, has a rich but specialised fauna ($\alpha = 2$). Here, invertebrates such as beetles cannot accidentally fall in, and water seeping through the bedrock is the major agent of transport. The animals present, all troglobites, are characteristic of the subterranean Jura (*Trichoniscoides mixtus, Royerella villardi, Trichaphaenops cerdonicus, Plusiocampa sollaudi, Pseudosinella vandeli*).

In general terms, the ease with which cave passage will permit transit of organic matter from the epigean zone ("module of openness") will depend on its speleogenesis, the nature of the overlying soil, and the extent of passage obliteration by precipitation and weathering products. The nature of the organic input will depend on the transport agent involved. For large modules, inputs are due to organisms obliged to spend part of their life-cycle underground (Biological Vector) and animals falling in by accident and unable to escape, together with plant debris similarly transported (Gravity Vector). Living and inert organic matter is carried into pot-holes by water (Water Vector). Entrances impenetrable to man allow entry to large subtroglophile insects such as Lepidoptera and Trichoptera, but have fewer trogloxenes than larger entrances (Turquin, Bouvet, Renault, Pattee, 1975). Smaller entrances allow transit of minute elements by water seepage. For horizontal and subhorizontal passages, in contrast to vertical ones, active penetration by the subtroglophile fauna is particularly important; the water vector is less important.

The distribution and abundance of cave communities depends upon the size and distribution of penetrable spaces and also the transport of food and the mobility of troglobites. The irregularities which occur in the distribution of both penetrable spaces and food supplies underground will result in an essentially heterogeneous troglobitic community.

References

Bouvet, Y., Turquin, M.J. Michalon, E. 1972. Étude des biocoenoses du tunnel artificiel de Drom (Ain). *Ann. Spéléol.*, 27(3); 563-574.

Bouvet, Y. Turquin, M.J. 1976. Influence des modules d'ouverture du karst vers l'extérieur sur la répartition et l'abondance de son peuplement. *Bul. Soc. Lyon* 45eme annee, no. 7, pp. 247-257.

Geze, B. 1965. La spéléologie scientifique. Ed. Seuil Paris, Rayon de la Science no. 22, 190 p.

Turquin, M.J., Bouvet, Y. Renault, P.H. Pattee, E. 1975. Essai de correlation entre la geomorphologie d'une cavite et la répartition spatiale de son peuplement actuel. *5e Cong. Soc. suisse Spéléol.*, Interlaken 1974, 46-60.

Acknowledgement

The authors wish to thank Dr. T. Piearce of the University of Lancaster, England, for redrafting their paper into English.

THE BIOSPELEOLOGICAL IMPORTANCE OF NON-CALCAREOUS CAVES

Shun-Ichi Uéno
Department of Zoology, National Science Museum
(Nat. Hist.), 3-23-1 Hyakunin-chō, Shinjuku,
Tokyo 160, Japan

Cave zoology has made progress mainly on the basis of the faunas of limestone caves. This is not surprising, considering that calcareous caves are the most abundant and widespread natural cavities in the world. Caves lying in other kinds of rocks were almost always neglected by biospeleologists before 1960's. In the past decade, however, the importance of lava cave faunas has been realized; numerous lava tubes have been biologically examined in various parts of the world, especially in Japan and Hawaii, and harbour specialized cave animals. These studies have shown that lava caves generally maintain subterranean faunas fully comparable with those of limestone caves if they are situated within a general area in which rich terrestrial troglobiontic faunas exist, or that they harbour peculiar cave animals if geographically isolated by impassable barriers from calcareous areas. The presence or absence of troglobionts in a certain lava cave lying in a fertile territory, for instance, in Japan, solely depends on whether or not the environment in that cave is favourable for the existence of specialized hypogean animals.

Further biospeleological importance is attached to lava caves by the fact that they are the only natural cavities whose approximate ages can be estimated by geological evidence. They are "primary" caves, the history of which is the same as that of the enclosing lava. The history of blind animals living in these caves, at least as cave-dwellers, must be shorter than that of the caves themselves. Thus, ancestors of all the troglobionts found in Japanese lava caves must have colonized them less than ten thousand years ago. Since almost all the lava cave forms belong to the same taxonomic groups as limestone cave ones, and since no substantial difference in the degree of adaptation can be observed between them, we can safely conclude that the history of subterranean evolution of troglobiontic animals is not dependent on the difference of rocks in which lie their habitat caves. This was not expected, as it seemed to indicate a very recent origin of cavernicolous animals.

Encouraged by my findings, I extended my studies to other non-calcareous caves. Sandstone caves, especially those developed in calcareous sandstones, usually proved to have rich faunas. Tuff caves were less interesting, but at least there were some rich in troglobiontic animals. With one exception, I could not find any wave-cut caves whose faunas were comparable with those of calcareous ones, but this may be solely due to the fact that environmental conditions in wave-cut caves are usually not favourable for the existence of terrestrial troglobionts. In any case, all these caves are "secondary" and rather sporadic, and though we have gained some new knowledge through their exploration, they cannot equal lava caves in their significance.

Much more important and striking was the discovery that mine adits frequently maintain rich troglobiontic faunas. In Japan, this fact was first seen in several adits dug through limestones. At that time, I could not follow up this research, considering that the troglobiontic animals found in the adits should have been derived from nearby natural caves not penetrable for human beings. However, my assumption was proved wrong by recent investigations. Troglobiontic animals do occur in mine adits which are considerably distant from limestone areas and which are dug into various kinds of rocks, including mudstone, shale, chert, breccia, tuff, rhyolite, diorite, and so on. In effect, so-called troglobiontic animals occur anywhere under the earth and can be met with in adits if environmental conditions are favourable for them.

It is true that not all the adits hitherto examined harbour specialized subterranean animals. On the contrary, the rate of their occurrence in artificial cavities is much lower than that in limestone caves. Moreover, population density of such animals appears to be generally low in mines as compared with caves. I have looked for blind animals in vain in many adits. However, the age of the adits is not significant with the fauna. Various blind animals, including trechine beetles, polydesmid millipeds, trichoniscid isopods, leptonetid and nesticid spiders, have been met with in old mines (more than 100 years old) as well as in very recent ones (only about 20 years old). The main factors determining their existence seem to be environmental conditions in adits and nature of rocks into which adits in question were excavated.

Needless to say, environmental conditions are the vital factors that limits the life of living organisms; but a brief comment may be needed on the significance of the nature of rocks. Terrestrial animals of special biospeleological interest have seldom been found in natural and artifical cavities lying in a very compact

rock, while they are frequent in such adits as were dug into loose fissured rocks. Most favourable adits seem to be those excavated in mudstones, for instance, manganese and antimony mines. This is not very fortunate for biospeleologists, since old adits lying in loose rocks are apt to entail dangers of collapse. On the other hand, an interesting deduction can be drawn from these findings; compact rocks do not contain continuous spaces for harbouring subterranean animals, whereas loose rocks offer sufficient habitats for them. When artificial adits are dug into those fissured rocks, blind animals emerge from their original habitats and secondarily settle down there. This view is supported by discoveries of some anophthalmic trechine beetles perfectly similar to troglobiontic forms in layers of mudstones beneath the soil, sometimes two metres or more under the surface. Thus, most of the so-called troglobionts, with possible exception of ultra-evolved ones, are nothing but such animals as live deep in the earth or in fissures of rocks beneath the soil.

The discovery delineated above has opened a new promising field in Japanese biospeleology. Though fairly numerous, limestone caves are not uniformly distributed in Japan; they do not exist almost in the whole area along the Japan Sea, and even in the other parts, they concentrate in particular areas. This poses a serious problem in analysing distributional patterns of cavernicolous animals, seeing that wide blanks remain here and there. Some of those blanks have been filled by the discovery of true cavernicoles in lava caves and other non-calcareous natural cavities, but they are much less numerous and more locally restricted than limestone caves. In such areas as are lacking in natural caves, adits of mines are the only means by which we can go under the earth and observe subterranean animals. I became aware of the biospeleological importance of artificial cavities only a few years ago and have not yet had much experience in this field. However, I have already succeeded in bridging certain wide gaps in our knowledge of distribution of Japanese subterranean animals. I expect that a more detailed information of cavernicoles will be gained by pursuing investigations of artificial cavities lying in non-calcareous areas.

SPELEOLOGIC ASPECT OF PACHMARHI (UPPER GONDWANA) SANDSTONE, CENTRAL INDIA

V.K. Verma and V. Ramesh
Department of Geology, University of Delhi,
Delhi-110007 (INDIA)

Introduction

The paper deals with the development of caves in the gently northward dipping and jointed massive coarse-grained interbedded with conglomerate, buff to brown Pachmarhi Sandstones (Upper Gondwana — Triassic), exposed around the hilltown of Pachmarhi (N. Lat. 22°30′ E. Long. 78°26′40″). The landscape around Pachmarhi is dominated by precipitous scarps. Scarps are often affected by cavernous weathering more pronounced at the base, in which the interiors are wasted away, leaving an exterior shell largely intact. In some cases these cavities coalesce. This flaking is similar to negative exfoliation (Twidale, 1966). The tubing and larger tunnels along joint planes are formed presumably by the voidal concretions (Verma, 1971) coalescing.

Caves develop

(a) where strata of contrasted lithologies and hence resistances to weathering and erosion are exposed on the scarp face, or
(b) due to the undermining of the scarp by a basal stream which laterally planates, or
(c) due to the particularly intense weathering near the phreatic zone of the oscillating ground water table.

The most susceptible area for cave formation seems to be the scarp foot (just above the piedmont zone).

Classification of Caves

Based on their genesis, their external geometry, decoration, relation to the litho-structure and position related to landscape, caves are classified as follows:-

i) Caves formed by spring flushing

Spring flushing is a process of subsurface mass wasting. Caves formed by spring flushing (Fig. 1) are generally found localized along zones wherever ground water emerges, and hence can occur at differing heights on the scarp face along joint planes (caves generally flattened along the joint planes and more or less lensoidal in shape) and their intersections with themselves or bedding planes (caves with a more complex outline), along the intersections of lithological discontinuities and contrasted lithologies, such as the conglomeratic beds (caves generally oval in shape with a marked flatter floor).

Geometrically spring flushed caves, 15 to 20 feet at the mouth and up to 50 ft long, are convex outside, and pinching inward. The floor of these caves may however, be flatter and occasionally covered by a thin layer of flushed out sand. The inner portions of these caves are ornamented by dripstone deposits.

ii) Caves formed by laterally corrading streams/lateral planation.

These are very significant in that they are most useful datum reference levels in study the denudational chronology of an area (Ramesh, 1975). Their occurrence indicates former piedmont junctions at the level of planation. They are also found at the scarp foot at the present planation level.

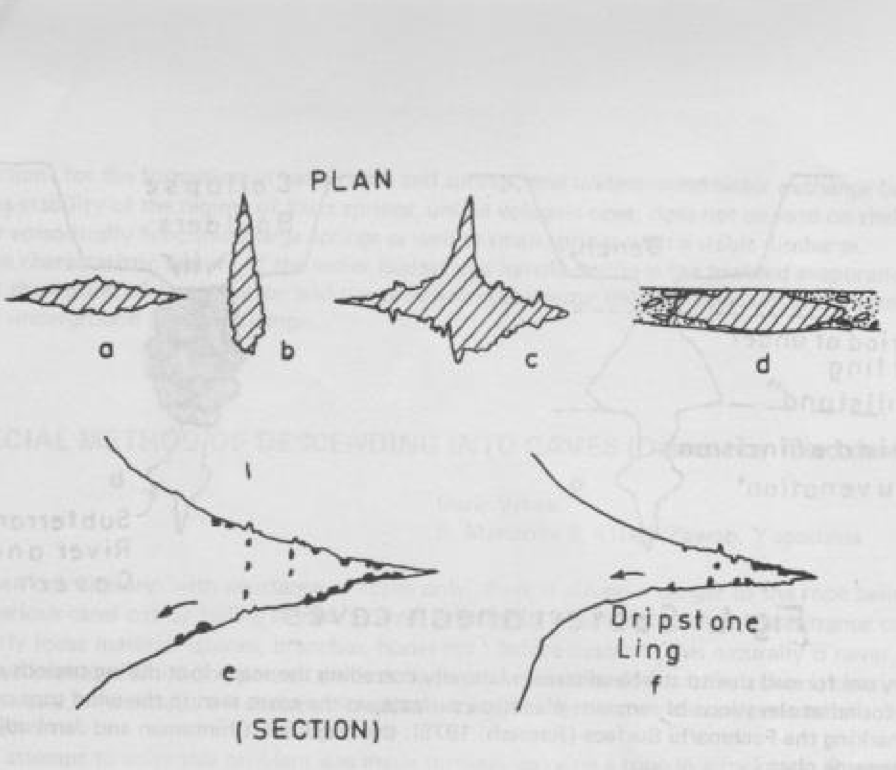


Fig1.Spring flushed caves

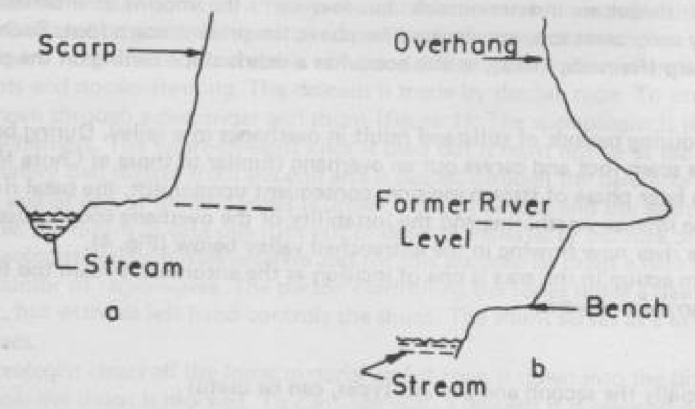


Fig. 2. Basal stream corrasion

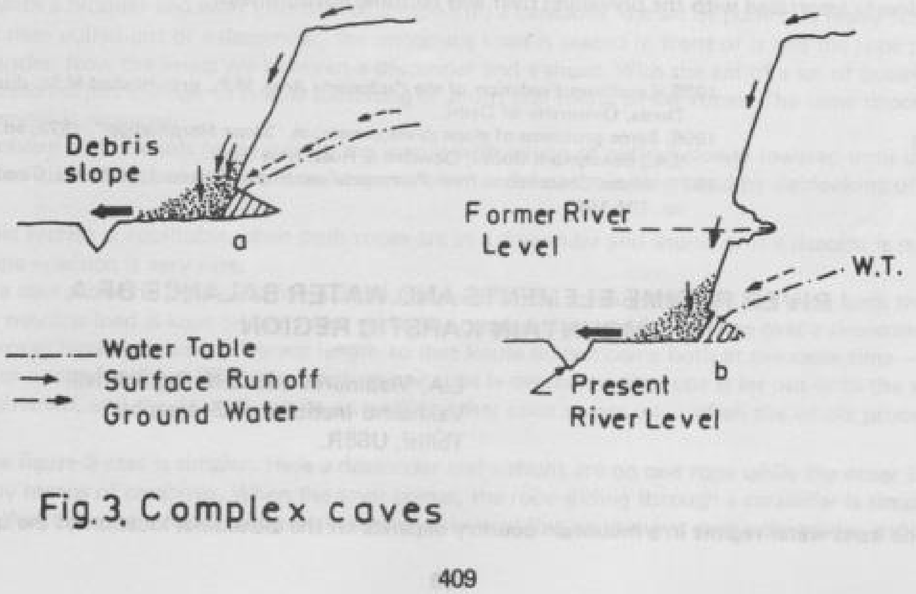


Fig.3. Complex caves

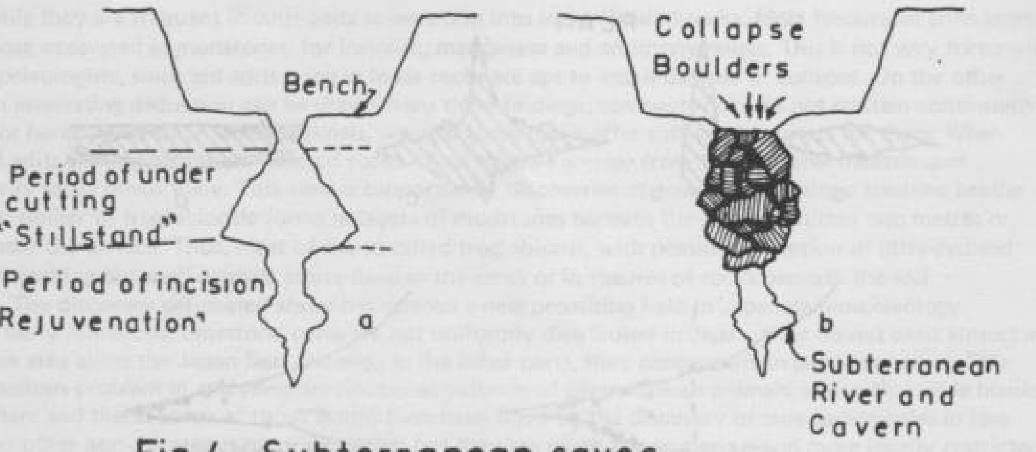


Fig.4. Subterranean caves

They are formed due to the basal stream laterally corrading the scarp foot during periods of stillstand, and thus are found at elevations of remnant planation surfaces, as the caves seen in the wind gaps of the Bainganga river marking the Pachmarhi Surface (Ramesh, 1975); the Nagduari, Chintaman and Jambudip overhangs, are also in the same class.

Geometrically these cave types are laterally elongate (along the course of the river) and typically concave to the outside (Fig. 2).

It is of interest to note that most of these caves are elevated, some 20 to 35 feet above the extant Pachmarhi Surface, indicating the extent of ground lowering since that episode of planation.

iii) Caves formed by the combination of aboves processes: complex caves

Geometrically their shapes are indeterminable, but may carry the imprint of whichever process is dominant. Quite frequently such caves too, are elevated far above the present scarp foot. Such caves (Fig. 3) occur on the Pachmarhi Scarp (Ramesh, 1975), as this scarp has a debris slope resting on the piedmont zone.

iv) Subterranean caves

Lateral planation during periods of stillstand result in overhangs in a valley. During basal sapping the stream impinges against the scarp foot and carves out an overhang (similar to those at Chota Mahadeo, Nagduari and Chintaman). In a later phase of stream incision, consequent upon uplift, the basal river entrenches itself into a gash valley. The intense weathering and the instability of the overhang soon causes collapse and in the process entombs the river now flowing in the entrenched valley below (Fig. 4).

The present stream action in the area is one of incision as the entombed stream too flows entrenched onto the floor of the subterranean cavern.

Conclusions

These caves, especially the second and the last types, can be useful

i) in drawing out the former planation levels, and
ii) to ascertain the ground water table level (since the river level is intimately related to the groundwater regimen).

Further investigations on the dripstone deposits, chromatic marks on the cave walls, direction and nature of cave-scour marks, intimately related to fluctuations in the groundwater level, are being carried out in this area. These are closely associated with the prevailing river and tectonic environment.

References

Ramesh, V. 1975, *Landform Evolution of the Pachmarhi Area*, M.P., unpublished M.Sc. dissertation Thesis, University of Delhi.

Twidale, C.R. 1966, Some problems of slope development; in *"Slope Morphology"*, 1973, ed. Schumm, S.A., Benchmark Books, Dowden & Ross, New York.

Verma, V.K. 1971, Voidal Concretions from Pachmarhi sandstone (Triassic), ***M.P. Intl. Gondwana Symp.*** pp. 191-194.

RIVER REGIME ELEMENTS AND WATER BALANCE OF A MOUNTAIN KARSTIC REGION

L.A. Vladimirov and G.N. Gigineishvili
Vakhushti Institute of Geography
Tbilisi, USSR.

Summary

The karst water regime in a mountain country depends on the altitudinal location of the underground

basin, conditions for the formation of karst rivers and springs, and underground water exchange between basins.

The stability of the regime of karst springs, unlike volcanic ones, does not depend on their discharge. There occur episodically functional large springs as well as small springs with a stable discharge.

The characteristic feature of the water budget in a karstic region is the lowered evaporation in view of the rapid absorption of precipitation and the presence in the water balance equation of the term ± U connected with underground water exchange.

A SPECIAL METHOD OF DESCENDING INTO CAVES (Descent by fixed descender)

Boris Vrbek
B. Maslarica 9, 41000 Zagreb, Yugoslavia

When one explores with assistance of ropes only, there is always a danger of the rope being damaged or in more serious cases cut by falling stones. Normal practice is, of course, to clear the entrance or shelves of loose or nearly loose material (stones, branches, bones etc.) before descent. This naturally is never done after the ropes have been set. While one part of the team is preparing for the descent, the other is clearing the entrance. However, what about the shelves somewhere down the descent which carry potentially dangerous loose material?

An attempt to solve this problem was made through carrying a rope in a rucksack. One end of the rope is tied to the anchor point and the other end goes through a descender and into the rucksack. The rope is gradually fed from the rucksack and in this way a descent is made. This method applies only for a depth of 40 metres as it is awkward to carry more than one rope in a rucksack. There is also a danger of faulty estimation of depth and it can easily happen that one runs out of rope too early. (For that reason the other end must be knotted). However, these experiments did not prove successful.

A solution was found in the use of the F. Petzl descender and F. Petzl shunt in speleology. A double descender is tied to the anchor point by a figure-of-eight knot. A mechanical shunt is attached to the same, or if possible to another anchor point. It has to be somewhat lower than the rope, i.e. nearer to the load than to the descender. (figure 1, a). Firstly, the rope is unwound and placed beside the anchor point to avoid the possibility of knots and nooses forming. The descent is made by double rope. To explain the technics when both ropes are drawn through a descender and shunt (figure 1); The speleologist is tied by both ropes into the seat of a body-harness. The figure-of-eight knot is used but it must not be at the end of the rope. A knot is made approximately two metres from the end and is passed through the carabiner of the seat of a body-harness. The free end of one of the two ropes is drawn through GIBBS and the safety system. This is necessary to enable the return in case one runs out of descent material or because of unforeseen technical hitches. The Speleologist carries a Walkie-talkie and for this purpose he drags a wire which serves as an antenna and conductor of radio-waves. The person controlling the ropes holds a descender as for a normal and usual descent, but with his left hand controls the shunt. The shunt serves as a safeguard which blocks when descent ceases.

The speleologist clears all the loose material and throws it down into the pit while descending. When descent stops, the shunt is blocked. To continue with a descent it is released by pressure on the lever and in this way is deblocked. The descent can be made to any depth allowed by the length of the rope. If the ropes are shorter, for example approx. 40, 45 or 50 metres, they have to be tied together and then one has a problem of knots, since knots cannot pass through descender and shunt. If the ropes are more than 100 metres long, no problem exists.

The ropes are tied by a principle of a complex set of pulleys (St. Bernard & Flaschenzug). (figure 4). The shunt is blocked and a multi-purpose bloquer (Petzl) is placed closer to the load. The carabiner is connected with a bloquer and with insertion of a rope into a carabiner the set of pulleys is ready for use. The rope is then pulled out of a descender, the oncoming knot is placed in front of it and the rope put back into a descender. Now the knots are between a descender and a shunt. With the aid of a set of pulleys the ropes are stretched just enough to enable loosening of shunt and fixing of the ropes. The same procedure as with a descender is repeated.

Problem of the knots being solved, the load is with a help of pulleys slowly lowered until shunt is blocked. After that the set of pulleys is no longer needed and descent is continued by deblocking of the shunt.

This system is applicable when both ropes are in a descender and shunt, or if a descent is made with only one rope — which is very rare.

In a case shown in figure 2 is in question, then we simply let out one rope and keep back the other one. In this way the load is kept on one rope, while the other one is used for moving over a descender and a shunt. The ropes have to be of a different length so that knots do not come both at the same time — which would ask for a set of pulleys. When the knot on one rope is overcome, the rope is let out until the whole system is tightened, and the descent can go on until another knot comes up — when the whole procedure is repeated.

The figure 3 case is simpler. Here a descender and a shunt are on one rope while the other is controlled by means of carabiner. When the knot comes, the rope sliding through a carabiner is simply stopped, so that the other rope is somewhat released thus enabling us to move over a descender and a shunt.

1. a = shunt Petzl; b = descendeur Petzl.

2. White letters = first system; black = second.
a= shunt Petzl; b = descendeur Petzl

3. a = shunt Petzel; b= descendeur Petzel
k = karabiner

4. a = shunt Petzel; b = descenduer Petzel
c = bloquer Petzl

The rope is slowly let out through a carabiner, and when the rope with a descender and shunt is tightened, the descent is continued. During use attention should be paid to sharp rocks. At sharp curves ropes should be protected by plastic tubes or even better by inserting special light pulleys. Figure 2 shows a descent of a same type, except that a separate pair of a descender and shunt is used per rope. Faster overcoming of knots is a considerable advantage of this system, but two men must control the ropes and their work has to be synchronized. It is suitable for thinner ropes because the friction is not so high.

Figure 3 shows a descent by a single rope and a system of a fixed descender with the obligatory second rope for the safety reasons. Its simplicity makes this style most suitable for descending.

It was for the first time used in Yugoslavia on 1/5/1973. during exploration of "Golubinka" pit in the Velebit mountain range and the depth reached was 102 metres.

After Golubinka this system was used in the "Skurjetova gropa" pit down to 123 metres, and finally in certain parts of the "Bunovac II" expedition in 1976., where the depth reached was 445 metres.

THE INFLUENCE OF LITHOLOGY ON JAMAICAN CAVE MORPHOLOGY

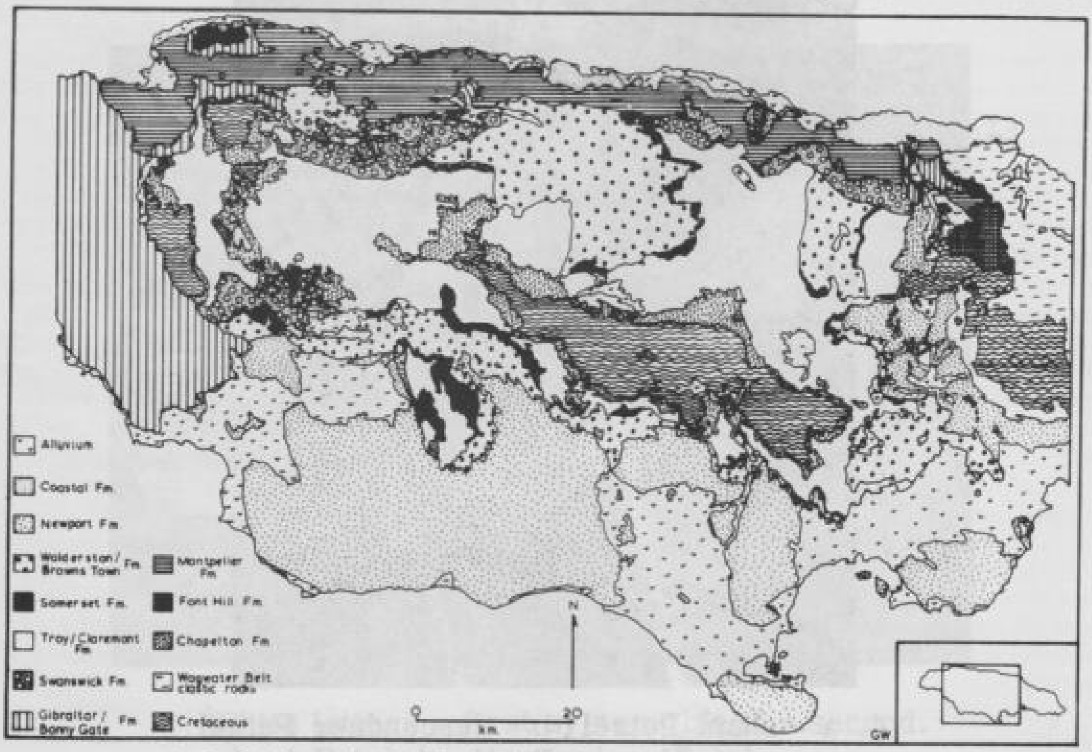
G. Wadge and G. Draper
Geology Dept., University of the West Indies,
Mona, Kingston 7, Jamaica.

Jamaica is one of the classic areas in the study of tropical karst. Caves are an essential feature of the Jamaican karst although much less work has been done on them than on the surface karst of the celebrated 'Cockpit Country', of the north central part of the island. Here we outline the possible influences that the lithology, bedding and jointing of the cavernous limestones has had on cave morphology.

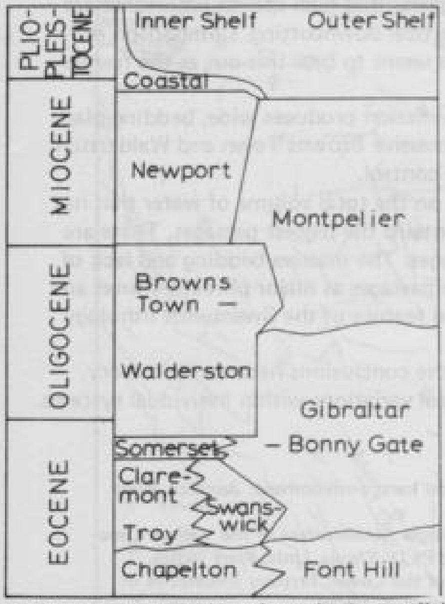
The Jamaican Caving Club has records of over 800 caves, sinks and resurgences within the island (Fincham, in prep). The majority of these are situated in Tertiary limestones in the central area of the island (Fig. 1). Caves are known in similar limestones both east and west of this area but are not considered here. Important caves also occur in the relatively thin limestones within the Cretaceous inliers but these have not been studied in detail.

The subdivision of the Tertiary limestone succession is based mainly on palaeontology and microfacies variations. The stratigraphy used here is essentially that of the Jamaican Geological Survey based on the work of Hose and Versey (1956); Versey (1962); Wright (1968) and others, Fig. 2. Lithological characteristics do vary within most stratigraphic units but a more refined approach based purely on mapped lithologies is not yet possible. The distribution of known cave sites and passage lengths is presented in Figure 3 and indicates that caves have developed preferentially in some limestones. Factors other than lithology alone must contribute to this.

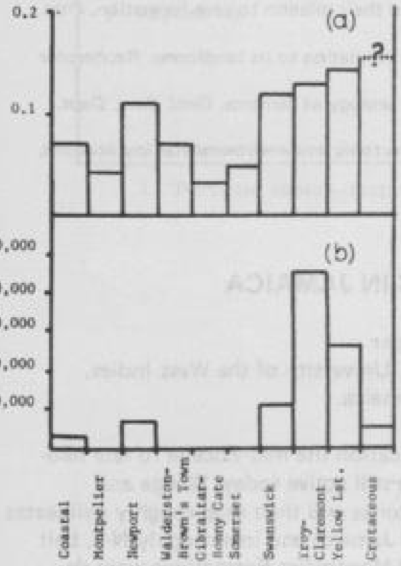
The Tertiary limestones rest unconformably on Cretaceous, mainly non-carbonate, rocks and are divided into two groups and nine formations (Fig. 2). The composition of the two groups is distinct. The White Limestone Group rocks have carbonate contents in excess of 99% (Hughes, 1973, p. 73). The limestones of



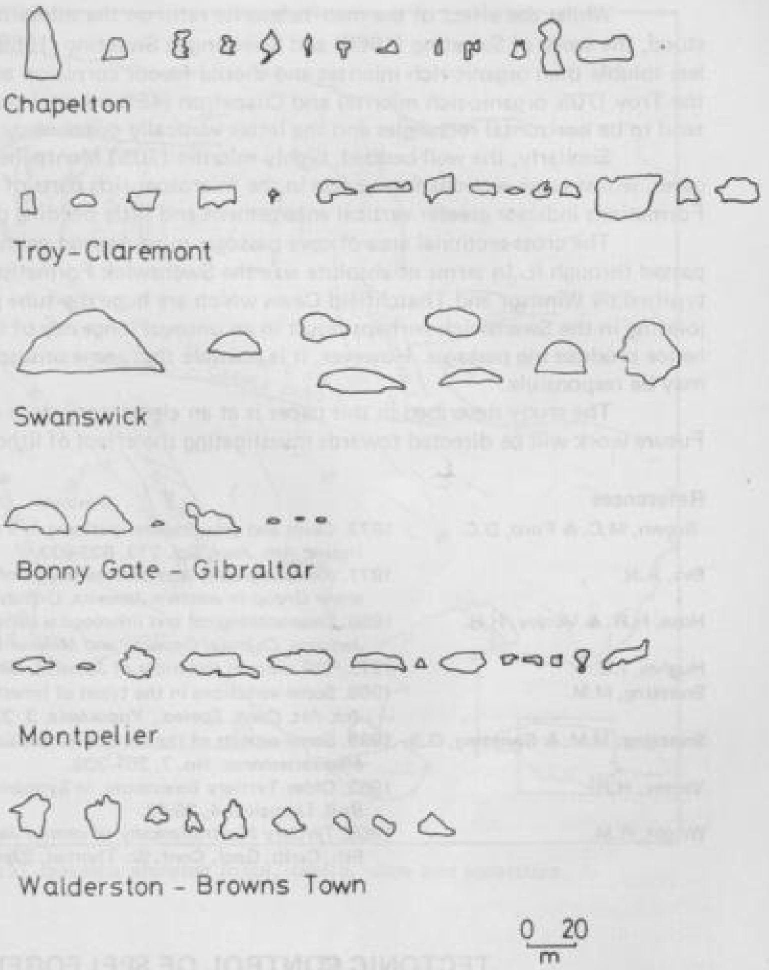
1. Geological map of central Jamaica showing the various Tertiary formations.



2. Schematic stratigraphic column showing parallel development of deep and shallow limestone facies



3. (a) Histogram of the frequency of known cave entrances per km^2 of each formation.
(b) Histogram of the total length of known cave passages in each formation.



4. Representative cross sections from caves in six limestone formations.

the Yellow Limestone Group are less pure with an average carbonate content of 93% (Eva, 1977, p.13). In addition, the Yellow Limestone Group contains appreciable thicknesses of sands and clays, mainly in the middle of the succession. Dolomitisation has been extensive in the Chapelton and Troy-Claremont Formations. In the latter, the dolomite beds are up to several hundred feet thick and tend to have a lower carbonate content of about 98% (Hughes, 1973, p. 70).

A brief survey of what is hoped are fairly representative lithological characteristics of each formation, based on a thin-section study, is presented in Table 1.

The thickness of individual formations are not given as they are laterally variable. Most however, with the exception of the Somerset Formation, are at least 100m thick and in the S.W. the thickness of the Newport Formation is over 1500 m.

Most of the known caves of great length in Jamaica occur in the Troy-Claremont and Chapelton Formations (Fig. 3b). Many of these are associated with the rivers which flow off the Cretaceous inliers and sink on reaching the Chapelton and Troy-Claremont Formations which surround them. Hence the explanation for the preponderance of large total, cave passage length in these rocks is probably stratigraphic and not lithological. In cross-section, some typical examples of which are shown in Figure 4, the caves of the Chapelton and Troy-Claremont Formations are characteristically rectangular, indicating the strong bedding and joint-plane control, both of which are well developed in these rocks. The particularly strong joint control exhibited in the caves of the Mouth River area (Brown & Ford, 1973) at the Chapelton-Troy boundary is due to the large joints developed in these dolomite-rich rocks. In general, the Chapelton Formation caves tend to be higher than wide and show stepped profiles indicative of variable solubility from one bed to another. The more shaly horizons of the Chapelton Formations might be expected to produce lithological perching of passages and although examples of Jamaican cave systems having developed on more than one level are rare, the Bristol-Quashies River system (Brown & Ford, 1973) does have such a perched upper level.

Whilst the effect of the micrite/sparite ratio on the solubility of cave limestones is not fully understood, the work of Sweeting (1968) and Sweeting & Sweeting (1969) suggests that high sparite limestones are less soluble than organic-rich micrites and should favour corrosion and vertical downcutting. Comparison of the Troy (70% organic-rich micrite) and Chapelton (45% micrite) profiles seems to bear this out as the former tend to be horizontal rectangles and the latter vertically orientated.

Similarly, the well-bedded, highly micritic (70%) Montpelier Formation produces wide, bedding-plane caves, whilst cross sections from caves in the microspar-rich parts of the massive Browns Town and Walderston Formations indicate greater vertical enlargement and little bedding plane control.

The cross-sectional area of cave passages must depend primarily on the total volume of water that has passed through it. In terms of absolute size the Swanswick Formation contains the biggest passages. These are typified by Windsor and Thatchfield Caves which are huge dip-tube passages. The massive bedding and lack of jointing in the Swanswick perhaps result in an unusual longevity of single passages as major phreatic routes and hence produce big passages. However, it is possible that some unsuspected feature of the Swanswick lithology may be responsible.

The study described in this paper is at an elementary stage and the conclusions necessarily cursory. Future work will be directed towards investigating the effect of lithological variations within individual systems.

References

Brown, M.C. & Ford, D.C. 1973. Caves and groundwater patterns in a tropical karst environment: Jamaica, West Indies. *Am. Jour. Sci.* 273, 622-633.

Eva, A.N. 1977. *Biostratigraphy and palaeoecology of the larger foraminifera of the Yellow Limestone Group in western Jamaica.* Unpublished Ph.D. Thesis, Univ. West Indies.

Hose, H.R. & Versey, H.R. 1956. Palaeontological and lithological divisions of the Lower Tertiary limestones of Jamaica. *Colonial Geology and Mineral Resources,* 6, 19-39.

Hughes, I.G. 1973. The mineral resources of Jamaica. *Geol. Surv. Dept. Bull.* (Jamaica) 8.

Sweeting, M.M. 1968. Some variations in the types of limestones and their relation to cave formation. *Proc. 4th. Int. Cong. Speleo., Yugoslavia.* 3, 227-232.

Sweeting, M.M. & Sweeting, G.S. 1969. Some aspects of the Carboniferous limestone in relation to its landforms. *Recherches Mediteraneenes,* No. 7, 201-209.

Versey, H.R. 1962. Older Tertiary limestones. *in* Synopsis of the geology of Jamaica. *Geol. Surv. Dept. Bull.* (Jamaica) 4, 26-43.

Wright, R.M. 1968. *Tertiary biostratigraphy of central Jamaica: tectonic and environmental implications.* 5th. Carib. Geol. Conf. St. Thomas. 22pp.

TECTONIC CONTROL OF SPELEOGENESIS IN JAMAICA

G. Wadge and G. Draper
Geology Department, University of the West Indies,
Mona, Kingston 7, Jamaica.

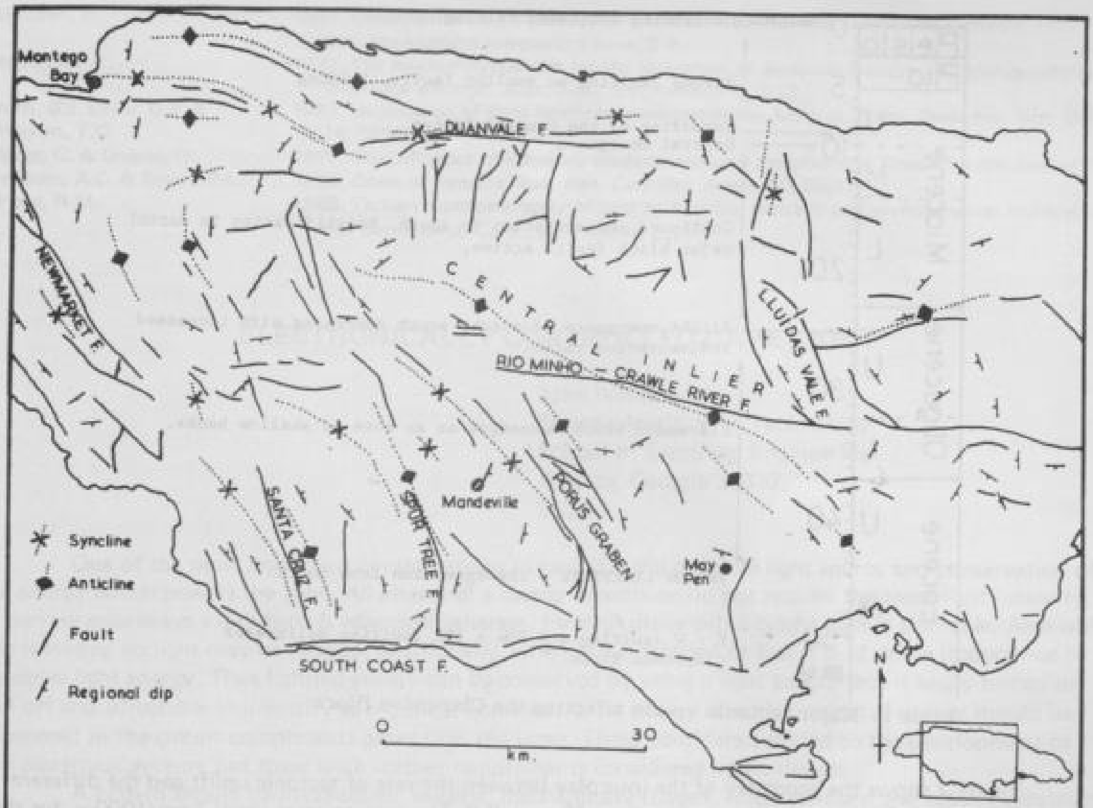
The tectonic processes which have uplifted and exposed to karstification the mid-Eocene to late Miocene limestones, in which the majority of Jamaican caves are developed, are still active today. Wadge and Draper, (1977), have outlined the varied lithologies of these Tertiary limestones and their map roughly delineates two areas of contrasting facies. Along the northern coastal region of central Jamaica and in a roughly N-S. belt to the west, deep water micrites of the Font Hill, Bonny Gate-Gibraltar and Montpelier Formations were deposited, whilst to the south a more varied succession of shallow water shelf limestones was produced. The Clarendon Block, which supports the shallow water facies is fault bounded. The faults to the north (Duanvale Fault system) and west (Santa Cruz — Newmarket fault zone) are the most important speleogenetically. The whole of the block itself is tectonically split into smaller units by the dominant E.-W. (095°) and N.N.W.-S.S.E. (155°) trending faults (Fig. 1).

In broad terms the tectonic history since the Tertiary is well-known (Wright, 1968; Robinson, 1971; and Horsfield, 1973, 1974) and is summarised in Table 1. Horsfield, (1975), presents evidence to suggest that significant rates of uplift of the northern side of the island occur at the present time.

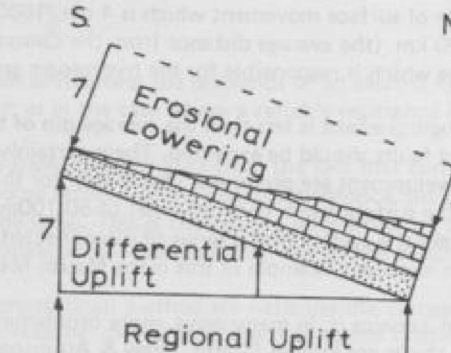
Although strong lineaments in the limestones are easily mapped from aerial photographs, the evidence for the degree and nature of faulting is difficult to assess due to the relatively poor stratigraphical control.

There is surprisingly little evidence of caves being developed along fault planes. The Bristol-Quashies River system (Waltham & Smart, 1975) has a very high gradient for a major river sink and is developed alongside a major fault system, possibly in a small, subsidiary fault. More characteristically, major faults produce large collapse features where they intersect cave passages at high angles. Examples of this are seen in the Cave River system where complete passage collapse at Noisy Water and Second Collapse mark the intersection of two E.-W. faults with the northerly draining river cave and in the potentially connected Riverhead and Worthy Park II Caves which are blocked by huge collapses along a subsidiary of the main Lluidas Vale Fault.

In addition to the faulting a signficant degree of folding was produced by the same tectonic activity. In addition to the major axes of folding (Fig. 1), folding also occurs in the vicinity of major faults. Dips of 40° to 50° are common within a few hundred metres of major fault traces, decreasing to the dips of up to 20° common over large areas between faults. Croft's River is developed in this situation where drainage is parallel to the strike and the resultant pattern of strike passage — dip tube displays some features of Ford's (1971,



1. Tectonic sketch-map of central Jamaica showing folds, faults, dips and localities.



2. Diagram to show the effect of differential uplift and erosion rates on the limestones of the northern Clarendon Block. Rates are in cm/1000 years.

p.89) model of genesis.

The most important type of cave in Jamaica is the very gently graded, large, river passage, fairly straight and simple in plan, flowing approximately down dip. Hydrologic gradients are small, between 1° and 2°30′, whilst explored passage gradients show an even smaller range, 1°30′ to 2°. The reason for these low gradients lies in the interplay between the rates of relative tectonic uplift and the rates of limestone surface solution. Between the Central Inlier, (which is the source of most of the allogenic water) and the north coast, there has been 2000m. of relative uplift of the Cretaceous/Tertiary interface. The longest time period available for this movement is 25 m.y. (Table 1) and this gives a minimum uplift rate of 5cm/1000 y. We are concerned, however, with the relative uplift in the period since the general emergence of the whole Clarendon Block (10m.y. B.P.). As Horsfield (1973), indicates, relative uplift on the Spur Tree Fault in the south must have been at a minimum rate of 8cm./1000 y. over the last 10 m.y., though this takes no account of erosion factors. This fault has the maximum vertical throw in the area and it is suggested that a lower uplift rate for the past 10 m.y. would be more representative of the northern area. A rate of 7 cm/1000 y. of relative uplift is proposed, intermediary between the minimum and maximum possible rates above, for the Central Inlier – north coast region, distributed in both fault displacements and folding.

Epoch	my.	Event
Pleisto	0	Continuing southward tilting?
Plio-	5	Strong faulting on smaller faults. Folding
Miocene U		Unroofing of the Central Inlier
	10	General emergence
Miocene M		
Miocene L	20	Continued sedimentation in south. Karstification in north? Major block faults active.
Oligocene U		Slight emergence of north, south depressed with increased sedimentation rates.
	30	
Oligocene L		Clarendon block submerged as an area of shallow banks.
Eocene U	40	
Eocene M		YELLOW LIMESTONE - transgression from south.
	50	E - W faulting and NNW - SSE faulting delineates Clarendon Block.

Table 1. Major tectonic events affecting the Clarendon Block.

Figure 2 shows the geometry of the interplay between the rate of tectonic uplift and the different rates of lowering of the limestone by erosion since 10 m.y. B.P. The erosion rates used; 7 cm/1000 y. for the uplifted central areas with high rainfall, and 4 cm/1000 y. for the northern coastal areas, are those calculated by Smith (1971) for the present day in north central Jamaica. Greater differences in rainfall and hence erosion rate exist at the present time than is indicated by these two rates (20"/y), but the difference in erosion rates would have been less when relative uplift first began. Hence from this model the relief of the eroded land surface will be determined by the net rate of surface movement which is 4 cm./1000 y. In 10 m.y. the total uplift will be 400m. over a distance of 20 km. (the average distance from the Central Inlier to the Duanvale Fault), which is a slope of 1°9'. It is this slope which is responsible for the hydrologic gradients of the present day river caves.

In those caves where hydrologic gradient is less than the average dip of the bedding, evidence of phreatic 'lift' passages along joints and faults should be expected. These certainly exist but few fossilised examples of any great length and strong development are preserved. One reason for this may well be that rapid surface lowering by erosion means that the surface karst 'cockpit' relief of 50-100m. soon intersects the near parallel course of the cave passage and breaks the system into a series of disconnected fragmentary passages occurring only in the inter-cockpit hills. An excellent example of this is the Mouth Maze system (Brown & Ford, 1972).

Vertical cave development in Jamaica is, in many ways, more problematic than that for subhorizontal systems. A great number of 'cockpit' shafts are known (Smith, Drew & Atkinson, 1972), most of which probably have some type of Pohl cell origin, whilst a smaller number of shafts are of undoubted collapse origin. More intriguing are the significant number of caves with mixed vertical and horizontal development, (e.g. Gourie and New Hall Caves). These caves seem to be concentrated in specific areas and the area around the Porus graben is particularly favoured with its many faults and steep hydrologic gradients. Some caves in this area are clearly abandoned vadose systems descending very rapidly in a series of shafts, e.g. New Hall Cave. It is highly unlikely, however, than an allogenic stream from any of the inliers was responsible for this example or indeed has ever reached much of the large N.N.W. — faulted blocks of Newport Limestone in the south of the island. The ideas of Comer (1974) who pointed out that thin beds (1 - 0.1m) of Upper Miocene bentonitic clays of volcanic origin could have provided the source for the bauxite deposits which rest on large areas of the limestone provide an attractive solution to the problem. These thin impermeable layers near the top of the limestones could provide sufficient concentration of surface drainage to account for the observed steep vadose development.

References

Brown, M.C. & Ford, D.C. 1973. Caves and groundwater patterns in a tropical karst environment: Jamaica, West Indies. *Am. Jour. Sci.* 273, 622-633.

Comer, J.B. 1974. The genesis of Jamaican bauxite. Econ. Geol. *69*, 1251-1264.

Ford, D.C. 1971. Geologic structure and a new explanation of limestone cavern genesis. *Trans. Cave Res. Grp. G.B.*, 13, 81-84.

Horsfield, W.T. 1973. Late Tertiary and Quaternary crustal movements in Jamaica. *Jour. Geol. Soc. Jamaica*, 13, 6-13.

1975. Quaternary vertical movements in the greater Antilles. Bull. Geol. Soc. Am.*86*, 933-938.

Robinson, E. 1971. Observation on the geology of Jamaican bauxite. *Jour. Geol. Soc. Jamaica,* 1st. Bauxite/Alumina symposium issue, 3-9.

Smith, D.I., 1971. The residual hypothesis for the formation of Jamaican bauxite – a consideration of limestone solution. *Jour. Geol. Soc. Jamaica* II, 3-12.

Smith, D.I. Drew, D.P. & Atkinson, T.C. 1972. Hypotheses of karst landform development in Jamaica, *Trans. Cave. Res. Grp. G.B.* 14, 159-173.

Wadge, G. & Draper, G. 1977. The influence of lithology on Jamaican cave morphology. *Trans. 7th Int. Speleo. Conf.*

Waltham, A.C. & Smart, P.L. 1975. Caves of Jamaica. *Bull. Brit. Cave Res. Assoc.* 10, 25-31.

Wright, R.M. 1968. *Tertiary biostratigraphy of central Jamaica: tectonic and environmental implications.* 5th Carib. Geol. Conf., St. Thomas. 22pp.

ELECTRONICALLY CONTROLLED CAVE LIGHT

John Wallace
Georgia Institute of Technology
School of Electrical Engineering
Atlanta, Georgia 30332,
U.S.A.

One of the most important considerations in caving is the personal light source and conservation of the energy which powers the light. All phases of a caving expedition do not require the same light intensity. In narrow crawlways a dim light is adequate; whereas, for high dome pits a bright light is desirable. Also while one is resting no light may be needed; additionally, when one is trapped or lost it is of prime importance to conserve light energy. Thus lighting energy can be conserved by using a light source that is easily turned on and off and adjustable in intensity as required. However, to be energy effective, minimal energy should be consumed in the circuit components other than the lamp. These considerations led to the development of this electronic system, but there were further requirements considered in the design.

A system should be inexpensive, reliable, mechanically rugged, water resistant and readily constructed from easily available components by the home builder. In order to minimize the mechanical work it should be adaptable to inexpensive commercial head lamps, and it should utilize lamps and batteries suitable for caving. The foregoing objectives were largely met using a 6-volt solid state switching circuit mounted in a Justrite (U.S. manufacture) head lamp. The cost of the circuit components (less the printed circuit board) is about $4.

Theory

The principal problem in reducing the brilliance of an electric light is that for some schemes no significant energy saving is realized; as in the case where a variable resistance is used in series with the lamp and battery.

The disadvantages of such a system arise from the fact that current flow in any circuit resistance gives rise to power loss. Thus, for some settings of the variable resistance, the power loss in the resistance is greater than the power delivered to the lamp. This is obviously a poor situation since we really want all the power delivered by the battery to be converted to light (actually, not all the electrical power to the lamp is converted to light).

An alternative (but impractical) method for reducing the average power to the lamp is to connect a switch in place of the variable resistor, then alternately closing and opening the switch very rapidly. If the switch is closed four-tenths of the time and open six-tenths of the time, only 40% of the full-ON electrical power would go to the lamp, thus the brilliance of the lamp is correspondingly reduced. Since there is no power loss in the switch, this scheme is 100% efficient. But, clearly, opening and closing the switch manually is impractical.

In a practical system the function of the switch is performed by a transistor which can be operated to behave very much like the switch. The transistor is a three terminal device, as shown in Figure 1; the three terminals are identified as collector (C), emitter (E), and base (B). The small base current, I_B, controls the collector current, I_C, which is typically 100 times larger than base current. The collector characteristics in Figure 1b show how I_B and I_C are related. For example, when the base current is 1 mA the collector current is 100 mA. Now if a resistance, such as a lamp, is included in the collector circuit, the effect of the lamp may be accounted for by drawing the "load line" on the collector characteristics, Figure 1b. With a load as shown, when the base current is 5 mA, operation occurs at A where $V_{CE} = 0.4$ V and $I_C = 500$ mA; on the other hand, when base current is zero operation is at B where $V_{CE} = 6$V and $I_C = 0$. The lamp would be on at A since current flows in the circuit, and off at B since no current flows. Since the power loss in the transistor is V_{CE} times I_C, it is nearly zero at both B and A, whereas the power would be much larger at operating points between A and B. The technique, then, is to switch between points A and B by switching the base current. So that if operation is at A 40% of the time and at B 60% of the time., approximately 40% of the full electrical power would go to the lamp, Thus, if the base current "duty cycle" can be varied, the lamp intensity can be varied.

The transistor in the foregoing description is an n-p-n type while the transistor in the actual circuit is a p-n-p type, but the operating principles are identical. The base current and its adjustable duty cycle feature is derived from the cross-coupled NOR gates of the CD4002AE seen in Figure 2; adjustment of the 1 megohm

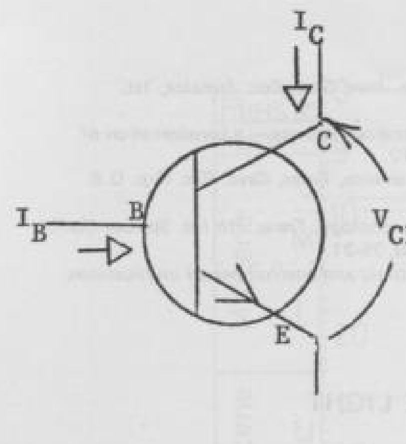
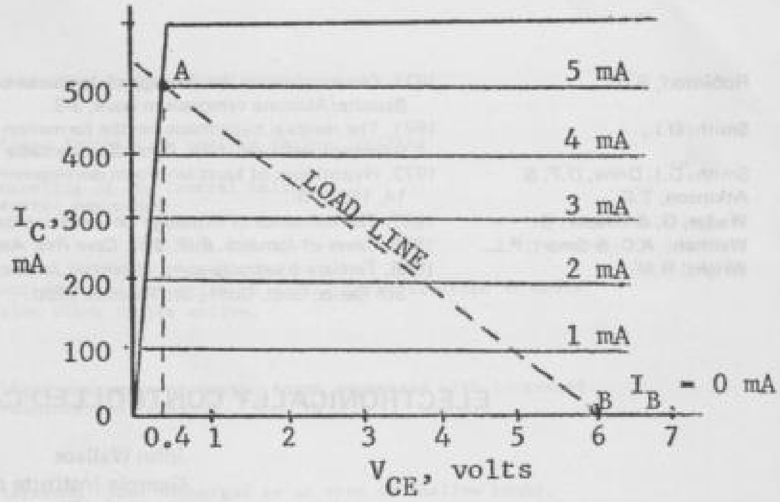


Figure 1

a. Transistor



b. Transistor characteristics curves with load line

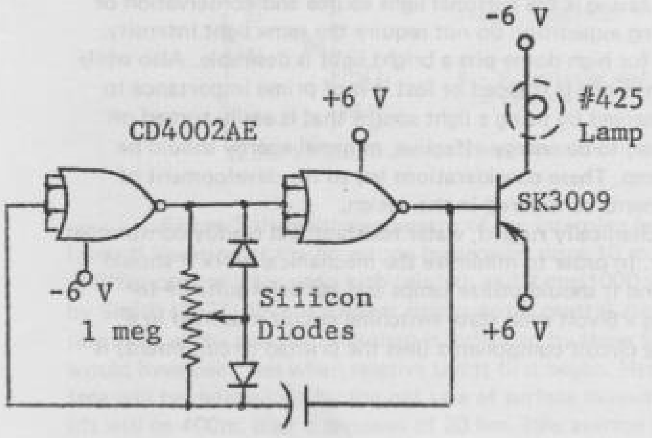


Figure 2 The circuit

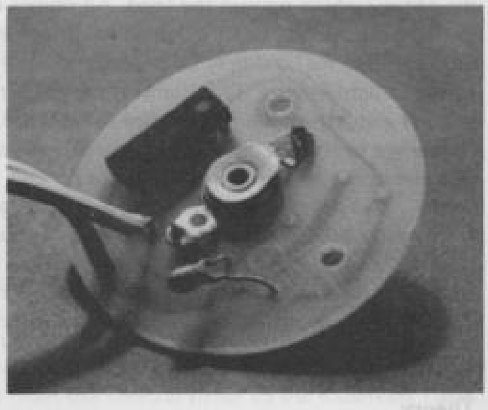


Figure 3

Rear view of the printed circuit board with mounted components

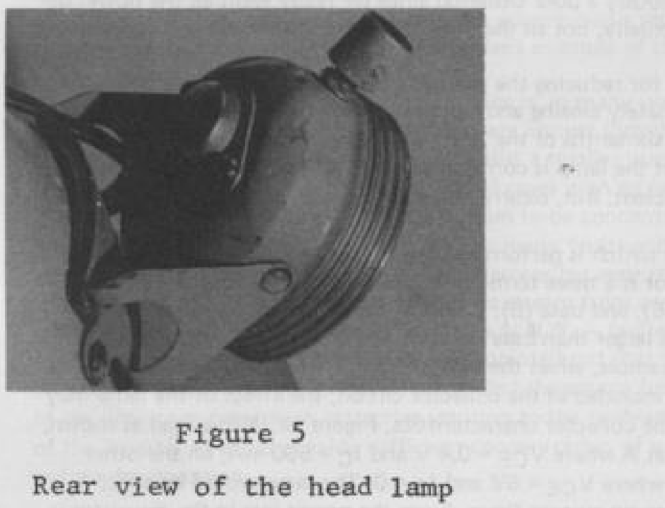


Figure 5

Rear view of the head lamp

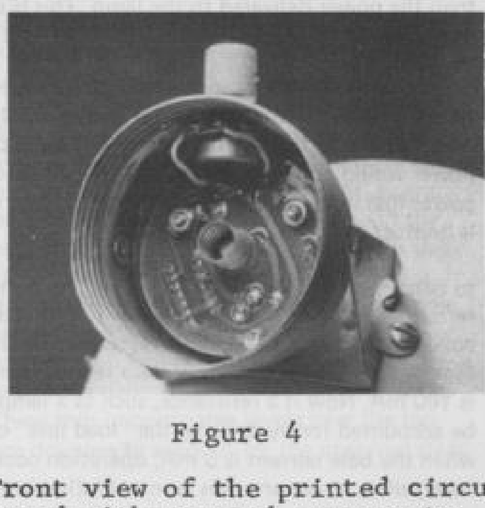


Figure 4

Front view of the printed circuit board with mounted components

potentiometer varies the duty cycle of the current from the driving circuit. The transistor is necessary since the CD4002 is not capable of supplying adequate current to the lamp.

The high efficiency on one hand results from the small current that the circuit requires; less than 0.8 mA over its entire range. On the other hand the power transistor which drives the lamp is operated in a switching mode which minimizes the power loss in the transistor.

System

The circuit was mechanically configured to be built into a Justrite 1904-4 head lamp, one of the more popular commercially manufactured outfits used in the U.S. However, the system can be adapted to fit other commercial or homebuilt systems.

The capacitor, integrated circuit and lamp socket are soldered directly to the back of the printed circuit as seen in Figure 3.

The potentiometer with diodes soldered directly to the terminals goes into the hole left after the removal of the switch from the original head lamp shell as seen in Figure 4.–

The power transistor is screwed to the rear of the lamp shell (as seen in Figure 5) with its base and emitter connections protruding into the lamp shell where they are soldered to the printed circuit board. The latter connections also solder to the circuit board via a wire which leads through the hard hat to a belt-mounted battery pack.

Results

As expected the actual operating characteristics were not ideal. First, there was a small drop across the transistor during its ON period; however, with a 5.6 volt lead acid battery it was less than 0.1 volts. Secondly, the total system required somewhat more average current than the lamp alone. The total current to the circuit, at maximum duty cycle was 450 mA, while of that 440 mA was lamp current. At minimum duty cycle (lamp off), the total current was 0.7 mA.

Environmental Considerations

Shock: No tests have been made to evaluate the circuit's shock resistance; however, no fragile elements are involved in the circuit so it is expected it should be as shock-resistant as the lamp.

Temperature: No change in operation is noted after two hours at -13°C. No observations have been made in the high temperature domain, but no difficulty is anticipated for normally encountered cave temperatures.

Moisture: As with any electric light its susceptibility to malfunction by splattered water, as from a waterfall, is remote. No tests have been made with the circuit totally immersed as the success of such a test largely depends upon the conductivity of the water. Although on one occasion it did perform when submerged in a pool.

Low battery voltage: CMOS integrated circuits, such as the CD4002AE are rated for operation from 3 to 15 volts; the circuit should operate over this range with due consideration for the type of lamp used. The prototype circuit operated successfully, but probably with reduced efficiency, at 4½ volts.

CAVE DEVELOPMENT AT THE BASE OF THE LIMESTONE IN YORKSHIRE

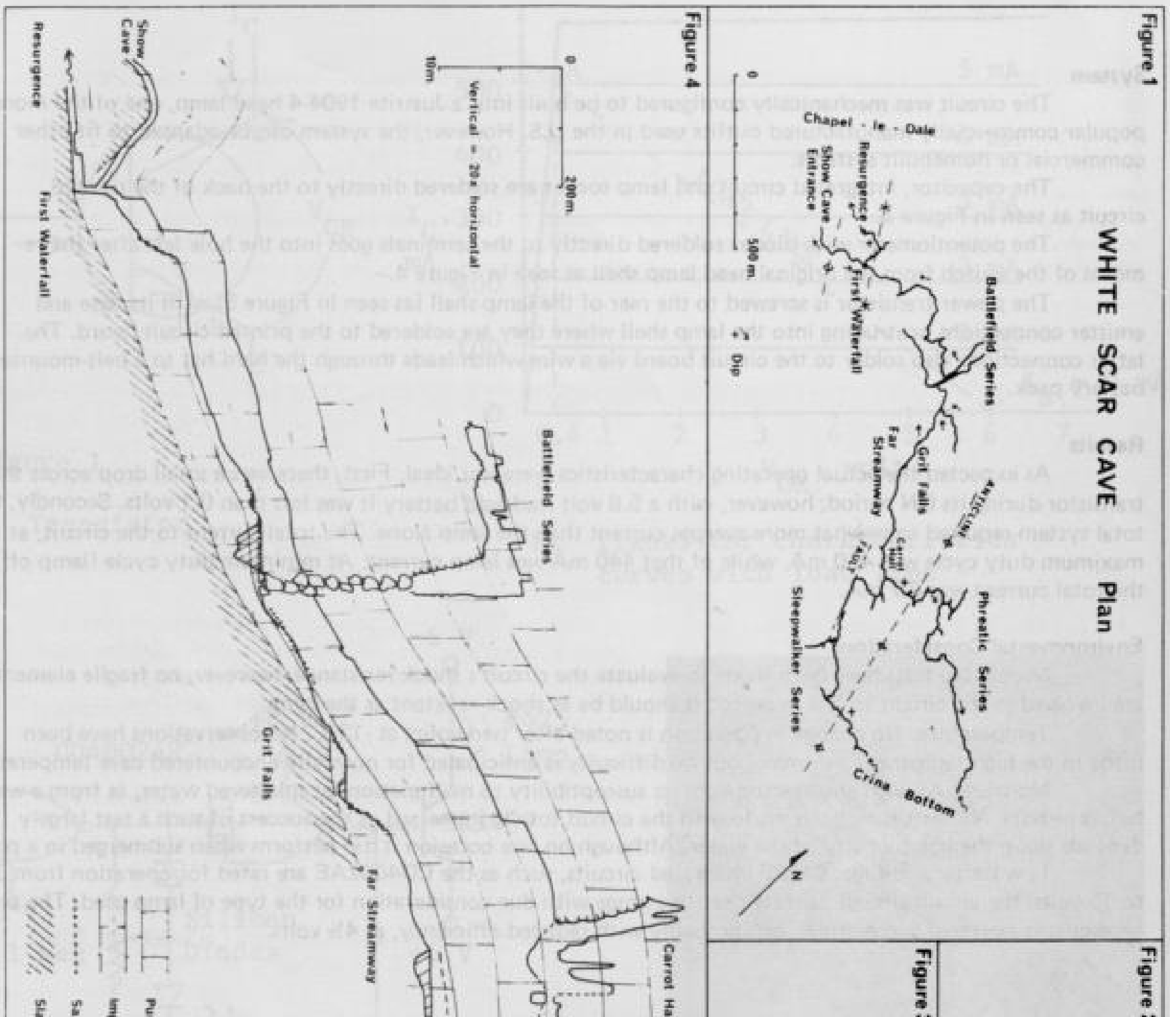
A.C. Waltham
Trent Polytechnic, Nottingham, England.

The Great Scar Limestone lies nearly horizontally on the impermeable basement of the Askrigg Block in North-west Yorkshire. It is a 100-200 metre thick unit of massively jointed bioclastic calcilutites with thin shale beds. Wide limestone benches, exposed in the Pleistocene, are overlooked by shale hills feeding water into sinkholes and an extensive series of vadose and phreatic, old and young, caves (Waltham, 1970). Beneath the limestone is an unconformable series of slates, and much water resurges at springs along the unconformity outcrops near the floors of glacial valleys which have cut down to this level.

This simplified picture, of water collection on the base of the limestone, does hold true on the general scale, but in detail the situation is more complex. The base of the limestone is an undulating surface representing a drowned pre-Carboniferous landmass, and the lowest 20 metres of the succession contains many shales, sandstones and conglomerates which formed during the early Carboniferous marine invasion. These non-carbonate beds account for the presence of many springs a few metres or more above the base of the limestone. It has long been suggested (Waltham 1971; Halliwell et al 1975) that ridges in the sub-Carboniferous unconformity could influence the deep hydrological circulation by acting as subterranean watersheds, but the situation is then complicated by the subsequent concentration of cave development in the unconformity troughs, where the clastic beds, due to their origin, are at maxima.

White Scar Cave is unique in the Yorkshire Dales as it is the only long series of cave passages accessible in a resurgence system which is on the base of the limestone. Study in the cave could only start in 1975, and the preliminary geological work to date has already inferred some unusual features. The cave passages are of two major types. A pre-glacial series of abandoned phreatic caves are only now seen in segments explored as far as major clastic blockages or collapse zones (figure 2). The Battlefield Series appear to have been formed by water from Chapel-le-Dale, while the Sleepwalker Series and branches, totally blocked downstream of Carrot Hall, carried water from the pre-glacial Crina Bottom. Following glacial excavation of Chapel-le-Dale, a series of interglacial and postglacial vadose passages developed (figure 3). These canyons can be traced upstream to nick points where the water flows from the preglacial phreatic tubes which are still active and only partly drained beyond.

Excepting a few avens, the whole known cave is formed in the lowest 30 metres of the Great Scar Limestone. The basal unconformity is only revealed in the various outlets downstream of First Waterfall, and in a single tiny inlier at Grit Falls. The lowest 15 metres of the succession contains a high proportion of clastic beds, mainly shale, with sandstone and conglomeratic limestone. There is considerable lateral variation and the un-



conformity transgresses the lowest beds to a height of about five metres. Above the 15 metre level, the limestones are pure with only thin shale beds. The regional dip of the limestone is northerly and rarely more than a few degrees, but is interrupted by shallow folds. There appears to be a plunging anticline crossed by the upper reaches of the cave (figure 1) though its axis orientation is uncertain. In most of the cave the dip is north-west but there are more small folds in the entrance series. Though it would seem likely that such folds were formed by compaction over basement ridges, the Grit Falls inlier appears unrelated to the fold pattern, so at present no postulation of the shape of the unconformity can be made.

The phreatic caves are all developed in the pure limestones just above the impure basal beds. Battlefield Series shows no relationship to structure, and the upstream series passages follow the bedding up and over an anticline (figure 4) finding the shortest sink to rising route regardless of structure.

There is little collapse in the Phreatic Series, and the phreatic tube can be seen to change beds at various points for no apparent reason and is enlarged on all the joints. The plan form of the phreatic caves is not influenced by the joints, and only along one section of Sleepwalker Series is the cave guided by a prominent fault.

The vadose canyons have cut down into the impure basement beds and there has not been extensive roof collapse. Only downstream of First Waterfall has the initial development been on the unconformity (figure 4). Hence even in the vadose zone the bulk of cave development is not at the base of the limestone. Downstream of where the roof, and site of initial development, were influenced by pre-existing phreatic caves, the vadose streamway was initiated on the thin shale and sandstone beds, for most of the cave's length on one horizon. Two steps downwards in the lower end of the cave took the initial pathway into a short phreatic zone ponded by the lift over the anticline and basement ridge in the show cave entrance passage. Subsequent development in the adjacent syncline axis has formed the modern wholly vadose route to the resurgence. The major clastic beds in the limestone have formed ledges in the cave and have controlled passage cross sections, but have had almost no influence in the long profile. None of the three flights of potholes is located across clastic beds. The ridge in the basement is also ignored by the cave development except for the 10 centimetre high cascade of Grit Falls. The overall plan of the vadose cave does however appear to be roughly down a strong set of joints which have deflected Far Streamway clockwise from true dip.

In conclusion, though both phreatic and vadose development in White Scar Cave does show a strong relationship to geology, it does not appear to be influenced by the impermeable base of the limestone as strongly as is inferred by the over-simplified, classical, hydrological model.

References

Halliwell, R.A., Cavanagh A.M. Pitty, A.F. 1975. The influence of the pre-Carboniferous basement rocks on karst development in the Ingleborough area of N.W. Yorkshire. *Proc. Internat. Symp. on Karst Denudation*, p.161-163, University of Ljubljana.

Waltham, A.C. 1970. Cave development in the limestone of the Ingleborough district. *Geog. Journ.* v.136, p. 574-585.

Waltham, A.C. 1971. Controlling factors in the development of caves. *Trans. Cave Res. Gp. G.B.* v.13, p. 73-80.

CHRONOLOGY OF CAVE DEVELOPMENT IN THE YORKSHIRE DALES, ENGLAND

A.C. Waltham
Trent Polytechnic, Nottingham, England.

R.S. Harmon
Michigan State University, U.S.A.

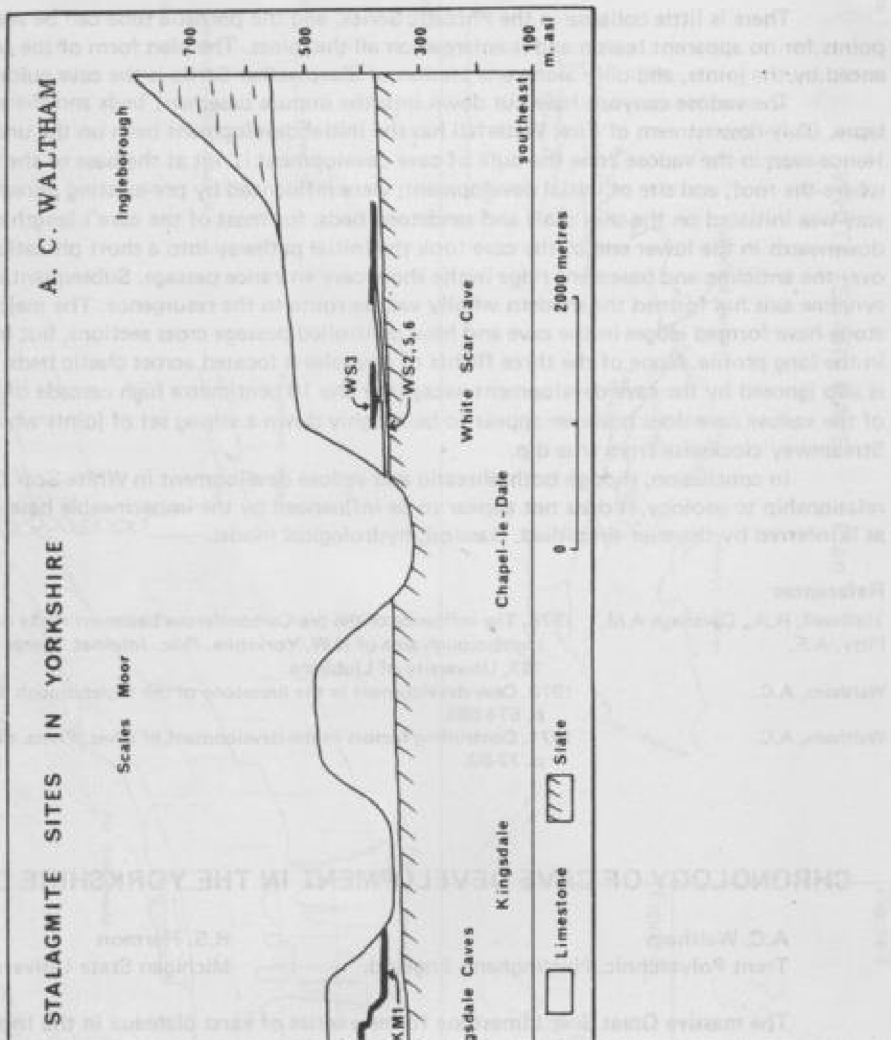
The massive Great Scar Limestone forms a series of karst plateaux in the Ingleborough region, separated by the glacially modified Yorkshire Dales which have cut down to an impermeable base beneath the limestone. The existence of impermeable rocks beyond the Craven Faults, across the southern margin of the karst, ensures that the limestones would be permanently flooded without drainage into the Dales which cut into the limestone and out across the fault zone. Numerous caves have been formed, both by streams flowing off shale hills which rest on the limestone platforms and also by sub-Dale drainage.

Essentially, there are two main groups of caves of contrasting age (Waltham, 1970). Segments of old abandoned passages contain extensive fills of clastic material and calcite, and are mostly fossil phreatic tubes, though some related high level vadose passages do occur. The younger caves carry the modern drainage and contain limited amounts of either clastic of calcite fill. Most known modern caves are vadose, but active phreatic caves have been explored by divers.

The fact that many phreatic tubes of the older series lie 50 metres or so above modern low level vadose caves indicates that a major rejuvenation separates the two main phases of cave development. Similarly, the perching of phreatic tubes above the floors of the adjacent Dales, which themselves are the modern base level for the caves, suggests that this rejuvenation was a function of the valley excavation. Without any firm evidence, this rejuvenation and valley incision has long been ascribed to the Pleistocene glaciations, and a fairly well developed relative time scale has been determined for some of the cave systems and their adjacent Dales (in Waltham, 1974).

It has only been possible to establish an absolute chronology for the Yorkshire caves since a framework of dates has been provided by isotopic age determinations of calcite stalagmites from within the caves. The uranium isotope concentrations were determined, and the ages calculated from them, at Michigan State University, following a procedure slightly modified from that described by Harmon et al (1975). At present, thirteen ages have been determined and allow some preliminary comments to be made, but it is hoped to confirm these with a future planned programme of sampling and analysis.

As shown in table 1, all but three of the measured stalagmite ages fall into two distinct groups. An age range from 14,000 to 2500 years B.P. encompasses six of the specimens and clearly indicates major post-glacial (Flandrian) deposition. A range of 131,000 to 90,000 years encloses four more samples and corresponds well with a depositional phase in the Ipswichian interglacial period. The top of specimen Y3 stands along at 60,000 years which dates in the Chelford interstadial. The age of WS5, 225,000 years, correlates with the Hoxnian interglacial, and the age of KM1, at over 350,000 years, would probably place it in the warm phase of the Cromerian. The figures therefore suggest that, within the statistical limits imposed by the small number of samples solutional activity was restricted to warmer periods before, between and after the main glaciations, during which solutional activity ceased. Most dated stalagmites rest on thick clastic sediments which were probably washed into the



caves during periods of intensive mechanical surface weathering under periglacial conditions just proceeding or following a glacial coverage. The freshness of the limestone pavements and some moraine features suggest that the Dales were glaciated as late as the Devensian, and there were no prolonged periods of purely periglacial activity during the cold phase.

Sample KM1 is from a flowstone layer in an old phreatic tunnel, and WS5 is from a vadose cave just be-

Sample	Location			Age (Years B.P.)	Possible error	Stage
GP2	Gavel Pot, Glasfurd's Passage			14,000	∓ 9000	Flandrian
GP3	"	"		6,000	∓ 1000	Flandrian
Y1	"	"		131,000	∓ 18000	Ipswichian
Y3	"	"	top layer	61,000	∓ 4000	Chelford
			middle layer	92,000	∓ 5000	Ipswichian
			bottom layer	112,000	∓ 5000	Ipswichian
KM1	Kingsdale Master Cave, Roof Tunnel			350,000	+ ?	? Cromerian
WS2	White Scar Cave, Main Streamway		top layer	13,000	∓ 7000	Flandrian
			bottom layer	contaminated		
WS3	"	Battlefield	top layer	2,500	∓ 1500	Flandrian
			middle layer	6,000	∓ 2000	Flandrian
			bottom layer	90,000	∓ 11000	Ipswichian
WS5	"	Main Streamway		225,000	+ 75000/–45000	Hoxnian
WS6	"	"		14,000	∓ 4000	Flandrian

TABLE 1 ISOTOPIC AGE DETERMINATION OF YORKSHIRE STALAGMITES

neath a similar old phreatic tube. Both these samples therefore post-date the drainage of the earlier phreatic caves as a result of rejuvenation which, owing to the nature of the Craven Faults, can only have been accompanied by the excavation of the Dales. Both samples lay close to present floor levels of the Dales, and therefore indicate that the Dales were cut very nearly to their present thalwegs by Anglian times at the latest, and in the case of KM1 by the Beestonian stage (though the relative proportions of preglacial fluvial erosion or valley glacier erosion cannot yet be determined). The formation of the extensive, large diameter, old phreatic caves must therefore be essentially preglacial — either Cromerian or Pastonian at the latest.

Within the younger caves of interglacial and post-glacial age, morphological relationships of successive phases of vadose and phreatic passages indicate a descending sequence of resurgence levels which may be correlated with contemporaneous valley floor levels. This periodic valley deepening was probably glacial, while cave development continued in each of the post-Anglian warm periods. The transitional periglacial phases then saw the partial clastic filling of the caves with subsequent re-excavation in the active passages but preservation in the old fossil systems.

References

Harmon, R.S. Thompson, P. Schwarcz H.P., & Ford. D.C. 1975. Uranium series dating of speleothems. *Bull. Nat. Spel. Soc.*, v.37, p. 21-33.

Waltham, A.C. 1970. Cave development in the limestone of the Ingleborough district. *Geog. Journ.*, v.136, p. 574-585.

Waltham, A.C. (editor) 1975. *Limestones and caves of Northwest England.* David and Charles, Newton Abbott, 477pp.

CONTROL OF LOCOMOTION ACTIVITY IN TROGLOBITE BEETLES
(Aphaenops, Geotrechus, Speonomus) *

Friedrich Weber
Zoologisches Institut der Universität
D-44 Münster (Westf)
Bade-Strasse 9, W. Germany

* Supported by Deutsches Forschungs Gemeinschaft

With regard to their behaviour in time the cavernicolous animals which have so far been investigated can be classified in a scheme exemplifying regressive evolution.

1. Troglophile species with an intact circadian clock operating in DD (dark) as well as in LL (light) and LD (light-dark). Examples: the carabid beetles *Laemostenus terricola* and *oblongus*[1].

2. Troglobite species with a circadian clock operating only in LL and LD, whereas in DD stochastic activity patterns predominate, e.g. the probably blind carabid beetle *Laemostenus navarricus*[1]. Whether the crayfish *Orconectes sp* belongs to step 2 is unknown[2].

3. Blind troglobite species without a self-sustained clock but with the capability for damped

oscillations of activity after a transmission from LD to DD or LL. When the oscillations have damped out, the animals' activity is stochastically distributed e.g. the blind cave fish *Anoptichthys jordani*[3].

4. Blind troglobite species without self- or foreign-sustained oscillations of activity. Reactions in L-D oscillations still exist. e.g. the cavernicolous amphipode *Niphargus*[4, 5]. Whether the animals' activity is stochastically distributed is not investigated.

5. Blind trogobite species without oscillations of activity under constant conditions or in LD's. Only changes in temperature induce a periodicity of locomotion. Examples: beetles of the genera *Aphaenops, Geotrechus* and *Speonomus* (tab. 1). The activity patterns are stochastically structured: neither periodical com-

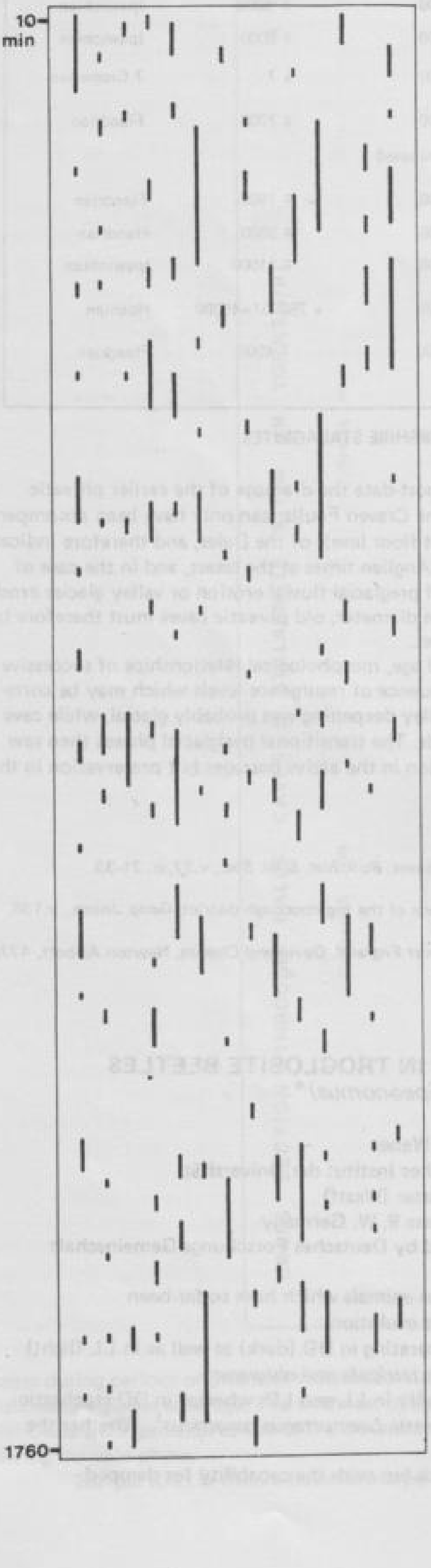


Fig. 1. Specimens of Aphaenops pluto at 9°C. Read the actogram vertically from top to bottom. The unit of measurement is 10 min. The black lines are activity bursts. The length of the actogram has no significance.

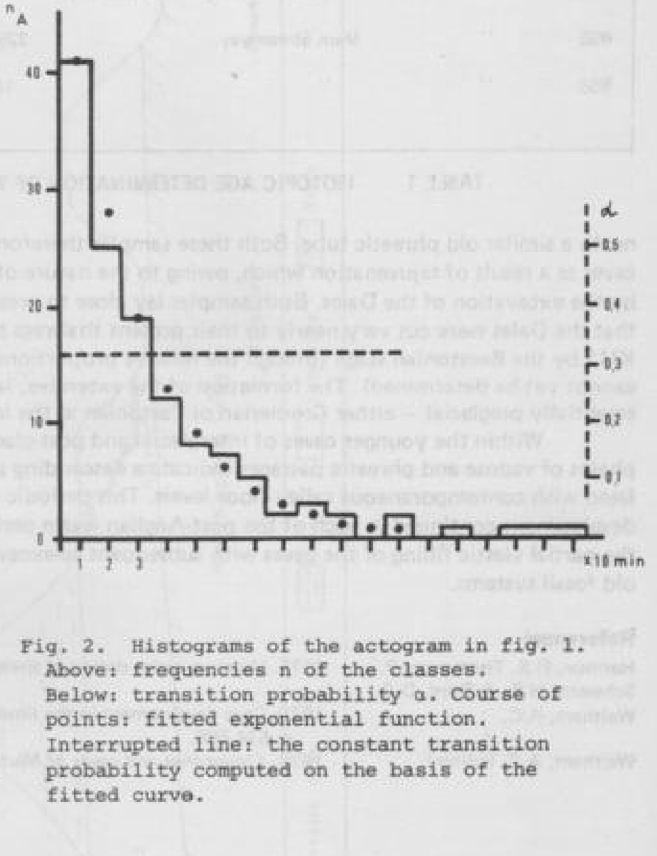


Fig. 2. Histograms of the actogram in fig. 1. Above: frequencies n of the classes. Below: transition probability α. Course of points: fitted exponential function. Interrupted line: the constant transition probability computed on the basis of the fitted curve.

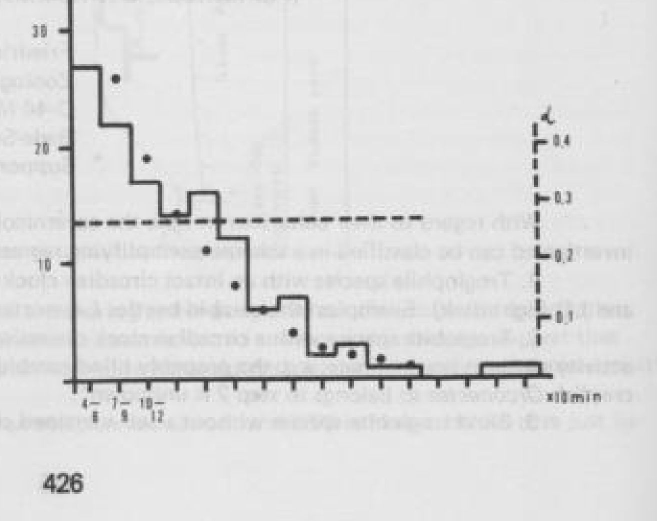


TABLE 1.

Species	number of analyzed actograms	number of actograms with significant correlations	number of correlations A positive	R negative	R positive	A negative	A/R	number of frequency distributions without correlations —	P	s	e
Aphaenops cerberus, A pluto	31	5	1	2	2	1	A	4	1	0	21
							R	0	0	0	26
Geotrechus orpheus	17	1			1		A	3	8	0	5
							R	4	0	4	8
Speonomus diecki	11	0					A	2	1	1	7
							R	3	3	0	5

ponents nor correlations between the durations of succeeding activity bursts and rest pauses can be found. The probability of a transition from activity to rest is constant (independent of the duration of the activity already passed), or the probability becomes continuously larger, the longer a burst of activity continues. The corresponding is true for the rest pauses. — the time-independence of the transition probability is evident if the frequency histogram of the durations of the activity bursts (A), respectively rest pauses (R), can be described by the Poisson or standard function.

Probably the control of activity by stochastically operating nervous mechanisms is a widespread phenomenon.[6] In most animals evidence of these basic mechanisms seems to be concealed by a circadian control and is therefore often overlooked. When in the regressive evolution the clock is degenerating, the endogenous random generators get the upper hand. No special activity-controlling mechanism appears to have evolved in cavernicolous animals.

References

1. Lamprecht, G. a. Weber, F. *Ann. Speleol.* 30, 471-482 (1975).
2. Jegla, T.T. a Poulson, T.L. *Jour. Exp. Zool.* 168 273-282 (1968).
3. Erckens W. a Weber, F. *Experientia* 32, 1297-1299 (1976).
4. Ginet, R. *Ann. Speleol.* 15, 1-254 (1960).
5. Gunzler, E. *Biol. Zentralbl.* 83, 677-694 (1964).
6. Lehmann, U., Neumann, D. a. Kaiser, H. *Jour. Comp. Physio.* 91, 187-221 (1974).

EVALUATING CAVES AND KARST

N.J. White and Elery Hamilton-Smith
Australian Speleological Federation
P.O. Box 36, Carlton South
Victoria, 3053, Australia.

Following the report of its Committee of Inquiry into the National Estate (1974), the Australian Government has now established the Australian Heritage Commission. This Commission is charged with the responsibility of establishing a register of the National Estate, both natural and cultural, and of advising the government on all matters relating to the National Estate (Yencken 1976).

The Australian Speleological Federation has been asked by the Commission to investigate and report upon the principles and criteria which should be used in deciding whether any specific cave or karst feature should be registered as part of the National Estate. At first sight, the decision to register or not to register is a simple binary one and criteria might readily be determined, but as the investigation has proceeded, so a number of complex questions has been raised.

Diversity

Even if one ignores the immense variety of surface landscapes in karst areas, the general concept of 'a cave' embraces a remarkable diversity of forms which cannot be treated as a single class. One cannot treat limestone caves, lava caves, caves in laterites (or many others) as members of a single class which can be compared with each other.

Even more importantly, caves may be recognised as 'significant' for a great diversity of reasons. Any single cave may be important because of beauty, geomorphic factors, biospeleological issues, archeological or palaentological features or any combination of such factors.

This problem suggests that one might design a multivariate matrix against which individual caves or other places could be 'scored' and assigned a significance rating. Although this raises a further set of questions about the relative weighting which should be assigned to various factors in the matrix, the Federation potentially has the basis for such an approach in its computer-based cave data system (Matthews, 1977).

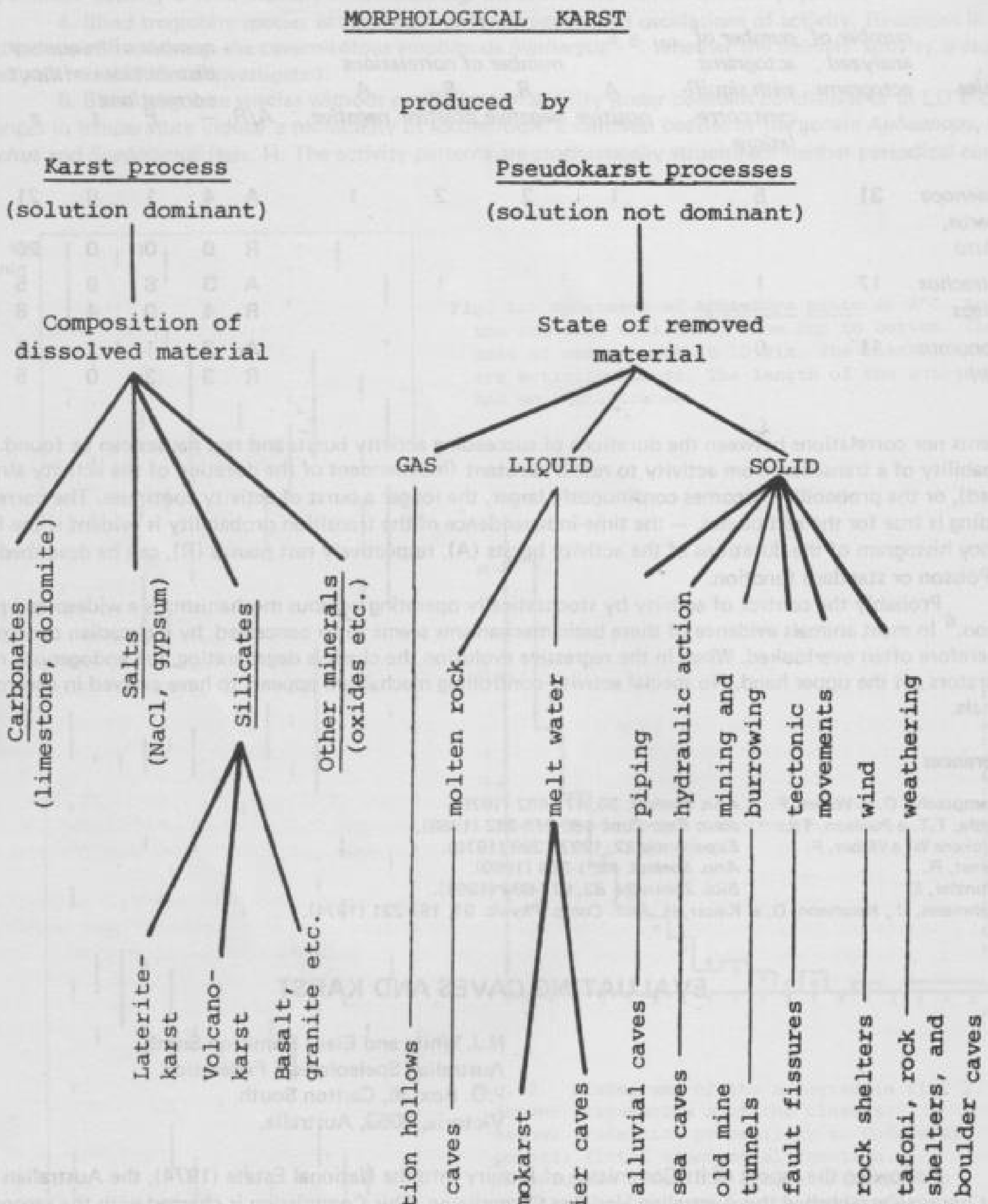


FIG. 1. : CLASSIFICATION OF KARST AND PSEUDOKARST.
(After Grimes, 1975.)

Significance

The National Estate register appears to be based upon an assumption that any specific place might be rated as significant in terms of being 'outstanding' on a world, national, state or local basis. Although one obviously cannot discard this assumption, we find it must be questioned.

In the first place, any assessment of significance on this basis is determined by cultural factors which may, and often do, change from one point in time to another. In Australia, places which were seen as sufficiently significant in the nineteenth century to warrant special reservation of land may now be seen as completely unimportant and the reverse is certainly equally true. Similarly, a determination of significance today may not be seen as valid by the residents of the twenty-first century.

This and other considerations lead to the notion of representativeness, namely that one should ensure registration of a sample of all possible type of feature, even though some may not be judged of great 'significance' at the present time. This in turn means that one must first establish a meaningful taxonomy of caves and karst features to provide a base from which the sample might be drawn. An example of a taxonomic approach is provided by Grimes (1975) and shown here in Fig. 1.

Although the Grimes taxonomy does not (and did not attempt to) deal with the taxonomy of limestone caves, it does highlight the potential value of this approach. As one example, Australia has probably many thousands of caves in laterites, but these have received minimal attention from speleologists (Lefroy & Lake 1972, Shannon 1975). The low level of present interest in these caves means that they are unlikely to be considered within the traditional assumption of significance, but adopting a representation viewpoint suggests that they must not be ignored. It is extremely difficult to judge how prevalent such caves may be in other countries, as they receive little attention in the research literature elsewhere, but it may well be that Australia offers an outstanding opportunity for the study of such caves.

Thus, we see that the criteria for registration must pay attention not oply to the notion of the extent to which any place is judged to be outstanding, but also the extent to which it is necessary to include a truly representative cross-section of places.

Two criteria generally accepted as important by speleologists and others are those of beauty and recreational value. The extremely subjective nature of both these criteria pose a special problem. Although attempts have been made in such fields as landscape evaluation to find a systematic way of quantifying subjective assessments, the validity and reliability of such methods has not yet been demonstrated.

Place

Purely from the significance viewpoint, one might select a single cave, or even part of a cave, as being signficant. However, from the viewpoint of conservation management, this is obviously inappropriate. As a minimum, the whole of a cave and the land above it must be recognised as a unit, and ideally, the total geomorphic and hydrological system of which the cave forms a part should be registered.

In practice, two constraints are likely to prevent the ideal being attained. The first is the extent to which existing land use or the sheer size of a watershed may prevent registration of a whole unit. More importantly, we generally lack the detailed understanding of specific natural systems necessary to determine the boundary of any one such system. In some cases this may be relatively self-evident, but this is rarely so. Few karst areas in Australia have been the subject of ecological or management-oriented studies which have given due attention to the issue of boundary definition (but see Hamilton-Smith et al 1974, Richards & Ollier 1976, Hamilton-Smith & Champion 1976).

Management

A further problem arises from the structure of the Australian legal system. The National Heritage Commission (and the register) are legitimated under federal law, while most land management is subject to state law. This means there is no necessary integration between registration of a place on one hand and its management on the other.

Registration may well serve to increase visitor pressure or even non-conforming use of a site, and if there is no provision for adequate management, the result may well be disastrous. Thus an element of judgement about the outcomes of registration becomes a necessary part of the decision to seek registration.

Conclusion

On viewpoint expressed by many concerned Australian speleologists in that caves and karst are such scarce resources in Australia (Jennings 1975) that every single example must be considered significant, and should be protected against destructive action such as mining. The extent to which despoilation has already occurred at such important areas as Bungonia (Ellis et al 1972) and Mt. Etna (Sprent 1970) demonstrates, however, the high priority assigned by governments to limestone mining.

It is therefore doubtful whether it will prove wise to register all karst areas, or that even if all were registered, that this would prevent any future exploitation.

This paper has been written during the course of the study described here. More information will be available at the time of the congress, and the results of the study will be published in book form.

References

Australia: Committee of Enquiry into the National Estate, 1974, *Report of the National Estate* (Canberra: Australian Government Publishing Service).

Ellis, R. et. al. 1972. *Bungonia Caves* (Sydney: Sydney Speleological Society).

Grimes, K.G. 1975. Pseudokarst: definition and types, *Proc. 10th. Conf. Aust. Speleol. Fed.* 6-10.

Hamilton-Smith, E., Champion, C.R. & Robinson, L. 1974. *Cave Reserves of the Katherine Area* (Melbourne: Australian Speleological Federation for Northern Territory Reserves Board).

Hamilton-Smith, E. & Champion, C.R. 1976. *Mt. Etna and The Caves* (Brisbane: University of Queensland Speleological Society).

Jennings, J.N. 1975. How well off is Australia for caves and karst? A brief geomorphic estimate, *Proc. 10th. Conf. Aust. Speleol. Fed.* 82-90.

Lefroy, T. & Lake, P. 1972. A laterite cave system in the Chittering region, Western Australia, *Western Caver,* 12(3): 68-77.

Matthews, P. 1977. A national cave recording system.

Richards, A.M. & Ollier, C.D. 1976. *Investigation and Report of the Ecological Protection of Exist Cave near Ida Bay in Tasmania* (Unpublished report to National Parks and Wildlife Service, Tasmania).

Shannon, C.H.C. 1975. Pseudokarst caves in Duricrust/Granite terrain, Banana Range, Central Queensland, *Proc. 10th. Conf. Aust. Speleol. Fed.* 20-24.

Sprent, J.K. (ed). 1970. *Mount Etna Caves* (Brisbane: University of Queensland Speleological Society).

Yencken, D. 1976. The Australian Heritage Commission, *Environs,* Sept-Oct. 1976: 17.

COMPUTER APPLICATIONS IN BRITISH SPELEOLOGY

J.D. Wilcock
Chairman, BCRA
22 Kingsley Close,
Stafford, England

The modern digital computer can be used in a variety of interlinked ways:

(a) for routine processing of data,
(b) for information retrieval,
(c) for statistical studies,
(d) for the production of graphics, and for publication.

The computer has been used in all these ways within British speleology. A summary of these applications has been given by Wilcock (1976a).

Routine Processing of Data

The routine processing of data typically arises in the reduction of cave survey readings (Wilcock, 1976b) and geophysical survey for the location of caves (see, for example, Palmer and Glennie, 1963; Bristow, 1966). Calculation of cave survey station coordinates is a tedious business, particularly if projected elevations are involved; while geophysical survey raises problems both in removal of background effects and in the interpretation and presentation of results (see Wigley and Brown, 1976): both these applications can be handled with advantage by computer, and would probably be regarded as the most practical uses of the computer in speleology by the majority of cave scientists.

Statistical Studies

Once a body of data (generally referred to as a *data base*) exists in the storage media of a computer, it can be submitted to all manner of statistical checks and calculations. Examples are flood pulse analysis in hydrological studies (Ashton, 1965, 1966, 1967; Wilcock 1968), morphometric analysis of Karst landforms (Williams, 1966) and of cave passages (Hanna and High, 1970), and cave chemistry (Picknett, 1976).

Graphics and Publication

Computer graphics and listings are an immense aid in publication. Diagrams, graphs, cave surveys and distribution maps may now all be produced automatically by the computer, using cathode ray tubes and pen or microfilm plotters. A summary of techniques was given by Wilcock (1970a, 1976a).

Information Retrieval

This paper concentrates on what will probably be the main use of the computer in speleology, viz. information retrieval. The cave biological records of the Cave Research Group of Great Britain, and latterly the British Cave Research Association, compiled over many years by Glennie and Hazelton, have been computerised by the Monks Wood Experimental Station of the Nature Conservancy (now the Institute of Terrestrial Ecology) (Perring, 1967; Jefferson, 1976). B.C.R.A. is now actively recording British cave archaeological and hydrological data on a central computer (Wilcock, 1970b, 1976c). Two main types of record are envisaged for future additions, the *non-intensive* and the *intensive*, as follows:

ARCHAEOLOGY: Non-intensive

Site reference number
location (NGR)
Administrative details: county, district, parish, legal status (scheduled, SSSI, etc.
Description: form (cave unexcavated/partially excavated/completely excavated/lost/destroyed; finds only; documents only)
condition (undamaged, partially damaged, destroyed, unknown)
period (Prehistoric, period uncertain; Palaeolithic; Mesolithic; Neolithic; Bronze Age; Iron Age; Roman, Post-Roman, period uncertain; Migration and Early Medieval; Medieval (1066-1485); Post-Medieval; unknown)
Control: Date entered into retrieval system, and person entering the record
Text: Name of site, characterisation, main publication reference.

ARCHAEOLOGY: Intensive

As above, plus the following:
Dimensions of cave site
Environmental data (from sediment, pollen and mollusc analysis, rodent and insect remains,etc)
Associated finds
Dating (including radiocarbon dating, etc.)
Further records (diagrams, plans, photographs, etc.)
Archival material (original excavation records, etc.)

Detailed description of site and finds.
Full bibliography

HYDROLOGY: Non-intensive

Name of system or cave
Control: Date entered into retrieval system, and person entering the record
Origin: Date of test, operator and club
Description of test: Dye or tracer used, quantity
Inflow description: Test site (NGR) and name of swallet, entrance, etc.
Exact time of insertion of test agent
Inflow comments (e.g. low flow, moderate flood, etc.)
Outflow description: Detector site (NGR) and name of rising, resurgence, etc.
Throughflow time
Outflow comments

Meteorological and other general comments

Test summary: Test result (Positive, negative, no conclusion)
Reason for inconclusion) if no conclusion
Finish time)

Main publication reference

HYDROLOGY: Intensive

As above, plus the following:

Administrative details: test area, county
Environmental data (soil, ground, aquifer comments)
Inflow: Numerical flow (l/s), inflow graph, method
Colour: Hazel, comments
pH, method
Ca, Mg, Bicarbonate, Total hardnesses, with methods
Chloride, sulphate and trace elements, with methods
Temperature
Conductivity: Temperature of measurement, value μmho cm^{-1}
corrected to temperature: corrected value μmho cm^{-1}
total hardness/corrected conductivity ratio
Parameter accuracies
Outflow: as for Inflow, plus the following:

Detection device
Detector assay
Number of detectors
Numberical value ppm
Start time or exact time of observation
Comments specific to detector site
Relationship to inflow site (horizontal distance, vertical distance, direction)

Full bibliography

Conclusion

The archaeological information is to be seen as a resource for the improvement of conservation and protection of important cave archaeological sites, and may be linked with palaeontological data. In due course the hydrological information may be linked with geomorphological, surface and cave survey data to build up complete pictures of the Karst areas of Britain.

References

Ashton, K. 1965. Preliminary report on a new hydrological technique *Cave Res. Grp. G.B. Newsletter,* 98, 2-5.

Ashton, K. 1966. The analysis of flow data from Karst drainage systems *Trans. Cave Res. Grp. G.B.* 7(2), 161-203.

Ashton, K. 1967. The University of Leeds Hydrological Survey Expedition to Jamaica 1963. *Trans. Cave Res. Grp. G.B.* 9(1), 36-51.

Bristow C. 1966. A new graphical technique for detecting air-filled cavities, *Studies in Speleology* 4(1), 204-227.

Hanna, K. & High, C. 1970. Spectral analysis of meanders in underground streams, *Trans. Cave Res. Grp. G.B.* 12, (3), 219-223.

Jefferson, G.T. 1976. Cave faunas. Chapter 10 in Ford, T.D. and Cullingford C.H.D. (eds), 1976 *The science of speleology,* 359-421, Academic Press, London, New York and San Francisco.

Palmer, L.S. and Glennie, E.A. 1963. The geoelectric survey and excavation in Tratman, E.K. (ed), 1963. *Reports on the investigations of Pen Park Hole, Bristol,* Cave Res. Grp. G.B. publication 12, 15-24.

Perring, F.H. 1967. The [computer information retrieval] requirements of the research worker in biology *Museum Journal,* 67, 108-111.

Picknett, R.G. 1976. The chemistry of cave waters in Ford, T.D. and Cullingford, C.H.D. (eds), 1976 *The Science of speleology*, 213-248, 569-574 Academic Press, London, New York and San Francisco.

Wigley, T.M.L. and Brown, M.C. 1976. The physics of caves, Chapter 9 in Ford, T.D. and Cullingford C.H.D. (eds), 1976 *The science of speleology* 329-358. Academic Press, London, New York and San Francisco.

Wilcock, J.D. 1968. Some development in pulse-train analysis, *Trans. Cave Res. Grp. G.B.* 10(2), 73-98.

Wilcock, J.D. 1970a. A review of computer hardware of particular use to the cave surveyor. *Trans. Cave Res. Grp. G.B.* 12(3), 201-210.

Wilcock, J.D. 1970b. Information retrieval for cave records, *Trans. Cave Res. Grp. G.B.* 12(2), 96-98.

Wilcock, J.D. 1976a. The computer in speleology. Chapter 14 in Ford, T.D. and Cullingford, C.H.D. (eds), 1976 *The science of speleology*, 551-578. Academic Press, London, New York and San Francisco.

Wilcock, J.D. 1976b. The computer as an aid in cave surveying Chapter 6 in Ellis, B. (ed)., 1976 *Surveying Caves*, 32-34. The British Cave Research Association.

Wilcock, J.D. 1976c. BCRA water tracing record scheme *Brit. Cave Res. Assoc. Bulletin*, 13, 6-8.

Williams, P.W. 1966. Morphometric analysis of temperate Karst landforms *Irish Speleology* 1(2), 23-31.

TRACING THE PRINCIPAL SOURCE OF NEW ZEALAND'S LARGEST SPRING

Paul W. Williams, University of Auckland,
Dept. of Geography, Private Bag, Auckland, New Zealand

The Waikoropupu Springs, usually known simply as the Pupu Springs, are the largest springs in New Zealand, with an average discharge of about 14 m^3/s. The springs are tidal, brackish, artesian and karstic, and issue from three main sites within a radius of 130 m of each other. They are located in the Takaka valley in the northwest of the South Island of New Zealand at 14-17 m above sea-level, roughly 2.6 km inland from the head of tide in the neighbouring Takaka River to which their discharge drains (Fig. 1). The waters are clear and cold (11.7°C) and show a range of discharge of 6-21 m^3/s. Tritium analyses suggest a groundwater age of 3-4 years.

A research programme was initiated to try to establish: (1) the origin of the Spring's waters; (2) the nature of the subterranean system; (3) the factors controlling the siting of the Springs; and also to test (4) the limits of pulse-train analysis as a method of karst water tracing. A paper in press (Williams, in press) reports the results in detail. This contribution focuses on the water tracing aspects.

Hydrogeological Setting of the Springs

The Springs are situated in a north-south oriented fault-angle depression. The valley is wedge-shaped, broadening and descending to the north where it grades gently into the shallow waters of Golden Bay. To the west and east are mountains formed predominantly of Palaeozoic schists and marble that rise to well over 1,000 m. The marble is at least 1,000 m thick and it probably also underlies the Takaka valley, although a thick veneer of Quaternary sands and gravels masks most of the lowland bedrock geology. Tertiary sediments unconformably overlie the Palaeozoics, with Oligocene coal measures forming the principal cap rock of the Pupu artesian system in the marble, which extends well below sea-level.

Tidal cycles at the Springs show an alternating double amplitude and precede the marine tides in Golden Bay by 0.5-1.5 hours (unless they lag by 10.5-11.5 hours). This oscillation pattern seems consistent with an earth tides origin, although the saltiness of the Springs suggests a connection to the sea. Freshwater upwellings in 12-14 m of water occur 1-5 km offshore in Golden Bay, and the chloride concentration in the water of the Springs suggests a sea water admixture of up to 1 part in 200 of fresh.

Sources of the Springs

Various geologists have suggested that the waters of the Pupu Springs originate from the upper Takaka River at a distance of 16-18 km inland from the sea and at 46-58 m above sea-level. The main evidence in favour of this being that the upper Takaka River commonly runs dry in summer in the reach in question, losing up to 9 m^3/s in a course of 4.5 km. However, no large stream-sinks are visible; the river merely infiltrates into its gravelly bed.

In attempting to test the connection of the upper Takaka River to the Pupu Springs, severe limitations are imposed upon conventional water tracing methods, because of the likely very large volume of the ground-water system (1.3-1.8 km^3), which could result in dilution of an injected tracer to beyond the limits of detectibility. It was therefore decided to try to prove the connection using a pulse-train analysis technique (Jakucs, 1959; Ashton, 1966; Wilcock, 1968; Brown, 1972). However, since the maximum fall of the possible ground-water system is only 50 m in about 17 km and since the conduits also seem likely to be choked with glacifluvial gravels, any pulse transmitted could be so tenuated and suppressed as to be undetectable. The pulse experiments thus become of interest in themselves, as tests of the limitations of the method.

Pulse Analysis

Input and output pulse data were obtained from water level records from two stage recorders installed 20.2 km apart: (i) on the Springs River below the Pupu Springs and (ii) on the upper Takaka River where it emerges from its confined course through the mountains onto the Takaka lowland (Fig. 1). Prior to statistical analysis of the data, field experiments were carried out using planned releases from the Cobb hydroelectricity

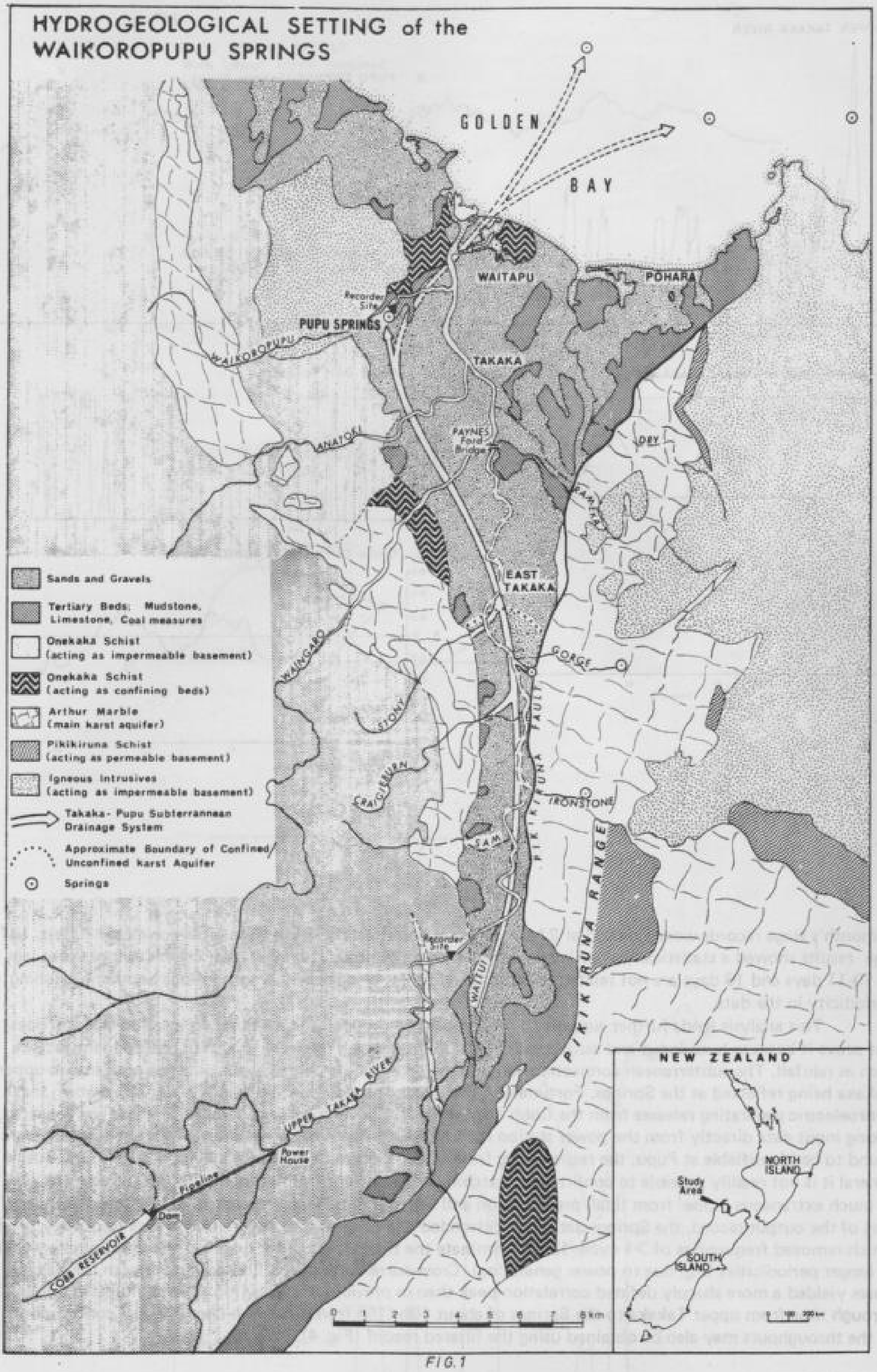
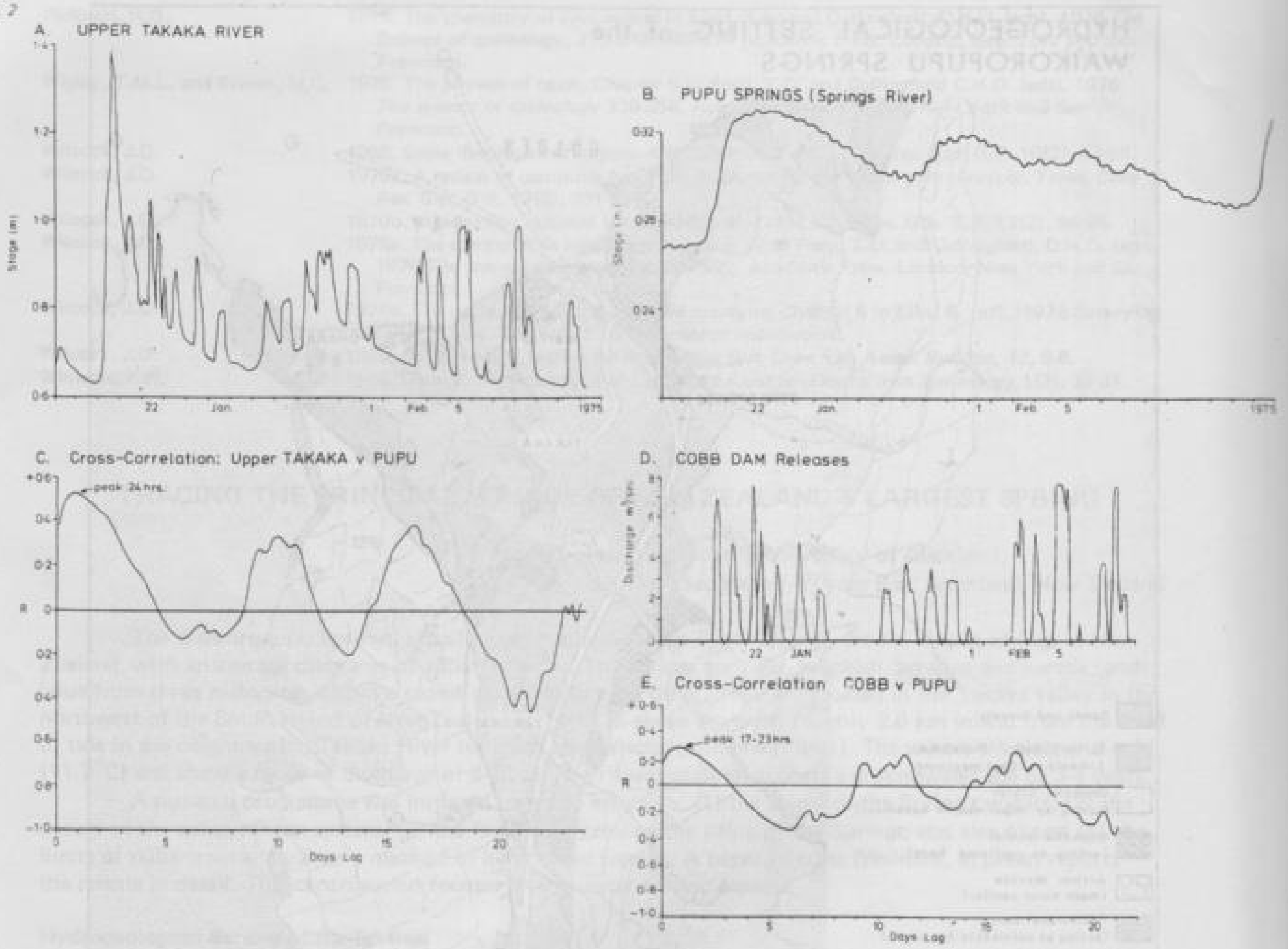


FIG.1

dam of up to 7.6 m^3/s into the upper Takaka River at a time when natural discharge was only 1-2 m^3/s. At the Springs River site the hydrograph showed what was inferred to be a slight reaction to these artificial pulses within 10-20 hours of their passage at upper Takaka.

Statistical analysis was next performed on the time series of input and output stage records to determine if the incoming and outgoing pulse patterns could be matched and, if so, what the throughput lag time is.

FIG. 2



A month's stage records were digitised at 2 hour intervals and the data arrays were cross-correlated (Davis, 1973). The results showed a statistically significant peak at a lag of 24 hours (Fig. 2). Other correlation peaks at lags of 10-11 days and 16 days are not related to pulse travel times, being spurious correlations between matching periodicity in the data.

This analysis lends further support to the hypothesised upper Takaka-Pupu connection but still does not prove it because both input and output pulse patterns could be a response to a third independent factor such as rainfall. The subterranean connection can only be proven by a unique event or series of events at upper Takaka being reflected at the Springs. Fortunately, the upper Takaka River has such a series of events in the hydroelectric generating releases from the Cobb Dam (Fig. 1). Thus the cross-correlation analysis was repeated, taking input data directly from the power station records. The pulses from generation releases at the dam were found to be identifiable at Pupu, the response lag from upper Takaka to the Springs being 12-18 hours. But in general it is not readily possible to confirm the matching pulse pattern from simple visual observation because of much extraneous 'noise' from tidal, precipitation and other effects. Thus in order to extract the significant part of the output record, the Springs data were detrended and subjected to a digital band pass frequency filter, which removed frequencies of >1 cycle/18h to eliminate the tidal effect and <1 cycle/144h to eliminate weekly or longer periodicities (e.g. due to power generating). Cross-correlation of the filtered output with the dam releases yielded a more sharply defined correlation peak than in previous analyses (Fig. 3) and indicated a pulse-through time from upper Takaka to the Springs of about 10h (15h from the Cobb Dam). Visual confirmation of the throughputs may also be obtained using the filtered record (Fig. 4).

Conclusion

The field and statistical evidence converge to demonstrate convincingly that a subterranean connection exists between the Waikoropupu Springs and the upper Takaka River, which is now confirmed as the principal source of the Springs. The successful results from pulse-train analysis demonstrate the sensitivity of the method and underline the value of applying the technique to problems of groundwater hydrology, especially as related to conduit flow in situations where artificial tracers cannot readily be used.

FIG. 3

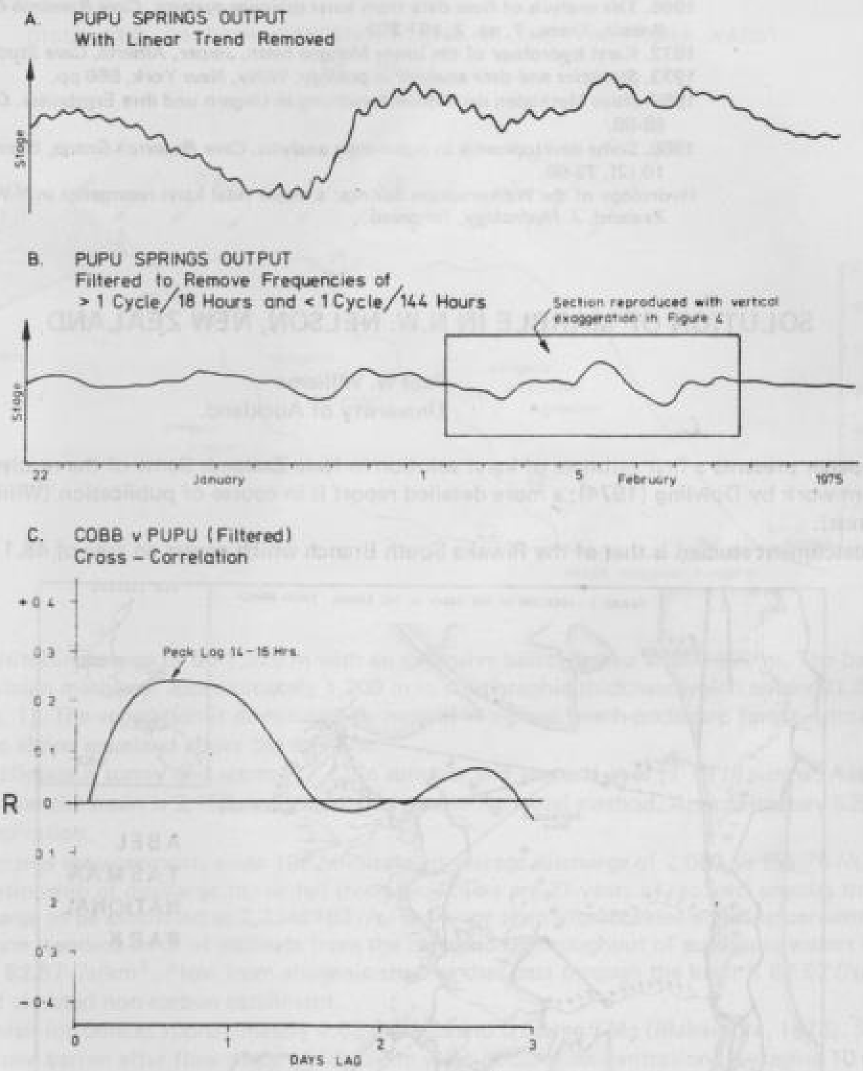
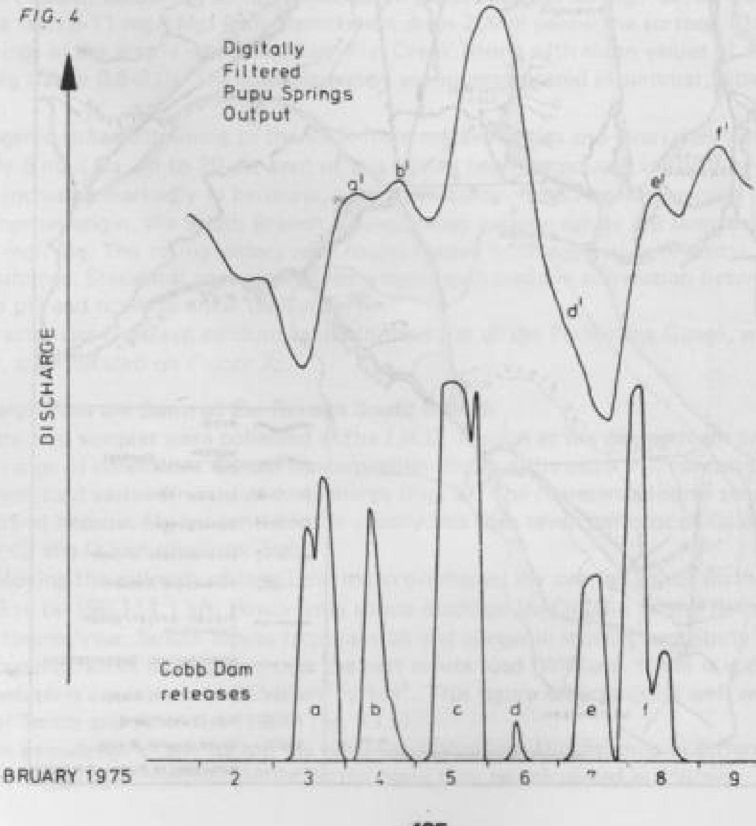

A. PUPU SPRINGS OUTPUT
With Linear Trend Removed
Stage
B. PUPU SPRINGS OUTPUT
Filtered to Remove Frequencies of
> 1 Cycle/18 Hours and < 1 Cycle/144 Hours
Section reproduced with vertical exaggeration in Figure 4
Stage
22
January
1
5
February
1975
C. COBB v PUPU (Filtered)
Cross - Correlation
+0.4
0.3
0.2
0.1
R 0
0.1
0.2
0.3
-0.4
Peak Lag 14 - 16 Hrs.
0
1
2
3
DAYS LAG

FIG. 4


Digitally
Filtered
Pupu Springs
Output
DISCHARGE
a'
b'
c'
d'
e'
f'
Cobb Dam
releases
a
b
c
d
e
f
FEBRUARY 1975
2
3
4
5
6
7
8
9

References

Ashton, K. 1966. The analysis of flow data from karst drainage systems. *Cave Research Group of Great Britain, Trans.*, 7, no. 2, 161-203.

Brown, M.C. 1972. Karst hydrology of the lower Maligne basin, Jasper, Alberta. *Cave Studies*, 13, 84pp.

Davis, J.C. 1973. *Statistics and data analysis in geology*. Wiley, New York, 550 pp.

Jakucs, L. 1959. Neue Methoden der Höhlenforschung in Ungarn und ihre Ergebnisse. *Die Höhle*, 10 (4) 88-98.

Wilcock, J.D. 1968. Some developments in pulse-train analysis. *Cave Research Group, Great Britain, Trans.* 10 (2), 73-98.

Williams, P.W. Hydrology of the Waikoropupu Springs: a major tidal karst resurgence in N.W. Nelson, New Zealand. *J. Hydrology*, (in press).

SOLUTION OF MARBLE IN N.W. NELSON, NEW ZEALAND

Paul W. Williams
University of Auckland.

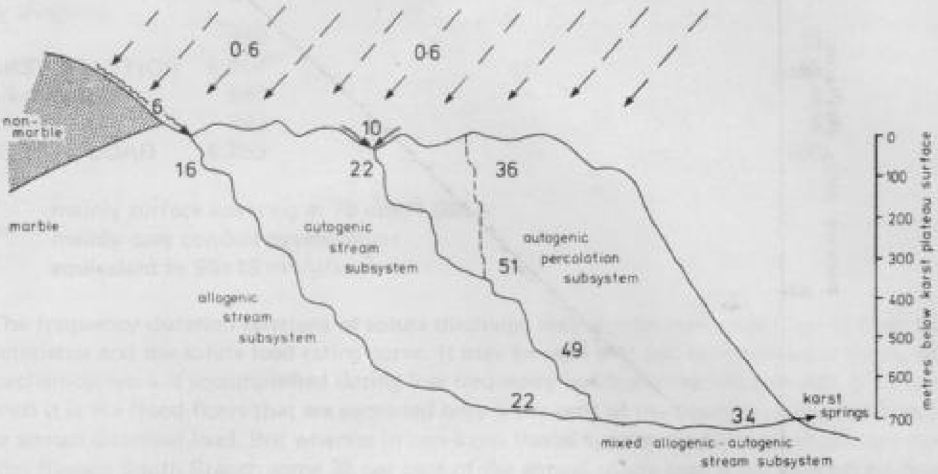
This paper presents a first estimate of karst solution in New Zealand. Some of the results considered here come from work by Dowling (1974); a more detailed report is in course of publication (Williams and Dowling, in press).

The catchment studied is that of the Riwaka South Branch which covers an area of 45.1 km^2 and

FIGURE 2

DISSOLVED CALCIUM CONCENTRATIONS IN THE PIKIKIRUNA KARST

(Ca mg/l)



occupies an altitudinal range of 60-1,329 m with an extensive karst plateau at 600-900 m. The basis of the karst is Ordovician marble of approximately 1,200 m in stratigraphic thickness which covers 21.02 km^2 of the basin (Fig. 1). The vegetation is dominated by natural evergreen beech-podocarp forest, a small area above 1,250 m being alpine grassland above the tree-line.

The climate is sunny and warm (17°C) in summer and wet and cool (7°C) in winter. Average annual precipitation over the basin is 2,158 mm, calculated by the isohyetal method. Approximately 525 mm is lost by evapotranspiration.

Discharge measurements since 1962 indicate an average discharge of 2,680 l/s (51.75 l/s/km^2). The statistical relationship of discharge to rainfall (for which there are 27 years of records) enables the long-term average discharge to be estimated as 2,334±483 l/s. The error term incorporates a ±5% uncertainty from stream gauging and one standard error of estimate from the regression. Throughput of autogenic waters in the karst is equivalent to 52.57 l/s/km^2. Flow from allogenic streams that pass through the karst is 62.52 l/s/km^2 from 12.47 km^2 of elevated non-carbon catchment.

Rainfall introduces approximately 0.63 mg/l Ca and 0.56 mg/l Mg (Blakemore, 1973). Samples of runoff from bare karren after flow paths of 50-250 m yield calcium concentrations averaging 10 mg/l. At a shallow depth (<30m) below the surface percolation waters average 36 mg/l Ca; a figure that increases to 45.51 mg/l Ca (and 5-11 mg/l Mg) from percolation drips 200 m below the surface. The hardness of entirely autogenic springs in the area is represented by Flat Creek Rising with mean values of 49 mg/l (range 42-60) and 1 mg/l Mg (range 0.5-3.0). These spring waters are supersaturated in summer, although sometimes aggressive in winter.

Allogenic streams draining to the karst from metavolcanics and quartzites yield an average hardness of approximately 6 mg/l Ca, up to 20 per cent of this having been introduced initially by rainfall. Allogenic cave stream water increases markedly in hardness, partly by addition of autogenic seepage water. A spring of mixed allogenic/autogenic origin, the South Branch Rising, shows average values (28 samples) of 34 mg/l Ca (range 30-40) and 2 mg/l Mg. The spring waters were found always to be aggressive in winter, but to be usually supersaturated in summer. Statistical analysis showed a significant positive correlation between water temperatures and both field pH and total hardness (as $CaCO_3$).

Characteristic dissolved calcium values in the karst of the Pikikiruna Range, which is drained by the Riwaka River, are indicated on Figure 2.

Solute Discharge from the Basin of the Riwaka South Branch

Eighty-two samples were collected at the I.H.D. Station at the downstream limit of the basin (Fig. 1) under a wide range of conditions. Solute concentration displays the usual inverse correlation with discharge, although dissolved load varies directly with discharge (Fig. 3). The representation of solute load in terms of $CaCO_3$ is justified because Mg concentration is usually less than seven per cent of Ca concentration, Cl and SO_4 are low (<3 mg/l) and alkalinity high.

Employing the estimate of long-term mean discharge, the average solute discharge may be estimated from Figure 3 to be 198.1±1.1 g/s. Hence total solute dischage (as $CaCO_3$) of the Riwaka South Branch is 6,252±1,246 tonnes/year. Solute inputs from rainfall and allogenic sources contribute about 15 per cent of the Ca + Mg concentration of the river; thus the *nett* solute load (Williams 1968) is approximately 5,3142±1,059 tonnes/year, which is equivalent to 95±19 m^3/y/km^2. This figure accords quite well with the 'Arctic/Alpine' relationship of Smith and Atkinson (1976, Fig. 13.5).

From knowledge of the Ca and Mg values and discharge throughputs in different parts of the corrosion system, the distribution of marble solution in the basin may be calculated as follows:

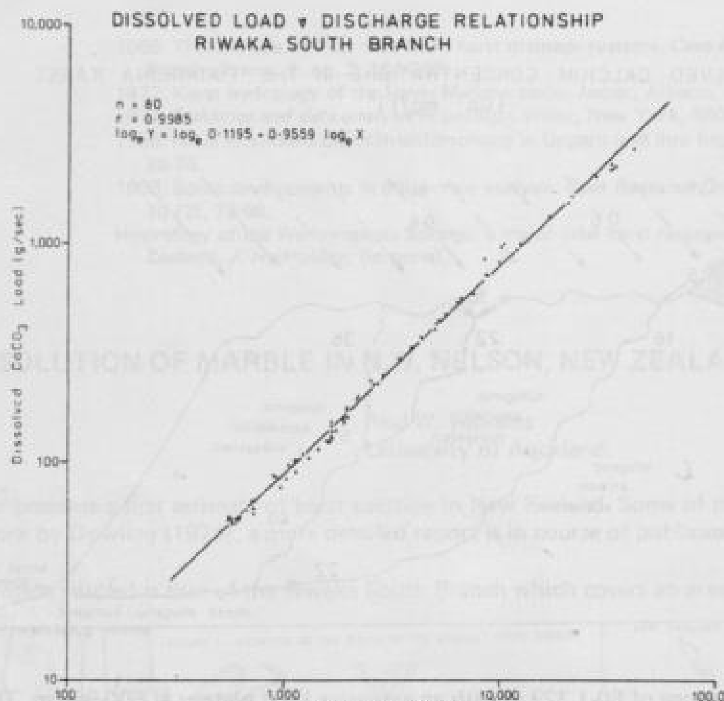
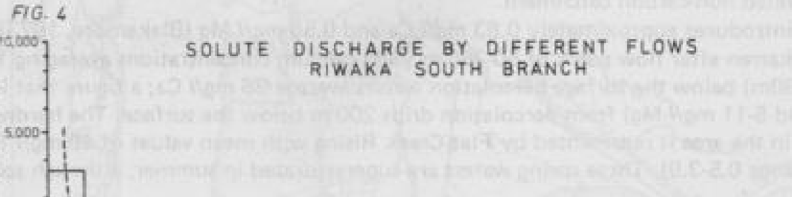

DISSOLVED LOAD v DISCHARGE RELATIONSHIP
RIWAKA SOUTH BRANCH
n = 80
r = 0·9985
log_e Y = log_e 0·1195 + 0·9559 log_e X
Dissolved CaCO3 Load (g/sec)
10,000
1,000
100
10
100
1,000
10,000
100,000
Discharge (l/sec)

FIG. 3

FIG. 4


SOLUTE DISCHARGE BY DIFFERENT FLOWS
RIWAKA SOUTH BRANCH
Dissolved CaCO3 Load Carried by Different Flows (Tonnes)
10,000
5,000
1,000
500
100
50
0
10
20
30
40
50
60
70
80
90
100
Percentage of Time Flow Equalled or Exceeded
Discharge Equalled or Exceeded (m³/sec)

Source of Solute Load	Tonnes/year ± 20%	Percentage of: (a) Karst solution	(b) Total solute load
Marble: by autogenic waters	4,394	83*	70
Marble: by allogenic waters	920	17**	15
NETT KARST SOLUTION	5,314+	100	85
From non-karst rocks	597	–	9.5
From precipitation	342	–	5.5
TOTAL SOLUTE LOAD	6,253	–	100

* mainly surface lowering at 79 mm/1,000 y
** mainly cave conduit development
\+ equivalent to 95±19 $m^3/y/km^2$

The frequency-duration relations of solute discharge may also be estimated (Fig. 4) from flow duration characteristics and the solute load rating curve. It may be seen that just as in non-karst rivers, where almost all mechanical work is accomplished during low frequency but high magnitude events, so in the Riwaka South Branch it is the flood flows that are exceeded only 5 per cent of the time that transport about 44 per cent of the annual dissolved load. But whereas in non-karst fluvial systems negligible work occurs during low stages, in the Riwaka South Branch some 35 per cent of the annual solute load is transported by mean to low flows that occur for 75 per cent of the time.

References

Blakemore, L.C. 1975. Element accessions in rainfall at Taita, New Zealand, 1963-1971. *New Zealand Soil Bureau Scientific Report*, 17, 16 p.

Dowling, R.K. 1974. *Solution processes in the karst of the Riwaka basin, northwest Nelson.* Unpub. M.Sc. thesis, Auckland University.

Smith, D.I. & Atkinson, T.C. 1976. Process, landforms and climate in limestone regions. In Derbyshire, E. (editor) *Geomorphology and Climate*, 367-409 (Wiley).

Williams, P.W. 1968. An evaluation of the rate and distribution of limestone solution and deposition in the river Fergus basin, western Ireland. In Williams, P.W. & Jennings, J.M., *Contributions to the Study of Karst*, A.N.U. Dept. Geog. Pub. G/5: 1-40 (Canberra).

Williams, P.W. & Dowling, R.K. In press: Solution of marble in the karst of the Pikikiruna Range, northwest Nelson, New Zealand.

CAVE RESCUE FACILITIES UNDER DIFFERENT CONDITIONS

Dr. inz. A. Wojciak
ul. Tyszowiecka 11
PL 04-949 Warszawa
Poland

The final results of a cave rescue action depend on many factors, objective and subjective. The first group comprises the physical condition of a victim, seriousness of injuries or shock, place of incident, difficulties of approach to the entrance of cave, weather etc. The latter is something over which we have no influence. Other factors are organisation of rescue teams, presence or absence of a physician in the team, experience and skill or rescuers and other cavers present, organisation of emergency services, transport, means of communication, technical equipment and so on. These factors are subject to alteration – improvement or change for the worse. It is obvious that every person responsible will do his best to make the final rescue successful – or let us say – to increase changes of the victim surviving. However, the methods can differ greatly. The aim of this paper is to discuss two subjective factors, namely problems of organisation and the capacity of men.

Organisation

Some countries have already developed special services to deal with cave accidents. Cave rescue organisations operating in Belgium, Great Britain or Alpine Countries are very good and pretty well known. If we simply imitate them, will we get equivalent effects? No, of course not. Those systems are working under their own conditions, and if transferred to some other country may prove of no use at all. This is simply because of the nature of karst regions in the latter country. Two different types of this location problems can be distinguished.

Localisation type A

Dissipation of karst regions – and therefore caving regions also – over the whole country is characteristic. It is possible to organise several rescue stations. Cities with strong caving clubs are not very far from them. With their most experienced cavers they provide immediate support. If need be, second assistance can be sup-

plied from other clubs over longer distances. Moreover, cavers' activities during the peak season are territorially dispersed.

Localisation type B

Karst regions concentrated on a small area, but strong clubs dispersed in many places through the whole country. There is only one rescue station provided by a local club. Because of concentration of caving expeditions in the area, support from other clubs becomes a necessity. But primary support comes from a distance and it will take many hours till suitable teams arrive.

Type B terms are typical for many countries like Poland, Hungary, Mexico, New Zealand and many others. There is no possibility of making an adequate emergency system, based on amateurs being temporarily in the area. They are involved in expeditions of their own clubs. Also the duration and operating centres of different groups are always changing. Therefore, it is impossible to establish a system of fixed rescue teams and fixed communication lines, well known to the community and always ready to use. An alternative for such countries may be seen in making each exploring or training group bigger, stronger and more self-sufficient. This is partly a problem of equipment, but first of all it is a problem of capacity of men.

Capacity of men

Sometimes professional mountain rescuers can co-operate with emergency services. In Poland, for instance, there is a certain specialised group consisting of professional surface rescuers additionally trained for action in caves. Well trained as they are, they still can not be equated with most experienced amateurs — familiar with the majority of different caves. The capacity of amateurs to operate in cave conditions will be much better, with their training lasting hours and years — hours of active caving and years of development of their skill, knowledge and physical resistance. Moreover, analysis of statistical data taken for more than ten years leads to the following conclusions (Wojciak 1972). Amateurs were involved in every rescue action known — professional rescuers in a quarter of cases only. Even then, they were amateur cavers, who reached the place of the incident first.

So the main task will be to increase the capacity of amateurs involved in rescue action. This may be done through adequate modification of teaching and training programmes, appropriate requirements connected with giving out certificates (if such exist), organisation of meetings dedicated to "self-service" in rescue — or better "self — rescue techniques" — and many other means.

A good idea would probably be to create a net of club rescue teams (CRT). Such CRT's — formed in each club, having an adequate special training programme meetings for exchange of experience and central co-ordination or supervision — could significantly increase the general level of security in caving. The author would like to suggest, that the concept of the CRT-system may be discussed in detail and evaluated by the IV the Cave Rescue Conference. If it is approved, the UIS International Cave Rescue Commission could give its recommendation. The principal idea is that they are amateurs who reach the victim fist, and immediate help is certainly the best help.

Reference

Wojciak, A. 1972. Cave Accidents in Poland (1958-71), *Speleologia* VII, 1-2, 45-50.

THE ORIGIN AND MORPHOLOGICAL DIVERSITY OF LAVA TUBE CAVES

C. Wood
6 Trafalgar Road,
Long Eaton,
Nottingham.
England

This paper, based upon research carried out by the writer in Iceland, Tenerife and Sicily, describes the common, multi-stage development of lava tube caves and explains how morphological diversity inevitably results from these caves evolving in widely differing environmental situations.

The evolution of a lava tube cave occurs in three stages: (1) conduit (lava tube) construction, (ii) conduit drainage, (iii) breakdown and collapse.

Conduit (lave tube) construction

Cave development commences with the construction of a complicated network of conduits, or lava tubes, beneath the congealed surface of the lava flow, through which liquid lava is transmitted from the vent to the advancing front. Conflict over the validity of models depicting the formation of lava tubes (Wood, 1976) was recently resolved by observations of actively forming lava tubes in Hawaii (Greeley, 1971 & 1972: Cruikshank and Wood, 1972; Peterson and Swanson, 1974). These observations showed that lava tubes evolve from either (i) open lava channels, or (ii) small flow units and 'pahoehoe toes', depending upon the distance from the vent.

(i) Major feeder tubes result from the roofing of the lava river carried in open channels. Roofing may be accomplished in a variety of ways: through the accumulation and fusing of crustal plates; through the accumulation and fusing of a surface scum; through the growth of a stable crust

from the sides to the centre of the channel; or through the agglutination of spatter to form arched levees which eventually fuse with the opposing levee.

(ii) Smaller distributary tubes are constructed further from the vent as part of the process of 'toe budding', a frequent method of extension of fluid lava flows. Toes and small flow units are amoeboid-like tongues of liquid lava which override one another as they push out from the front of the flow. They develop a surface skin through chilling: this is inflated by the addition of new lava from behind, the skin ruptures, liquid lava breaks out and a new toe or flow unit is formed as the process is repeated.

Although the full extent of a lava tube network in a large basaltic flow is never seen, the composite picture is envisaged as resembling a vast number of anastomosing small tubes ramifying from one or more larger feeder tubes. (Wentworth and Macdonald, 1953).

Conduit drainage

The evacuation of lava from a lava tube commences with the cessation of effusive vent activity, or when flow in one lava tube has been 'pirated' by a more favourable flow route in another. In addition, for evacuation to proceed, two further conditions must be fulfilled: the residual lava must maintain mobility on the existing slope and there must be a space into which this lava can drain (Wood, 1975). These conditions are rarely met throughout the whole tube network and drainage is usually selectively related to favourable topographic situations. During drainage the lava in the tube may be lowered either constantly or sporadically, and the tube may be emptied either wholly or partially. This is accompanied by extensive passage modification caused by the accretion of cooled lava to the roof and walls of the conduit, forming such features as linings, benches, shelve, false floors, etc.

Breakdown and collapse

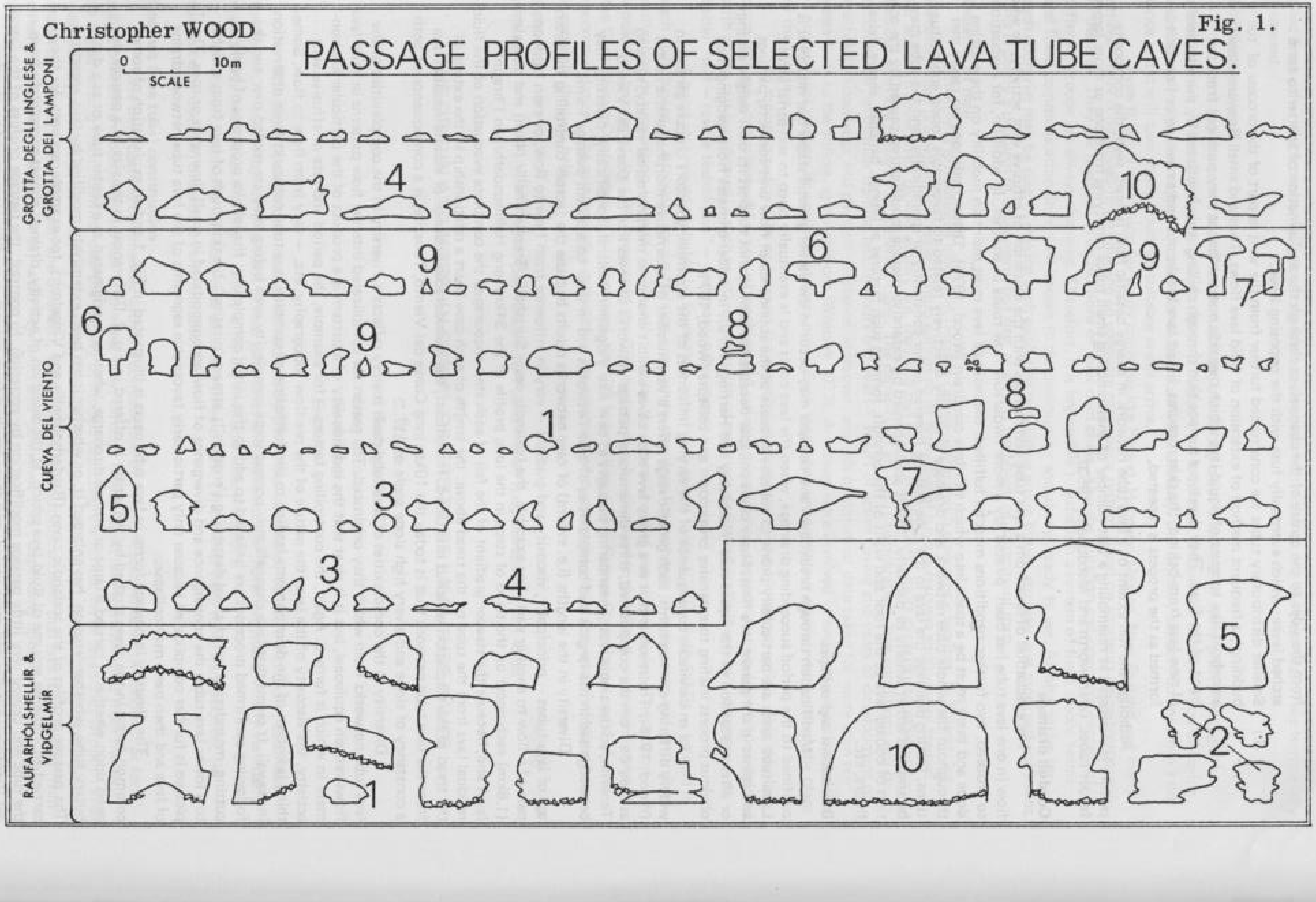
Modification through breakdown and collapse may occur in the earlier genetic stages but mainly it is confined to the period succeeding drainage, when the lava cools and is eventually open to sub-aerial attack. Lava tube caves are particularly prone to collapse because of the abundance of flow unit contacts, partings and joints in the parent lava flow. Many caves collapse because the roof cannot support its own weight during or after evacuation of the liquid core (Hatheway and Herring, 1970). In colder climates frost wedging is an obvious process leading to extensive breakdown and collapse (Wood, 1971).

As an inevitable consequence of the varying influences of the controlling factors on cave genesis in widely differing environments, each genetic stage offers a vast number of alternative morphogenetic routes (Wood, 1975). The result is that as a group lava tube caves exhibit enormous morphological variety, ranging as they do from the complicated, three-dimensional passage networks of caves like the Cueva del Viento, Tenerife, to the single, vast, meandering passages of cave like Vidgelmir, Iceland. Specifically, diversity may be recognised in the lengths and complexities of cave networks and in their constituent passage forms.

Diversity in the lengths (i.e. extent) of cave networks results because the factors controlling the drainage of lava tubes – principally, viscosity and gradient – vary in influence from flow to flow, or even from one part of a flow to another part. For example, the Icelandic caves Surtshellir/Stephanshellir (4km) and Vidgelmir (1.8km) each occur on the tread of steps in the long profile of the 34km long Hallmundarhraun ('hraun' = lava) and, because the steeper gradient of the fall of each step encouraged the complete evacuation of the fluid residual lava from the tube on the tread above: the length of each cave bears a relationship to the extent of the tread of the step upon which it is situated. In contrast, the considerable drainage of viscous residual lava from the lava tube network that is today the 10km long Cueva del Viento, Tenerife, is a consequence of both a constancy of slope and a very high slope angle of 11°.

Diversity in the complexities of lava tube caves mainly reflects a diversity in the complexities of the lava tube networks from which they originated. The reason for complicated internal flow patterns in fluid lava flows remain equivocal, but it is clear that the individuality of a pattern is a product of the particular environment in which it formed. Again, the controlling factors – for example, the period and rate of effusive vent activity, the viscosity of the lava, the nature of the pre-flow topography, etc. – vary from flow to flow. Something is known of the developments leading to the formation of complex lava tube networks from observation in Hawaii. It seems that lava channels may possess some complexity even before they are roofed over and the following confirmed processes are believed to add to this initial complexity: fluvial-like processes of bank-cutting, meandering and channel deepening ('erosion'); stream 'pirating': breakthrough of lava from a higher to a lower lava tube; the convergence and divergence of flow accommodated in small flow units or toes. The picture is further complicated because only particularly favourable segments of the lava tube network drains of lava and then parts may collapse.

The diversity in passage forms in lava tube caves is illustrated in Fig. 1 and an explanation of some common forms in the caves studied by the writer is offered in Fig. 2. Differences in the size of a passage depend upon whether it carried a large or a small discharge, whether it originated as a feeder tube or as a distributary tube, whether 'erosion' has enlarged it, or whether it has been extensively modified by lava accretion. The passage profiles of the Icelandic caves (Raufarholshellir and Vidgelmir), for example, are vast, for they carried an immense volume of fluid lava which, at the cessation of activity, drained almost completely from the tube and caused very little passage modification by accretion. In contrast, the passage profiles of the Cueva del Viento are smaller and more varied, and these resulted from extensive modification caused by the slow and difficult drainage of very viscous residual lava from the tube. There is some correlation between passage type and varying gradients in the Tenerife caves.


Christopher WOOD
Fig. 1.
PASSAGE PROFILES OF SELECTED LAVA TUBE CAVES.
0
10m
SCALE
GROTTA DEGLI INGLESE & GROTTA DEI LAMPONI
CUEVA DEL VIENTO
RAUFARHÓLSHELLIR & VIDGELMIR
4
10
9
6
9
7
6
9
8
8
1
5
3
7
3
4
5
2
1
10

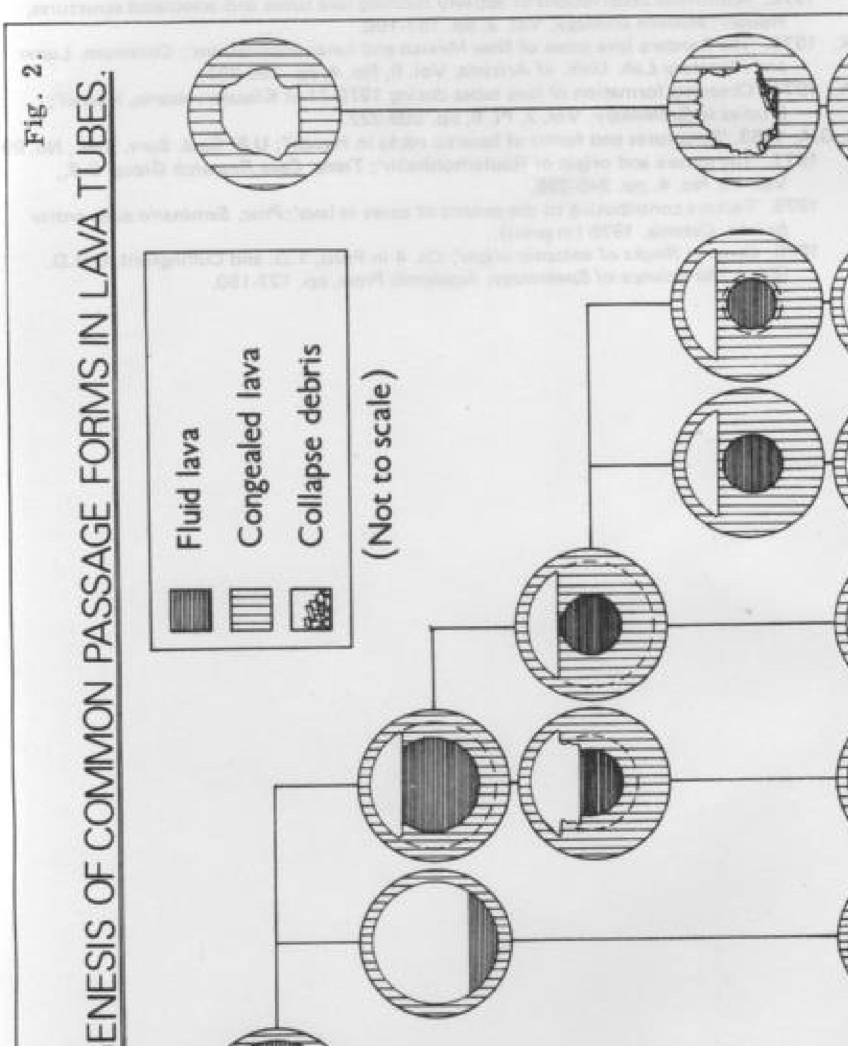


Fig. 2.

References

Cruikshank, D.P. & Wood, C.A. 1972. 'Lunar rilles and Hawaiian volcanic features: possible analogues'; *The Moon,* Vol. 3, pp. 412-447.

Greeley, R. 1971. 'Observations of actively forming lava tubes and associated structures, Hawaii'; *Modern Geology,* Vol. 2, pp. 207-223.

Greeley, R. 1972. 'Additional observations of actively forming lava tubes and associated structures, Hawaii'; *Modern Geology*, Vol. 3, pp. 157-160.

Hatheway, A.W. & Herring, A.K. 1970. 'The Bandera lava tubes of New Mexico and lunar implications'; *Commum. Lunar and Planetary Lab. Univ. of Arizona*, Vol. 8, No. 4, pp. 299-327.

Peterson, D.W. & Swanson, D.A. 1974. 'Observed formation of lava tubes during 1970-71 at Kilauea volcano, Hawaii'; *Studies in Speleology*, Vol. 2, Pt. 6, pp. 209-222.

Wentworth, C.K. & MacDonald, G.A. 1953. 'Structures and forms of basaltic rocks in Hawaii'; U.S. Geol. Surv. Bull., No. 994,

Wood, C. 1971. 'The nature and origin of Raufarholshellir'; *Trans. Cave Research Group G.B.*, Vol. 13, No. 4, pp. 245-256.

Wood, C. 1975. 'Factors contributing to the genesis of caves in lava'; *Proc. Seminario sulle grotte laviche, Catania*, 1975 (in print).

Wood, C. 1976. *Caves in Rocks of volcanic origin'*; Ch. 4 in Ford, T.D. and Cullingford, C.H.D. (Eds.) *The Science of Speleology*, Academic Press, pp. 127-150.