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Vol. 1

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9.° Congreso Internacional de Espeleología

ESPAÑA 1986

Barcelona, agost 1986

9.° Congreso Internacional de Espeleología

ESPAÑA 1986

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– Bajo el auspicio de la UNION INTERNACIONAL DE ESPELEOLOGIA

– Patrocinat per la FEDERACIÓ ESPANYOLA D'ESPELEOLOGIA
– Patrocinado por la FEDERACION ESPAÑOLA DE ESPELEOLOGIA

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PRESENTACIÓ

Quan el 1665, Athanasius Kircher, publicava el seu «Mundus Subterraneus» ja feia 59 anys que a Catalunya i en el 1606 el Dr. Jeroni Pujades havia deixat constància escrita d'unes descripcions de cavitats subterrànies. També havia escrit sobre el tema en Francesc Martorell i de Luna al 1627 i es coneixien exploracions a la cova del Salitre de Montserrat, el 1511 i el 1654.

Aquestes dades formen part del patrimoni històric de l'espeleologia catalana, que sempre ha volgut arrenglerar-se en posicions capdavanteres de les diferents especialitats, així com intercomunicar-se amb d'altres col·lectius espeleològics.

Proves d'aquesta voluntat ho constitueix tant el fet de que la moderna espeleologia catalana neixi amb la visita del francès E.A. Martel, l'any 1896; com el que organitzés el 1970 el 1er. Congrés de la nostra especialitat a tot l'Estat Espanyol. Que expedicionaris catalans hagin explorat cavitats a qualsevol indret del món, des d'Islàndia fins a la Patagònia, des de Nova Guinea fins les Galápagos; com el que bona part de l'espeleologia espanyola tingui part dels seus origens vinculats a personatges o actuacions de l'espeleologia catalana.

A bon segur l'Assemblea de la Federació Espanyola d'Espeleologia valorà tots aquests mèrits, entre d'altres, per a decidir responsabilitzar a la Federació Catalana de l'organització del IX Congrés Internacional d'Espeleologia. Triple repte, doncs, el que reberem a l'assumir el compromís. Com a catalans, l'ésser dignes continuadors del nostre historial espeleològic; com a receptaris del manament de l'Assemblea de la FEE, l'ésser capaços de prestar un servei col·lectiu, pel cap baix, similar al 1er. Congrés Espanyol de 1970 i, finalment, com a espeleòlegs, l'assolir un IX Congrés Internacional de l'alçada de les vuit edicions precedents.

Sense renunciar a la responsabilitat assumida de constituir-nos en el nucli gestor i impulsor del Congrés, a l'haver estat escollida Espanya per l'Assemblea General de l'UIS com a seu del Congrés, ens semblà adient l'estructurar les activitats d'aquest de tal manera que fós possible als congressistes, el conèixer l'ampla i variada gama d'horitzons i treballs existents a l'Estat Espanyol.

D'aquí uns anys, dels esforços de tots nosaltres, restaran només aquestes Actes. El nivell de participació i la qualitat dels treballs presentats, confirma la vitalitat d'aquesta disciplina a cavall de la ciència i de l'esport.

No és el moment per incidir en els problemes que sens deriven d'aquesta dicotomia i que, en moltes ocasions, fa que les institucions acadèmiques no es facin ressó de les nostres activitats, en base, precíssament, al caire esportiu de l'espeleologia. Malgrat que la mateixa celebració del IX Congrés Internacional d'espeleologia, ha estat propiciada per les més altes autoritats esportives catalanes i espanyoles, també és cert que, en d'altres ocasions, les incompresions s'han rebut dels organismes esportius per raó, paradoxalment, de l'aspecte científic de l'espeleologia.

En tot cas el que compta, ara i aquí, és que de l'esforç d'uns i dels ajuts d'altres, incloses institucions; el IX Congrés ja és una realitat.

PRESENTACION

Cuando en 1665, Athanasius Kircher, publicaba en su «Mundus Subterraneus», ya hacía 59 años que en Cataluña y en 1606 el Dr. Jeroni Pujades había dejado constancia escrita de unas descripciones de cavidades subterráneas. También había escrito sobre el tema Francesc Martorell i de Luna en 1627 y se conocían exploraciones en la cueva del Salitre de Montserrat, en 1511 y 1654.
Estos datos forman parte del patrimonio histórico de la espeleología catalana, que siempre ha querido situarse en posiciones delanteras de las diferentes especialidades, así como intercomunicarse con otros colectivos espeleológicos.

Pruebas de esta voluntad lo constituyen, tanto el hecho de que la moderna espeleología catalana nazca con la visita del francés E.A. Martel, el año 1896; como el que organizara en 1970 el 1.er Congreso de nuestra especialidad en todo el Estado Español. Que expedicionarios catalanes hayan explorado cavidades en cualquier lugar del mundo, desde Islandia hasta la Patagonia, desde Nueva Guinea hasta las Galápagos; como el que buena parte de la espeleología española tenga parte de sus orígenes vinculados a personajes o actuaciones de la espeleología catalana.

A buen seguro la Asamblea de la Federación Española de Espeleología valoró todos estos méritos, entre otros, para decidir responsabilizar a la Federación Catalana de la organización del IX Congreso Internacional de Espeleología. Triple reto, pues, el que recibimos al asumir el compromiso. Como catalanes, el ser dignos continuadores de nuestro historial espeleológico, como receptores del mandamiento de la Asamblea de FEE, el ser capaces de prestar un servicio colectivo, por lo menos, similar al 1.er Congreso Español de 1970 y, finalmente, como espeleólogos, el alcanzar un IX Congreso Internacional a la altura de las ocho ediciones precedentes.

Sin renunciar a la responsabilidad asumida de constituirnos en el núcleo gestor e impulsor del Congreso, al haber estado escogida España para la Asamblea General de la UIS como sede del Congreso, nos parece adecuado estructurar las actividades de éste de tal manera que sea posible a los congreasistas el conocer la amplia y variada gama de horizontes y trabajos existentes en el Estado Español.

De aquí a algunos años, del esfuerzo de todos nosotros, quedarán sólo estas Actas. El nivel de participación y la calidad de los trabajos presentados, confirman la vitalidad de esta disciplina a caballo de la ciencia y del deporte.

No es el momento para incidir en los problemas que se derivan de esta dicotomía y que, en muchas ocasiones, conlleva que las instituciones académicas no se hagan eco de nuestras actividades, en base, precisamente, al aspecto deportivo de la espeleología. A pesar de la misma celebración del IX Congreso Internacional de Espeleología, ha estado propiciada por las más altas autoridades deportivas catalanas y españolas; también es cierto que, en otras ocasiones, las incomprensiones se han recibido de organismos deportivos por razón, paradójicamente del aspecto científico de la espeleología.

En todo caso lo que cuenta, ahora y aquí, es que del esfuerzo de unos y de la ayuda de otros, incluidas instituciones; el IX Congreso es ya una realidad.

COMITE DE HONOR

S.A.R. El Príncipe D. FELIPE DE BORBON, Príncipe de Asturias.

Molt Honorable JORDI PUJOL I SOLEY
President de la Generalitat de Catalunya.

Excmo. Sr. JAVIER SOLANA MADARIAGA
Ministro de Cultura.

Excmo. Sr. DEMETRIO MADRID LOPEZ
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General

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Speleogenesis in the groundwater mixing zone: The coastal carbonate aquifers of Mallorca and Menorca, Spain

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RESUM

L'espeleogènesi dels aqüífers carbonatats costaners de Mallorca i Menorca (Espanya) pot ser deguda a fenòmens de dissolució per aigua subterrània agressiva, resultant de la mescla originada en introduir-se aigua de mar en l'aigua dolça de descàrrega. El grau de reactivitat de l'aigua salabrosa depèn de la proporció en que es troben els components en la barreja final. Es van prendre mostres d'aigua subterrània, abarcant una vasta gamma de salinitats, de cavitats i de sorgències properes a la costa. Les composicions de les aigües analitzades foren les següents:

1. *Mescla conservativa de NaCl de l'aigua del Mediterrani, amb aigua dolça local subterrània (amb bicarbonat càlcic)–.*
2. *Dissolució i alteració de la dissolució d'aragonit, dissolució i precipitació de la calcita i dolomitització.*
3. *Fluxe de gas CO_2. Les reaccions químiques pronosticades foren simulades, amb especiació de l'equilibri geoquímic computat i models de transferència de massa. Les zones d'elevada porositat secundària, àmpliament esteses en els aqüífers carbonatats costaners de Mallorca i Menorca, poden provenir d'un augment del procés de dissolució de la zona de mescla subterrània.*

RESUMEN

La espeleogénesis en los acuíferos carbonatados costeros de Mallorca y Menorca, España, pueden ser el resultado de la disolución por agua subterránea agresiva, formada por la mezcla de introducir agua de mar con agua dulce de descarga. El grado de reactivida del agua salobre depende de la proporción de los componentes de la parte final en la mezcla. Se tomaron muestras de agua subterránea cubriendo una vasta extensión de salinidades, de cavidades y manantiales cercanos a la costa. Las composiciones del agua observadas fueron de: 1) mezcla conservativa de Na-Cl del agua del Mediterráneo con agua dulce local Ca-HCO_3- subterránea, 2) disolución y alteración de la disolución de aragonito, disolución y precipitación de calcita, y dolomitización, y 3) CO_2 flujo de gas. Las reacciones químicas pronosticadas fueron simuladas con especiación de equilibrio geoquímico computado y modelos de transferencia de masa. Las zonas de elevada porosidad secundaria y ámpliamente extendidas en los acuíferos carbonatados costeros de Mallorca y Menorca, pueden resultar del aumento del proceso de disolución en la zona de mezcla subterránea.

SUMMARY

Speleogenesis in the coastal carbonate aquifers of Mallorca and Menorca, Spain, may be the result of agressive groundwater solutions formed by the mixing of intruding seawater with discharging freshwater. The degree of reactivity of brackish water depends upon the proportion of endmember solutions in the mixture. Groundwater samples covering a wide range in salinities were collected from caves and wells near the coast. Observed water compositions were the result of 1) conservative mixing of Na-Cl Mediterranean seawater with local fresh Ca-HCO_3- groundwater, 2) dissolution and alteration of aragonite, dissolution and precipitation of calcite, and dolomitization, and 3) CO^2 gas flux. The predicted chemical reactions were simulated with computerized geochemical equilibrium speciation and mass transfer models. Zones of high secondary porosity and widespread cave occurrence in the coastal carbonate aquifers of Mallorca and Menorca may result from enhanced dissolution processes in the groundwater mixing zone.

Introduction

The hydrogeologic setting of Mallorca and Menorca is typical of small limestone marine islands. A lens of fresh groundwater floats on saline water of nearly oceanic composition. Fresh groundwater flows toward the coast through limestone aquifers (Fig. 1). Seawater encroaches into the coastal aquifers where the mixing of fresh and saline waters forms a zone of brackish water. We believe that this zone is a reactive geochemical environment in which alteration and dissolution of carbonate minerals are enhanced. We hypothesize that high secondary porosity and permeability in the coastal carbonate aquifers of Mallorca and Menorca result at least partially from dissolution processes in the groundwater mixing zone.

The geochemical significance of mixing is the result of the nonlinearity of mineral solubility as a function of variables such as salinity, partial pressure of CO_2, temperature, and ionic activity (Back and Hanshaw, 1965). The importance of mixing in carbonate

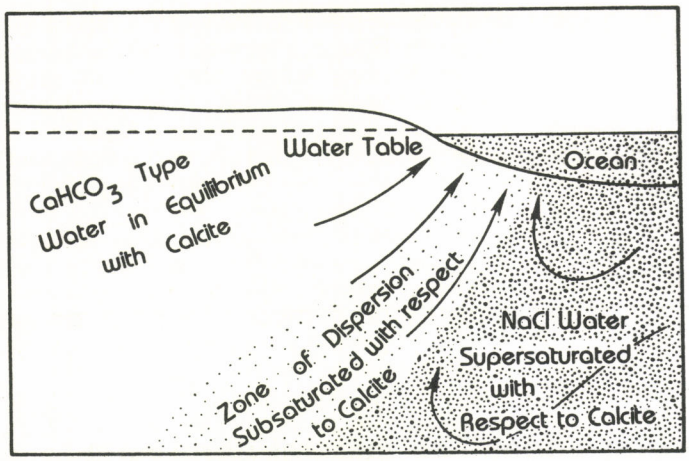

Fig. 1. Sketch showing cyclic flow of ocean water and discharge of brackish water from the groundwater mixing zone. Superimposed on the schematic of the flow system is information about the chemical type of the waters and their saturation state with respect to calcite.

aquifers has been discussed (Hanshaw and Back, 1979), and the mixing zone concept has been used to explain the development of geomorphic features along the coast of the Yucatan Peninsula, Mexico (Back et al., 1979). Dissolution is occurring where fresh groundwater mixes with saline water before discharging to the surface. Exploration of the cave at Xcaret permitted direct observation of extensive dissolution of the Pleistocene reef (Back et al., 1986).

We believe that the concept of enhanced geochemical reactivity in the groundwater mixing zone can be applied to many coastal carbonate aquifers. In particular, we undertook the present investigation of the groundwaters along the coasts of Mallorca and Menorca to test hypotheses developed from earlier studies of the Yucatan mixing zone. We believe that the observed groundwater chemistry in the result of a combination of the processes of 1) mixing two endmember solutions, 2) carbonate mineral dissolution, precipitation, and alteration, and 3) variable fluxes of CO^2 gas.

Geologic Setting

Mallorca and the other Balearic Islands in the Betic Cordillera are characterized by thick limestone masses and steep sea cliffs. The exposed limestones are basically of two main sequences. In the northern part of Mallorca, shallow marine limestone deposited from the Jurassic and early Cretaceous up to the Miocene has been affected by mid-Miocene tectonic activity. A reef complex was deposited in the upper Miocene, and it is now exposed in the southern part of the island. Further tectonic movement, especially isostatic uplift, continued into the Quaternary. Many caves are developed in the limestone bedrock of Mallorca. Their occurrence is concentrated near the coast, and caves are more common in the Miocene than in the Jurassic rocks.

Methods

In July 1984 a total of 14 water samples were collected on Mallorca: two from wells, 11 from three different caves, and one from the surface of the Mediterranean Sea. The water samples were selected to cover the range in salinity from that of freshwater to that of seawater. Relatively fresh groundwaters were collected from an irrigation well in the Miocene at Son Forteza, southeast of Manacor near the Coast, and from another irrigation well in the Jurassic limestone west of Alcudia. A coastal seawater sample was collected near Punta Negra south of El Arenal. We collected samples from two caves in the Miocene reef complex, at Vallgornera and at Cala Varques, and one in the Jurassic, Cueva de Bassa Blanca.

In August 1985 a total of 10 water samples were collected on Menorca: 6 from wells and 4 from two different caves. All samples came from Miocene-aged rocks. The freshest groundwaters were collected from irrigation wells at Son Olivaret and Parella south of Ciudadela. Four other samples were obtained from irrigation wells and water-supply wells in the vicinity of Ciudadela. We also collected samples from Cova de sa Figuera and at Covad de S'Aigo.

The cave water samples were all collected from lakes. We obtained a range in sample salinity by collecting from various depths in the pools of water. Samples were pumped through polyethylene tubing using a small battery-operated bilge pump. Temperature, pH, alkalinity and conductivity were determined in the field. Chemical analyses for major ions and analyses for stable isotopes were performed by standard methods in the laboratories of the U.S. Geological Survey. The saturation state with respect to various mineral phases was calculated using the computerized geochemical model WATEQF (Plummer et al., 1976).

The processes that led to observed compositions were considered, beginning with predicting the results of conservative mixing of two solutions. The mixing fraction of conservative chloride was used to estimate the concentrations of other constituents in solution if they were also conserved during mixing. The fresh groundwaters of the islands are Ca-HCO_3 type waters with low Na^+, Cl^-, and SO_4^{2-} concentrations and relatively low total dissolved solids content. The freshest Mallorca water collected was from an irrigation well at Son Forteza. Compositions of conservative mixtures of Son Forteza and Mediterranean Sea waters in various proportions were calculated using the computerized geochemical model PHREEQE (Parkhurst et al., 1980).

Results

The predicted saturation states of mixtures of the two endmember waters are shown in Figures 2 and 3. The water collected at Son Forteza was itself supersaturated with respect to calcite (SI_C=+0.26, Fig.2). Mixing this freshwater with the highly supersaturated seawater (SI_C=+0.84) resulted in a decreased saturation state for up to 67 % seawater. The minimum SI_C was -0.02 near 30 % seawater. However, given the uncertainties in the thermodynamic data, that SI_C cannot be distinguished from equilibrium. So although the predicted saturation state of the mixture decreases compared to the Son Forteza sample, it never becomes undersaturated with respect to calcite. The aragonite saturation index curve parallels the calcite curve but is offset by -0.143 units (Fig. 3). From a slightly supersaturated Son Forteza water, upon addition of seawater, the resulting mixture becomes

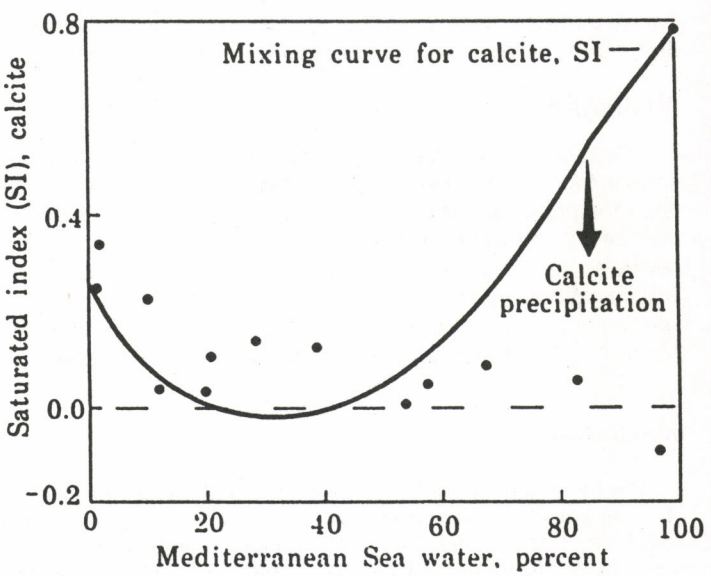

Fig. 2. Calcite saturation index plotted as a function of percentage Mediterranean Sea water. Points are observed values of groundwater samples, and the line is a calculated conservative mixture.

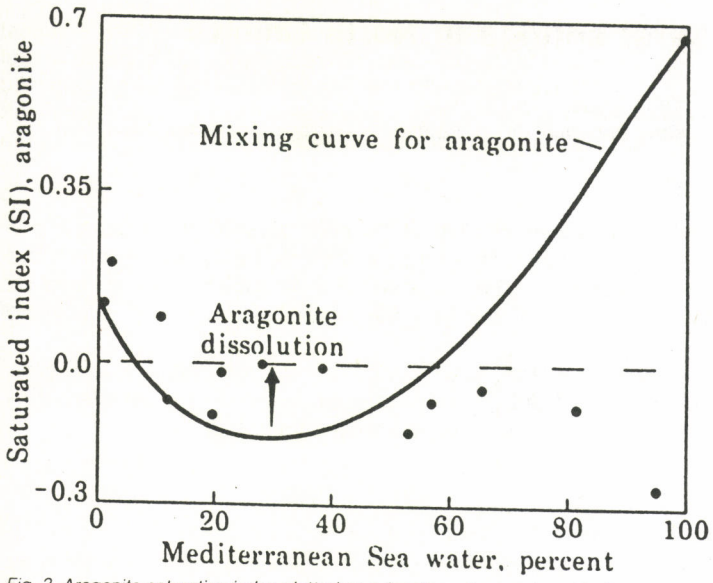

Fig. 3. Aragonite saturation index plotted as a function of percentage Mediterranean Sea water. Points are observed values of groundwater samples, and the line is a calculated conservative mixture.

undersaturated with respect to aragonite, reaching a minimum SI_A=-0.16. For mixtures >62 % seawater, the solution is supersaturated.

In contrast, the fresh groundwater samples from Menorca are slightly undersaturated with respect to calcite. The mixture of the Parella freshwater endmember with a seawater sample is predicted to be even more undersaturated over a wide salinity range. Thus, the decreased saturation state predicted for the mixture actually yields an aggressive water. Compared to the calculation of a mixture that is significantly aggressive to calcite, the observed water samples are only slightly undersaturated.

Discussion

Differences in composition between the calculated conservative mixture and the observed water samples are then used to illustrate nonconservative processes. Based upon the predicted saturation states of the mixtures, we expect mineral precipitation from supersaturated solutions and mineral dissolution from undersaturated solutions. These reactions would tend to move an observed groundwater composition from the predicted mixing curve toward equilibrium at SI=0.

Many of the Mallorca water samples are supersaturated with respect to calcite but are more supersaturated than the mixing calculations predict (Fig. 2). This result may be understood through examination of the aragonite results (Fig. 3). From a predicted undersaturated solution, at composition less than approximately 50 % seawater, aragonite may have dissolved from the bedrock moving the SI_A values toward zero. The result is supersaturation for calcite. The dissolution of aragonite without immediate precipitation of calcite would lead to significant development of secondary porosity and permeability. At greater percentages of seawater, the observed water samples are less supersaturated with respect to calcite than is predicted by the mixing calculations (Fig. 2). In fact, the compositions are all near equilibrium. These results would be observed if calcite precipitation occurred. However, excess CO_2 compared to seawater would also contribute to a less supersaturated solution. These two effects can only be sorted out through mass balance calculations.

Conclusions

The qualitative interpretation of the results of the mixing calculations and the observations of natural water chemistry lead to a proposal of aragonite dissolution and calcite precipitation for Mallorca. The data for Menorca support aragonite and calcite dissolution and calcite precipitation across the salinity gradient. This scenario for chemical reactions in the groundwater mixing zone underscores the fact that an unstable mineralogy containing aragonite will lead to the greatest reactivity. Although there is no aragonite remaining in the Jurassic bedrock and very little left in the Upper Miocene limestone, both lithologies at one time contained aragonite. After the sediments became lithified and uplifted, the groundwater mixing zone may have fluctuated through them several times in response to global sea-level changes during the Pleistocene or as a result of relative sea-level change due to isostatic uplift of the island following tectonic activity. Regardless of the exact mechanism, the coastal limestones of Mallorca and Menorca have been exposed to the groundwater mixing zone, a reactive environment where aragonite and, in some cases calcite, dissolves. These mineral dissolution reactions lead to the development of secondary porosity, permeability, and, ultimately, caves in coastal limestones.

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Analysis of regime of large karst springs in North China

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RESUM

Aquest treball analitza les característiques del règim de les grans surgències càrstiques del nord de la Xina. Se suposa que les principals zones càrstiques controlen la circulació subterrània de les aigües càrstiques. Amb aquest criteri, les conques subterrànies de les grans surgències càrstiques es poden dividir en vàries parts. Cadascuna d'elles amb característiques pròpies a l'hora de procedir a la descàrrega de la surgència. El règim d'aquestes deus ve determinat per les característiques de les precipitacions i de la situació de les zones càrstiques més importants.

Sota aquest punt de vista, s'ha suggerit un model que relaciona l'anàlisi de la regressió del corrent de precipitació amb l'anàlisi de la disminució de la descàrrega per a imitar el règim de les surgències. Utilitzant aquest model, es poden valorar les diferències de distribució del corrent de les fonts i les condiciones hidrogeològiques de cada punt de la conca subterrània.

RESUMEN

Este trabajo analiza las características del régimen de los grandes manantiales kársticos en el Norte de China. Se supone que las principales zonas kársticas controlan la circulación subterránea de las aguas kársticas. Según esto las cuencas subterráneas de los grandes manantiales kársticos se pueden dividir en varias partes. Cada una tiene sus características propias en la contribución de la descarga del manantial. El régimen de los manantiales se determina por las características de precipitación y situación de las principales zonas kársticas.

Según el punto de vista que acabamos de citar, se ha sugerido un modelo que relaciona el análisis de regresión de la corriente de precipitación con el análisis de disminución de descarga para imitar el régimen de las surgencias. Usando este modelo se pueden estimar las diferencias de distribución de la corriente de los manantiales y condiciones hidrogeológicas de cada parte de la cuenca subterránea.

SUMMARY

This paper analysed the characteristic of regime of large karst springs in North China. It is believed that the main karst zones control the subsurface flow of karst water. According to them, the groundwatershed of large karst springs can be divided into several parts. Each has its own characteristic in the contribution to the spring flow. The regime of springs is determined by te characteristic of precipitation and the location of main karst zones.

According to the viewpoint mentioned above, a model, combining the regression analysis of flow-precipitation with the decay analysis of discharge, has been suggested to imitate the regime of springs. By using this model, the diferences of distribution to the spring flow and the hydrogeologic condition of each part of groundwatershed can be estimated.

Introduction

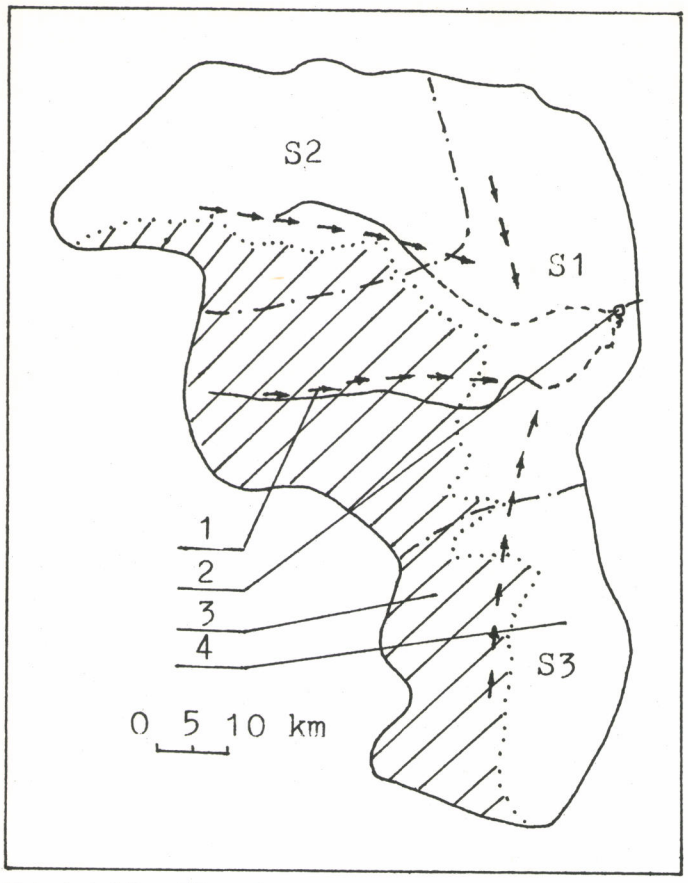
In the research of regional karst water flow conditions, the analysis of regime has important significance. There are two main methods to analyse the regime of karst spring. The first is the decay analysis of discharge curve. By using it the pore type and storage capacity of regional karst aquifer can be evaluated. The second, regression analysis is used to find the relation between rainfall and flow of karst spring. It is helpfull to identify the effect of recharge of rain fall.

In North China karst area spring flow is quite stable, and recharged by a large area of water shed and rainfall of several years. On the curve of regime we could not find a clear boundary between the course of recharge and of discharge. Thus, it is unlikely to be suitable to use the methods mentioned above in analysis of regime. By combining the two methods and taking acount of the effect of flow zone in its watershed to the regime, a model has been suggested to imitate the whole curve of regime, and been used to analyse Niang Zhiguan spring.

The Charasteristic And Formation of Regime

The climate in North China is semidrought, and the mean precipitation is about 500-600 mm per year. Rainfall is uneven distribution in time and space, precipitation of month 6-9 makes up 70-80 percent of total of the year. Spring is the main form of discharge of karst water. Flow of dozens of springs is greater than 1 M^3/s, and most of them Q max : Q min < 2. The infiltration of rainfall is the first source of springs and the permeation along rivers is the second. The flow of springs has a delay of one to several months relative to rainfall, and no such complete yearly cycle as rainfall. The duration curve of flow neither a smooth wavy line nor a smooth decay line, but a line with several fluctuations (peaks), big or small. A lot of prospecting data show that the karst fissure and small hole is the main space which karst water stored in and flowed through. Big holes, transfering and storing karst water at present, are only found within a small area around the springs. Therefore, the fluctuations of discharge curve can not be explained as that they are caused by the change of pore type in karst aquifer during discharge. Comparing the interval of peaks on discharge curve with that of rainfall we know at least that the fluctuation of flow are not caused by rainfall only. Because the watershed of the springs is often very large, we can not disregard the effect of the differences of the rainfall and of hydrogeologic conditions in space in their watersheds.

The remarkable characteristic of karst aquifer is evidently nonhomogeneous and nonisotropic. In North China, the springs mainly emerge from carbonatite of Cambrian and Ordovician System. The fracture is the main form of geological structure in this area, many of them keep alive after Mesozoic Era, and since Cenozoic Era, blocks between fractures have moved up and down. Accompanying the activity movements, several periods of karst developed. As a result of the large scale movement of blocks, the karst formed before Tertiary Period has been rised up or burried deeply. The karstification of present time mainly developed underground and around the large and alive fracture zones. Based on the fracture pattern and added the karst, often several periods, the groundwater flow zones formed. In the flow zones water level is relatively lower and have a good flow condition. They collect and transfer karst water therefore they controle the ground water flow in a spring watershed. Furthermore in a spring watershed, different geomorphologic unit, often consistence with geologic unit, usually has different sediment cover, vegetation cover and rainfall. Think of these factors we can imagine that water from different flow zone come to spring at different time, this made the discharge curve fluctuate. It will be reasonable that we divided the spring watershed into several



Watershed of Niang Zhiguan Spring.
1. Flow zone
2. Spring
3. Area covered by fragmental rock
4. Carbonatite exposure

subwatersheds according to the distribution of main flow zones, and each has its own characteristic of recharge to the spring flow, and its own coefficient of permeability, decay speed and delay period.

Model

Above discussion given us a conceptual model, through analysing the regime we can understand the relation between flow and rainfall, also we can get some informations about the differences of the hydrogeologic conditions in a spring watershed. In order to imitate to karst aquifer we have following restricted conditions:

1. recharge proportion to the rainfall;
2. after a delay, the recharge of a subwatershed to spring immediately reach the maximum, then decay following an exponential function;
3. only one pore type in the aquifer in one subwatershed;
4. using month as time unit (certainly we can use shorter time unit if the flow is sensitive to rainfall).

The model we suggested is as following:

$$Q_k = \sum_{j=1}^{J} A_{ji} \sum_{i=1}^{I} H_{i+mj+k,j} \quad EXP(-B_j \cdot i)$$

Q_k = spring flow of time k (m^3/s);
A_j : «weight» of effect to spring flow, j subwatershed;
M_j : : delay of j subwatershed (months);
B_j : decay coefficient of j subwatershed;
$H_i + mj + k, j$: effective month rainfall of j subwatershed, i + mj months before time k;
J : numbers of subwatershed;
I : numbers of months in which one time rainfall has certain effect to spring flow.

Recharge characteristic of a subwatershed can be discribed by three parameters: A, B, M. Effective rainfall means the rainfall when it is very small we take it as zero, and when the rainfall intensity is very high, it ought to be corrected so as to keep the approximate proportion relation between recharge and rainfall.

All parameters in the model can be estimated first as initial value according to hydrogeologic conditions and obtained discharge curve, then we refine A, B, M using a computer by fitting the model with observed curve. Several groups of parameters may have the similar degree of fitting, the hydrogeologist can do some choice according to hydrogeologic condition of that spring.

Using in Niang Zhiguan Spring

Niang Zhiguan Spring is the largest spring in North China karst area, with a recharge area (watershed) of about 1.840 km^2, and its mean flow is about 12 m^3/s. The watershed is divided into 3 subwatersheds: S1, S2, S3, Fig. 1. On the discharge curve we can find delays of about 0-1, 3-4 and 7-8 months. And according to the discharge curve we take, I as 48 months. We fit the model using flow data of 1961-1968, and got the results as following:

A: 0,0123
0,0040
0,0057
B: 0,0016
0,0015
0,0004
M: 1
4
7

From the results we can understand that the spring water mainly recharged by S1 and S2. The delay data seams indicate that the permeation along rivers is an important source of S1, for the M1 (delay of S1) much shorter than M2 and M3, and by comparing M2 with M3 we know that the flow condition in S2 is better than in S3.

Using these parameters we calculate the spring flow of 1969-1976, the result does not deviate from that of observed very much, thus we know that until 1976 the groundwater with draw in its watershed had not given evident effect to the spring flow, the decrease of spring flow is mainly caused by the decrease of rainfall.

Conclusion

The existence of flow zones and differences between them can affect the regime of karst springs. It is helpfull to take account of the differences of hydrogeologic conditions in watershed when we study the regime and the water resource distribution in the spring watershed. The model can be a complement for other methods. But still the decay function of subwatershed ought to be studied theoretically, and the intensity of rainfall has much influence to the recharge, it also worth to be studied quantatively. Based on such development, the results from this model can be used to evaluate the hydrogeologic condition and estimate the coefficent of precipitation and the capacity of storage of different subwatershed.

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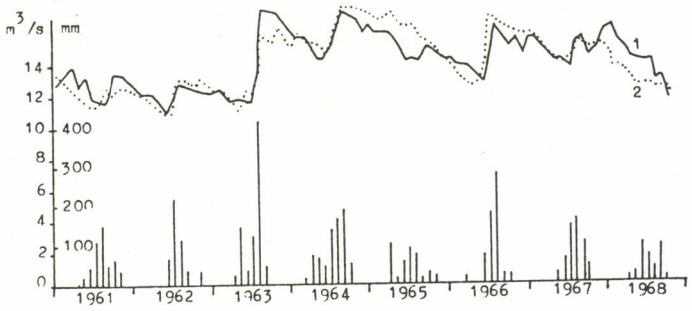

Fig. 2 a. Rainfall data, observed flow data (1961-1968) and the results of fitting.
1. Observed flow data
2. Fitting results

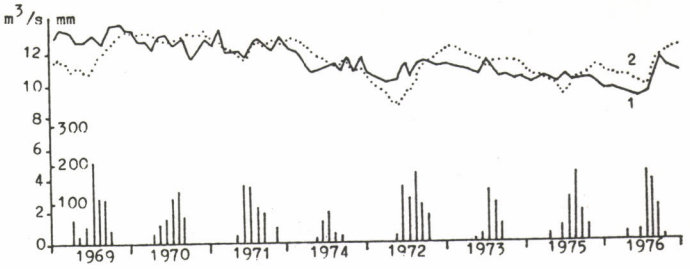

Fig. 2. b. Rainfall data, observed flow data (1969-1976) and calculated results.
1. Observed flow data
2. Calculated results

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Recent geohydrological studies at Crowsnest Pass, Alberta, Canada

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RESUM

El Crowsnest Pass és una àmplia obertura enmig dels massissos carbonatats del Paleozoic superior. El drenatge, orientat segons les capes cap a la collada, resorgeix en dues importants surgències (la font de Crowsnest i la font de Ptolemy) i en diverses surgències menors. La coloració inicial va revelar l'existència de corrents molt més ràpids a la surgència de Corwsnest que a la de Ptolemy (100 m. per hora i 16 m. per hora, respectivament), si bé paradoxalment, la variació diurna del cabal és més important en l'última surgència. Les característiques de l'aqüífer s'estan estudiant actualment, utilitzant tècniques fluoromètriques, hidrològiques, isotòpiques, hidroquímiques, i les variacions del cabal d'aigua.

RESUMEN

El Crowsnest Pass es un amplio desfiladero a través de los macizos carbonatados del Paleozoico superior. El drenaje, orientado según las capas hacia el collado resurge en dos principales surgencias (la fuente de Crowsnest, la fuente de Ptolemy) y en diversas surgencias menores. La coloración inicial reveló corrientes mucho más rápidas en la surgencia de Crowsnest que en la de Ptolemy (100 m por hora y 16 m por hora respectivamente), si bien paradójicamente la variación digna del caudal es más importante en la última surgencia. Las características del acuífero se están estudiando actualmente, utilizando fluorometría, hidrología, isotópica, hidroquímica y variaciones de caudal.

RÉSUMÉ

Le Crowsnest Pass est une large brèche à travers les carbonats massifs du paleozoic superieur. Le drainage, orienté selon les couches vers le col ressort à deux principales sources (la source de Crowsnest, la source de Ptolemy), et à plusieurs sources mineures. Le traçage coloré initial a révélé des écoulements bien plus rapides à la source de Crowsnest qu'à la source de Ptolemy (100 mètres à l'heure et 16 mètres à l'heure respectivement), bien que paradoxalement, la variation diurne de débit soit plus importante à la derniere source. Les charactéristiques de l'aquifère sont actuellement étudiées, utilisant la fluorometrie, l'hydrologie isotopique, l'hydro-chimie et les variations de débit.

Crowsnest Pass is a deep breach through massive Upper Paleozoic carbonates. Strike-oriented drainage towards the pass resurges at two major springs (Crowsnest Spring, Ptolemy Spring) and at several minor springs. Initial dye tracing has revealed much higher flow velocities to Crowsnest Spring than to Ptolemy Spring (100 m/hr and 16 m/hr respectively), though, paradoxically, the diurnal variation in discharge is much greater at the latter spring. Aquifer characteristics are currently being investigated, using fluorometry, isiotope hydrology, hydrochemistry and discharge variations.

Structural, lithologic and hydrologic controls on cave development at Friars Hole System, West Virginia, USA

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RESUM

El sistema de Friars Hole, amb els seus 67 Km. de galeries, és el sistema de cavitats de longitud més gran que es coneix als Apalaches. La cavitat s'ha desenvolupat en una seqüència de calcàries de 200 m. d'espessor amb esquists argilosos i dolomies menors que cabussen suaument cap el N.O.

Es coneixen tres tipus de sistemes:

Els sistemes d'aigües amunt són de fort pendent i cabussament i s'han format en zona vadosa.

Les xarxes intermitges que conecten les xarxes d'aigua superiors amb un col-lector i que ho fan perpendicularment.

Els col-lectors es troben orientats en la direcció dels estrats de pendent suau i s'estenen precisament dessota la superfície piezomètrica. Freqüentment es troben en la intersecció de falles invertides amb un o altre dels dos plans d'estratificació en la base de la calcària «unió limestone». L'enfonsament d'aquestes falles invertides ha provocat la ruptura del sistema de dissolució que condueix a la creació d'amplis espais que vénen a representar el 30 % del volum de la cova. Sediments silícics clàstics en tot el recorregut de les parets inferiors de les galeries impedeixen la dissolució de zones més inferiors, formant petits rierols d'aigua situats bastant més amunt de la superfície piezomètrica.

RESUMEN

El sistema de Friars Hole con sus 67 Km de galerías es el sistema de cavidades de mayor longitud conocido en los Apalaches. La cavidad se ha desarrollado en una secuencia de calizas de 200 m. de espesor con esquistos arcillosos y dolomías menores buzando levemente hacia el Nor-oeste. Se conocen tres tipos de sistemas:

Los sistemas aguas arriba son de fuerte pendiente y buzamiento y han sido formados en la zona vadosa.

Las redes intermedias que conectan las redes aguas arriba con un colector y le son perpendiculares.

Los colectores están orientados según la dirección de los estratos de pendiente suave y desarrollados justo debajo de la superficie piezométrica. Se encuentran frecuentemente en la intersección de fallas inversas con uno u otro de los dos planos de estratificación en la base de la caliza «unión limestone». El hundimiento a lo ancho de estas fallas inversas ha provocado la ruptura del sistema de disolución que conduce a la creación de varios amplios espacios que totalizan el 30 % del volumen de la cueva. Sedimentos silícicos clásticos a lo largo de las partes inferiores de las galerías impiden la disolución hacia abajo, formándose pequeños cursos de agua situados largamente por encima de la superficie piezométrica.

RÉSUMÉ

Friars Hole system est, avec ses 67 km de galeries, le système de grottes le plus long, connu dans les Appalaches. La grotte s'est développée dans une sequence de calcaires de 200 m d'épaisseur avec des schistes argileux et dolomites mineurs plongeant faiblement vers le nord-ouest. Trois types génétiques de réseaux sont connus:

Les réseaux amonts sont de forte pente, plongeants et ont été formés dans la zone vadose.

Les réseaux intermédiaires qui connectent les réseaux amonts avec un collecteur et sont perpendiculaires à celui-ci.

Les collecteurs sont orientés selon la direction des couches, de pente douce et développés juste en-dessous de la surface piézométrique. Ils sont frequemment trouvés à l'intersection de failles inverses avec l'un ou l'autre des deux plans de stratification à la base du calcaire union limestone. L'effondrement le long de ces failles inverses a provoqué la rupture du système de dissolution, aboutissant à la création de plusieurs larges espaces vides qui totalisent le 30 % du volume de la grotte. Des sédiments silicieux clastics le long des parties inférieures des couloirs empêchent la dissolution vers le bas, créant des ruisseaux situés bien au-dessus de la surface piézométrique.

Friars Hole System, with 67 km of passage, is the longest known cave system in the Appalachian Mountains. The cave is developed in a 200 m thick sequence of limestones, with minor shales and dolomites, which dip gently to the north-west. Three genetic types of cave passage are recognised. Inlet passages are high-gradient, downdip, and were formed in the vadose zone. Linking passages integrate the inlets with the main drains, and are normal to the latter. Main drains are strike-oriented, low gradient, and developed just below the piezometric surface. They are frequently found at the intersection of a thrust fault and one of two bedding planes in the basal Union Limestone. Breakdown on thrust faults has disrupted solution patterns, resulting in several large voids which account for 30 % of the cave volume. Siliciclastic sediments on passage floors inhibit downward solution, causing streams to be perched far above the piezometric surface.

Hydraulics and dissolution kinetics of a phreatic conduit

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RESUM

El desguàs subterrani del llac Glondal, a Swartisen (Noruega septentríonal) és totalment freàtic i s'ha pogut investigar mitjantçant immersions a la cova, coloracions, hidroquímica i tècniques d'estimació de la microerosió. La galeria té 580 m. de longitud, amb un diàmetre mig de 5,0 m. El volum topografiat per immersió coincideix amb el volum calculat a través de càlculs de coloració i descàrrega. Tenint en compte la superfície del conducte, segons les observaciones dels escafandristes, el grau de dissolució en tot el recorregut del conducte és de l'ordre de E-7 mMols cm^{-2} seg^{-1}. Aquest fet està en consonància amb els resultats dels estudis realitzats amb comptadors de microerosió, amb d'altres experiments efectuats amb taules de pèrdua de pes i amb els graus publicats de dissolució de la roca calcària i dels nivells del pH en qüestió.

RESUMEN

El desagüe subterráneo del lago Glondal, en Swartisen, Noruega septentrional, es completamente freático y se ha investigado mediante inmersiones en la cueva, coloraciones, hidroquímica y técnicas de medición de la microerosión. La galería tiene 580 m. de longitud, con un diámetro promedio de 5,0 m. El volumen topografiado por inmersión está de acuerdo con los volúmenes calculados por cálculos de coloración y descarga. Teniendo en cuenta la superficie del conducto según las observaciones de los escafandristas, el grado de disolución a lo largo del conducto es del orden de E-7 mMols cm^{-2} $seg.^{-1}$. Esto se corresponde bien con los resultados de los estudios con medidores de microerosión, experimentos con tablas de pérdida de peso y los grados publicados de disolución de calcita y niveles de pH en cuestión.

SUMMARY

The underground outlet of lake Glomdal, Svartisen, North Norway, is totally phreatic, and has been investigated through cave diving, dye tracing, hydrochemistry and micro-erosion meter techniques. The passage is 580 m long, with an average diameter of 5,0 m. The volume surveyed by diving is in accordance with volumes calculated from dye-tracing and discharge calculations. Taking account of the surface area of the conduit, as calculated from the diver's observations, the rate of dissolution along the conduit is in the orden of E-7 mMoles cm^{-2} sec^{-1}. This corresponds well with results from micro-erosion meter studies, tablet weight-loss experiments and the published rates of calcite dissolution at the pH ranges in question.

6. Introduction

The purpose of this report is to present some preliminary results of hydraulic and hydrochemical experiments in a totally phreatic conduit of known geometry and dimensions.

Lake Glomdal, at the Arctic Circle in Northern Norway (Figure 1), meet the requirements of a natural laboratory. First, the system is hydrologically well defined, with only one dominant input and one resurgence. Second, in spite of its remoteness, local geography and manpower allow thorough instrumentation and sampling. Third, the entire system may be inspected through cave diving to obtain a fixed geometric basis for the interpretation of hydraulic and chemical parameters. Geometric and hydraulic considerations of this project is in press (Leuritzen et. al. 1986)

6.1. Site Description

The lake has no surface outlets, sinking as a small cove at the contact zone between mica schist and a pure calcite marble stratum. The outlet forms a short rapid, then sinks vertically down into a conduit of 6 m diameter. The resurgence is of similar dimensions, situated 500 m further downstream. The conduit is accessible through two «Middle Entrances» about one third of the downstream distance from the sinkhole. The entire cave was explored and surveyed by cave divers in 1985 (lauritzen et. al. 1986). Direct observations and tape measurements of the submerged conduit confirm that it is largely unbranched (i.e. a true master conduit) and of uniform dimensions.

6.2. Scallop Morphometry

Discharges calculated from scallops through the cave do accord the continuity equation, which support the diver's observation of an unbranched conduit (Lauritzen et. al. 1986). The conduit is largely circular or rectangular in cross-section, averaging 5 to 6 m diameter, Figure 2.

6.3. Hydraulic Experiments

Water stage recorders and water sampling stations were arranged as indicated in Figure 2. The stage recorder was calibrated against Flugel and salt dilution gauging at a wide range

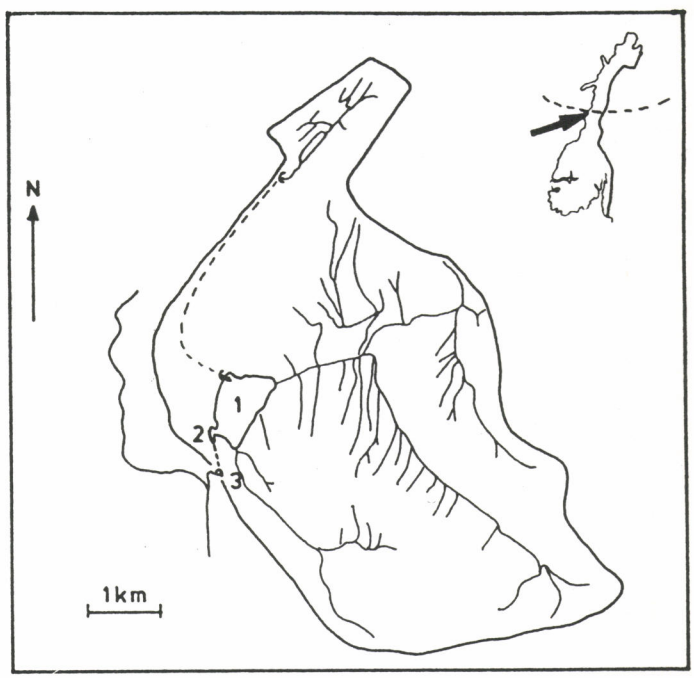

Fig. 1. Key map to the area. 1: Lake Glomdal; 2: Underground outlet of the lake; 3: Resurgence, catchment area 27.7 $km.^2$

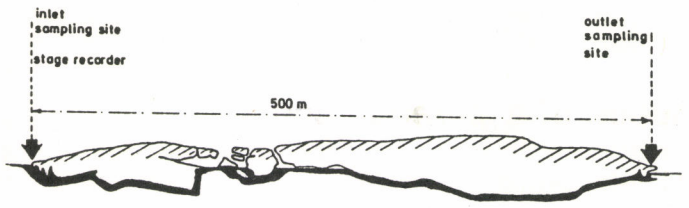

Fig. 2. Vertical, longitudinal section of the cave. Flow from left to right. Surveyed by cave diving, the middle entrances possess characteristics of truncation by glaciers in the past.

of discharges. To investigate the phreatic nature of the conduit, a multiple trace program was performed at a wide range of discharges. Dye breakthrough curves were recorded by automatic water sampling and fluorometer analysis in the field. Fluorescein was used in all experiments. A selection of breakthrough curves are shown in Figure 3a. Transit time varied between 30 and 200 minutes at 10 and 1 $m^3 s^{-1}$, respectively, long time versus log Q plotted as straight lines with slopes close to −1 (i.e. 0,9 +/- 0,1, Fig. 3b). This suggests that neither the cross-sectional area nor the conduit length varied significantly with discharge. These are characteristics of phreatic, full pipe flow (Smart 1981, Stanton and Smart 1981).

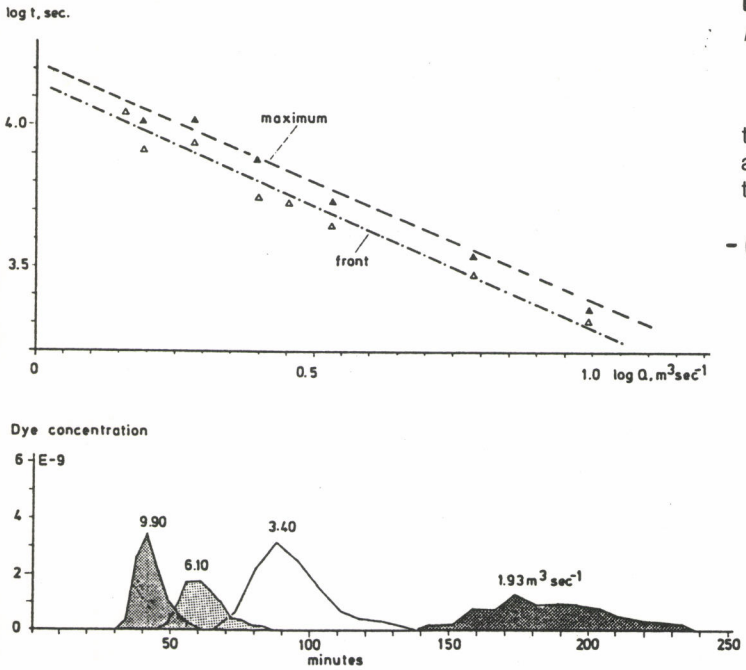

Fig. 3. Results of multiple dye traces in the cave. a) (bottom): Dye (fluorescein) break-throungh curves at varios discharges. The dye pulses are not standardised with respect to the amount injected in each experiment. b) (top) Time of travel vic. discharge. Full pipe flow should theoretically give a slope of -1.

Breakthrough curves are unimodal, except for very low discharges and long transit times, suggestible of an un-branched conduit with few side-pockets or open storage annexes.

Conduit volumes were calculated from discharge and transit time for both the front and maxima of the breakthrough curves, Figure 4. The cave divers' line survey was 580 m long, and the best estimated volume based on the details of cross-sections is 13 500 m^3. Error bars in Figure 4 represent largest and smallest cross-section observed; the error bars in the dye calculations is the total variation of all experiments. The volumes based on peak fronts accord better with the surveyed volume than those based on peak maxima.

6.4 **Hydrochemistry**

Water samples were drawn at sink and resurgence at a wide range of discharges. Samples were analyzed for pH, conductivity, temperature, Ca, Mg, Na, K, Cl^-, HCO_3^- and SO_4^{2-}. Data are still under processing, and only Ca+Mg (total hardness) for the available samples will be considered here.

From the cave volume and the surveyed conduit length, the area of water/marble interface could be calculated. A circular conduit profile yields 9,91 E7 cm^2, whilst a square cross-section corresponds to 1.12 E8 cm^2. The circular approach was used in the following calculations. Total hardness increase between sink and resurgence was assumed to origin from direct corrosion of the marble surface, and the average rate of dissolution could then be calculated from discharge and the parameters discussed above. Reaction rate as a function of discharge is shown in Figure 5. The data suggests that dissolution rate increases with discharge, levelling out at a constant, maximum rate at high discharges.

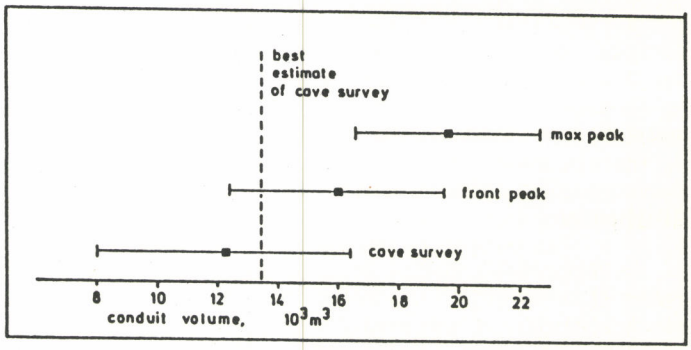

Fig. 4. Conduit volume estimated by various techniques.

6.5. **Direct measurements of denudation rate.**

Direct measurements of denudation rates were performed with the Micro-erosion meter (MEM) technique (High and Hanna, 1970) and by weight loss of standardized marble tablets immersed into the water. Observation time was 5 years for MEM, with annual

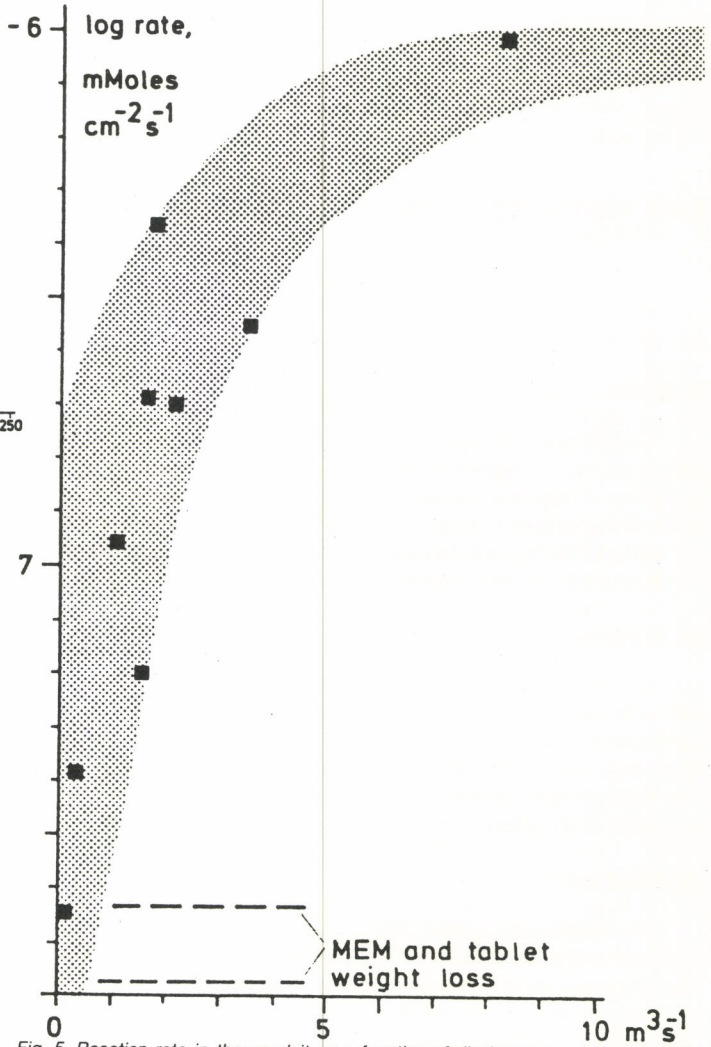

Fig. 5. Reaction rate in the conduit as a function of discharge, compared to MEM and tablet weight loss measurements.

reading. Marble tablets were immersed for one year (Lund, in. prep). The water samples shown in Figure 5 represent the period of immersion.

The MEM stations are periodically dry, whilst tablets were submerged all year around, except that they might have been encapsulated in ice for some time. Both measurements thus possess a bias towards slight underestimates of the annual mean values.

6.6 **Discussion and Conclusions**

Cave diving, scallop morphometry and dye tracing experiments all suggest that the cave is an unbranched master conduit of large dimensions. Based on this, an estimate of the reactive surface between marble and water may be done, having in mind that both a cylindrical and a prismatic approach are probable underestimates of the reactive area. Moreover, possible minor tributaries of harder water of long residence times cannot be corrected for. The resulting reaction rates are therefore not absolute, being maximum estimates.

The apparent rate of reaction increases with increasing discharge until a constant value is suggested at high discharges. Constant rate do not seem to occur before discharge exceeds 10 m^3 s^{-1}. For comparison, turbulent friction (DÁrcy-Weissbach friction factor, see Lauritzen et. al. 1986) is not fully developed before $Q \geqslant 14$ m^3 s^{-1}, suggesting that the apparent corrosion rate is a function of turbulence.

MEM and tablet weight–loss experiments are probable underestimates, suggesting that the «true» rate of enlargement of the conduit is in the order of E-7 mMoles cm^{-2} sec^{-1}. This rate corresponds roughly to a radial increase of 0,8 mm a^{-1}. With a conduit diameter of 6,5 m at the sink, an exponential growth function of cross-sectional area with time (Renwick 1959), suggests a total time of growth of 3xE5 years since it was on the pre-cave stage (< 1 cm diameter). A linear growth model of passage radius at maximum growth rate, i.e. short time of transit (Palmer 1981), suggests 4xE4 years of growth time. Both approaches suggest that the origin of the cave conduit is well back in pre-Holocene time. This is in accordance with the Middle Entrances, which display diameters of about 2 meters and glacial truncation after their formation.

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Les relations entre la surface et la nappe d'eau dans le karst du Burnot (Belgique)

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RESUM

Un sistema de caverna i de «chantoir» particularment extens del procés avançat de cartificació de la calcària Givetiana de la vall de Burnot (marge esquerre del Meuse, Bèlgica).
L'objectiu d'aquesta col–laboració és el de fer públics els resultats d'una sèrie d'observacions que permeten de resumir les relacions entre la superfície i la capa freàtica del carst, aquesta última aprofitada per a l'abastament d'aigua i la piscicultura.
Els tres punts negres d'aquestes relacions són, per ordre de gravetat: L'abo cador de deixalles del Bois-de-Villers, els pesticides i els adobs de les explotacions agrícoles de l'altiplà i els enderrocs dels «chantoir» actius d l'altiplà.

RESUMEN

Un sistema de caverna y de «chantoir» especialmente extenso del desarrollo avanzado de karstificación en la caliza Givetiense del valle de Burnot (margen izquierda del Meuse – Bélgica).
La finalidad de la presentación es proporcionar los resultados de una serie de observaciones que permiten una síntesis de las relaciones entre la superficie y la capa freática explotada para el abastecimiento de agua y la piscicultura.
Los tres puntos negros de estas relaciones son por orden de gravedad: El depósito de desperdicios del Bois–de–Villers, los pesticidas y los abonos de las explotaciones agrícolas de la meseta y los escombros de tierras en los «chantoir» activos de la meseta.

SUMMARY

The especially spread tracery of cavers and «chantoir» attest the advanced expansion of the karstification in Givetian chalky soil of the Burnot valley (left side of the Meuse – Belgium).
The purpose of this presentation is to give the results of a succession of observations enabling us to give the synthesis of the relations existing between the surface and the undergound sheet worked for water distribution and pisciculture.
The three black points of these relations are per seriousness order: dirt storage at Bois–de–Villers, pesticide and manures of agricultural exploitations of Platform and ground spoiled earth in active «chantoir» of the platform.

Karst Hydrology asd Geomorphology of Belize

Dr. Thomas Miller

RESUM

Milers de km². de Belize presenten un important desenvolupament càrstic, que constitueix una font vital per al subministrament d'aigua del país. La major part dels principals rius del país es veuen afectats en gran manera per la naturalesa càrstica de la regió. Alguns d'ells es formen en alguna surgència càrstica; d'altres, en atravessar algun terreny càrstic, incrementen el cabal d'aigua que circula pel sistema. Les investigacions, encetades a començament de la dècada dels 70 varen proporcionar una idea general de les característiques hidroquímiques i hidrològiques d'aquestes àreas.

La geologia i la tipologia han influenciat el diferent desenvolupament càrstic de les diverses àreas.

RESUMEN

Millares de km². de Belize presentan un importante desarrollo del karst, que constituye una fuente vital de suministro de agua para el país. La mayoría de los ríos principales del país están profundamente afectados, ya sea proveniendo de surgencia kárstica, o bien añadiendo mayor afluencia de agua al atravesar terreno kárstico. Las investigaciones empezadas a principio de los años 1970 dieron una idea general sobre la hidroquímica e hidrología de estas áreas.

La geología i topografía han influenciado los distintos desarrollos kársticos en las diversas áreas.

SUMMARY

Thousands of km² of Belize are covered with karst, a vital water resource for the country. Most of the major rivers of the country are profoundly affected, either having headwaters in karst, or by adding major influxes of water as they traverse karst terrane. Research begun in the early 1979's has produced an overview of the hydrochemistry and hydrology of these areas.

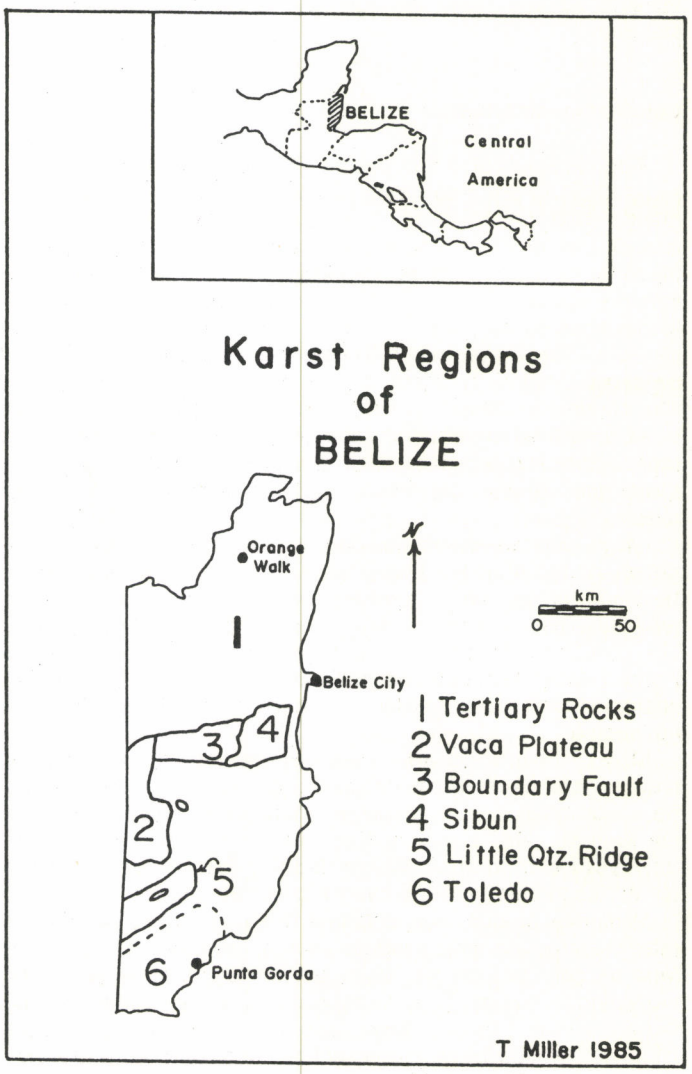
Geologic and topographic influences have resulted in the formation of several areas of distinct karst development.

Belize is located in the southeastern section of the Meso-American Karst Belt. Carbonate rocks form the uppermost bedrock of more than a third of the country, ranging in age from Paleozoic to Tertiary. Karst is present in at least 3000 km² of the Cretaceous carbonates.

Topography and geographic distribution have created a number of karst regions with distinctive characteristics. The two major divisions are due to geologic distribution: the northern area of the country has very immature karst present on Tertiary carbonates. They are low-lying, often snwampy, with no known caves. Shallow sinkholes and a few apparent cenotes are the only karst features present, but some groundwater flow has been reported. A terriginous clastic cover is present over much of this area.

The southern half of Belize is dominated by the low arc of the Maya Mountains. Nearly all the carbonate rocks here are of Cretaceous age, although some Paleozoic limestones occur. The Cretaceous rocks are geographically separated by higher-lying non-carbonate meta-sediments and intrusives, and their karst development has been profoundly affected by runoff from these rocks.

A significant difference in climate –chiefly rainfall– has been created by the large topographic bulk of the Maya Mountains between northern and southern Belize. The wet season in the south is lengthier and more pronounced: mean annual rainfalls of 200-450 cm greatly exceed the 100-150 cm of the north, with consequently greater runoffs.



Surface Development

The Karsts developed on Cretaceous rocks in southern Belize are by far the most extensive. Differing tectonic and erosion histories have separated them topgraphically into five regions with distinctive sur-and subsurface characteristics.

Four of the five regions form contiguous wholes (Figure 1); the Toledo region alone consists of long, isolated, faulted ridges. The tower karst of the Sibun area sets it somewhat apart from the others, but even there large mega-dolines (cockpits) are

occasionally present. Different textures are visible within each region, in some cases due to past fluvial activity, but also to lithologic and compositional variance. (Table 1).

TABLE 1. Cretaceous Karsts of Belize

Location	Area	Relief	Contiguous	Cockpits	Poljes	F/T*
Sibun	660	100 m	X		X	T
Boundary Fault	640	200 m	X	X	X	F
Vaca Plateau	1.100	350	X	X		F
Little Qtz Ridge	610	700	X	X		F
Toledo	300	300		X		F

* F. Fluviokarst present (Areas are in km^2
T. Tower karst present

Many of the Cretaceous rocks have been heavily brecciated and recrystallized, apparently due to tectonic action. A limited number of analyses have shown only highly pure limestones in both these and the bedded limestones. Linear orientation of features north of the Maya Mountains on these rocks appear to parallel the NE-SW orientation of faulting in this part of the country.

Evidence for well-integrated fluvial systems preceding Karstification is present in several large areas, and suggested in much of the remainder, especially near the carbonate/non-carbonate contact. It has exerted a major influence upon surface development. Remmants of past fluvial activity include the presence of large poljes in two regions, and dry channels and valleys. The lengths of these abandoned streamcourses correlates well with their catchment size.

Enormous collapse shafts to 150 meters depth and 100's of meters in diameter occur, but form only a small percentage of the total surface. Many are found in association with subsurface streams.

Cavern Development

Approximately 80 km of passage has been surveyed in Belize as of 1985. As previously mentioned, the surface karst has been greatly influenced by invading non-carbonate streams. All but the largest sink near the contact and are primarily responsible for the large impressive caves of Belize. At present, these separate streams appear to have each cut independently from sinkpoint to resurgence: none are yet known to merge within the body of the karst. These river caves commonly contain higher level fossil passages, frequently offset, and often still used in exceptional flow conditions. All carry large quantities of cobbles and smaller clastics, and have frequent sumps,including those caves of the Little Quartz Ridge region which are of relatively high gradient, unlike the others, and have vertical relief exceeding 200 meters.

Large isolated chambers, occasionally of huge size (>300 meters in diameter) are known as individual high level caves in the karst or as side chambers overlying the allogenic river conduits. Their origins are nearly always obscured by massive rock collapse. It is difficult to determine whether they represent a prior phase of phreatic conduit development later guiding the location of the trunk conduits, or have simply been randomly intersected.

Most of the major caves known in Belize to date are in breccia. In absence of bedding planes, joint sets and topographic dip are the major influences on passage location and orientation. Fault intersections are common, but serve primarily as foci of breakdown and collapse. Where bedding has been observed, it has corresponded with the overall local topographic dip.

Numerous stream inlets of diffuse flow origin in the carbonates enter the large allogenic conduits as they traverse the karst. They enter as springs from the walls, or from short, small passages originating in sumps. They rarely carry significant clastic debris, and are similar in hydrochemical and morphologic characteristics to independent caves developed entirely within the various karsts.

Swallet holes occur by the hundreds in the cockpit areas, often located at the end of a channel cut in the bottom of the soil and clay fill of the dolines. They are active only after heavy rains of at least 12 mm. in the Caves Branch Karst. Isolated examples located partway up doline slopes may reflect migration of the cockpit bottom through time.

Hydrochemistry

Although total solute concentrations may vary between karst areas in Belize, the general pattern of solution is similar. Flow through the karst either originates as direct rainfall or as invading allogenic streams. Both are modified by passage through the carbonates, and their subsequent mixing results in a wide spectrum of waters dependent upon the season, individual catchmen characteristics, flow–through time, etc.

Hardnesses of the allogenic streams increase from about 10 mg/L to 120 mg/L (as $CaCO_3$) as they flow through the conduit caves. This results both from additions of karst inlet water and from solution of the conduit walls, although they usually remain undersaturated with respect to calcite and dolomite throughout their underground traverses. The authigenic karst inlet waters are all saturated or super–saturated with respect to these minerals. Mean total hardnesses vary between regions, from a minimum of 190 mg/L in the Caves Branch of the Boundary Fault region to a maximum exceeding 250 mg/L in the Chiquibul section of the Vaca Plateau. Solutional removal rates calculated from these figures range from 90-150 $m^3/km^2/yr$. The ions removed are nearly all Ca^2+, Mg^2+, and HCO^3-.

Although soil P_CO2's measured on limestone soils in Belize have averaged O.7 %, authigenic spring P_CO2's commonly exceed 1.1 %. This anomaly may be explained both by solution under predominantly open system conditions and by intra–aquifer production of CO_2 from decaying vegetation washed in during floods.

The highly satured authigenic waters have produced enormous volumes of precipitated calcite. Although growth may be extremely rapid (at least one meter–high stalagmite is known to have grown within the past 1000 years), the huge features present (e.g. 30 meter stalagmites and columns 20m in diameter) appear to be the result of the great age of devolopment of these tropical karsts.

The numerous authigenic springs rarely exceed 2 m^3/sec and most discharge only a few 10's of liters/second. Conduit streams are fewer but may exceed 50 m^3/sec following wet season storms. Both conduit and authigenic streams may go dry in the dry season.

Summary

Karst in Belize is diverse and well–devoloped in both surface and sub–surface forms, and ranges from below sea–level to 900 m elevation. An extensive geological and hydrological study now under way will answer many of the questions concerning its age and development. Over 100 km of cavern passage will be surveyed by the end of 1986, most of it in massively brecciated limestone.

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Karst of the Caves Branch, Belize

Dr. Thomas Miller

RESUM

Un carst extensament desenvolupat en calcàries del Cretaci, a la selva tropical, fou objecte d'un estudi hidroquímic, hidrològic i morfològic. Alguns centenars de mostres d'aigua van confirmar una correlació positiva de descàrrega y quimisme en una galeria principal de la cavitat, deguts a la mescla de dos components d'un reservori acumulat durant molt de temps i a la pèrdua del riu superficial. El sistema obert, d'evolució de solució calcita amb producció interna de CO_2, por indicar-se per proporcions de separació del carbonat de 90 $m^3/km^2./any$

Es varen topografiar més de 40 km. de cavitats, el desenvolupament de les quals es troba fortament influenciat pel model de fractura regional i el cabussament topogràfic.

RESUMEN

Un karst desarrollado extensamente en calizas del Cretácico en la selva tropical, fué objeto de un estudio hidroquímico, hidrológico y morfológico. Algunos centenares de muestras de agua confirmaron una correlación positiva de descarga y quimismo en una galería principal de la cavidad, debida a la mezcla de dos componentes de un reservorio largo tiempo acumulado y pérdida del río superficial. El sistema abierto, de evolución de solución de calcita con producción interna de CO_2, puede estar indicada por proporciones de separación de carbonato de 90 $m^3/km^2./año$.

Se topografiaron más de 40 km. de cavidades, con desarrollo influenciado principalmente por el modelo de fractura regional y buzamiento topográfico.

SUMMARY

An extensive karst developed on Cretaceous limestones in tropical rainforest was the site of a hydrochemical, hydrologic, and morphologic study. Several hundred water samples confirmed a positive *correlation of discharge and solute concentration in a major cavern conduit due to two-component mixing of long-term aquifer storage and pirated surface river water. Open-system calcite solution evolution, with internal CO_2 production, may be indicated, with carbonate removal rates of 90 $m^3/km^2/yr$.*

Over 40 km of caverns were surveyed, with development chiefly influenced by regional fracture patterns and topographic dip.

Introduction

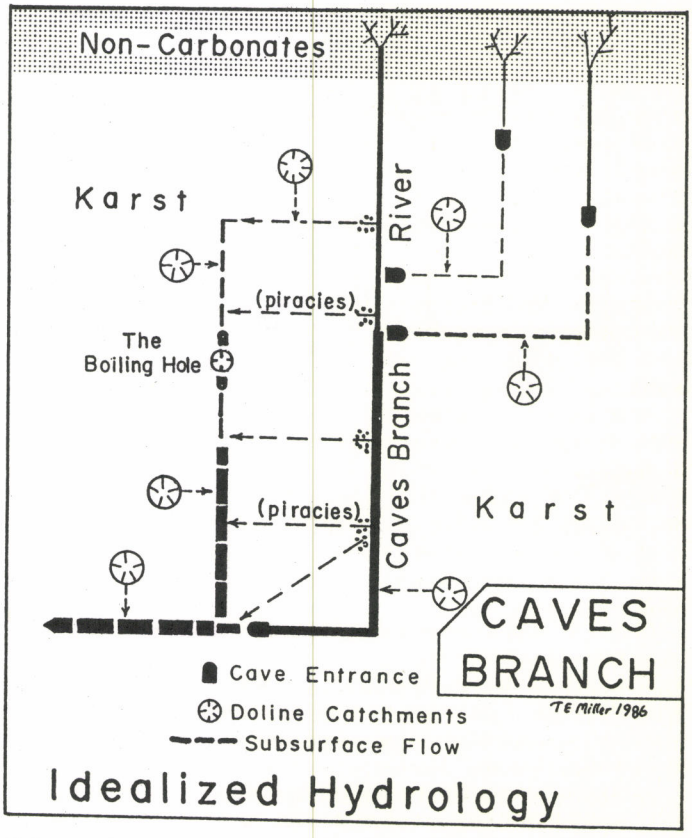
The Caves Branch Karst covers an area of approximately 145 km^2 in the center of Belize, Central America. It consists of a platform (at 40-300 m elevation) of heavilly brecciated Cretaceous carbonates sloping northward away from the Northern Boundary Fault. The Caves Branch River originates on the non-carbonate rocks of the 1.000-meter-high Maya Mountains to the south, then flows 10 km into its polje before sinking. Two smaller allogenic streams debouch into the main polje: the three streams drain catchments totalling 90km^2. The Caves Branch was at one time throughflowing to the sea.

Climate

The Caves Branch lies in tropical rainforest. Mean annual temperature and rainfall are 24°C. and 240 cm, respectively. Most rain falls in the June to November wet season, as convective precipitation, with recorded 24-hour maxima of 232 mm. Evapotranspiration is calculated at~120 cm/year.

Surface Features

The karst borders the Caves Branch River polje as escarpments. Within the body of the karst, different surface «textures» result from past geomorphic history (e.g. fluviokarst) or probable lithologic/compositional bedrock variance. The majority of the area, consisting of large mega-dolines (> 30 m relief) can be termed a «cockpit karst» because of its similarity to those of Jamaica. These cockpits and dolines are frequently drained by swallets in the clay and soil of the cockpit bottom. The hilltops are usually fissured bedrock. Alluvium is rarely more than a few meters overlying bedrock in the cockpits.



Collapse features are areally insignificant, although they may expceed 150 meters in depth. The cockpits forming most of the surface show significant association with lineations and fracture patterns observed on airphotos.

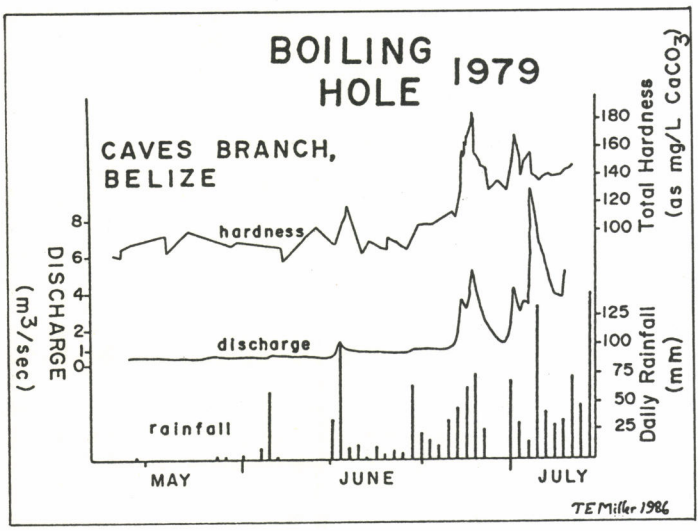
Cavern Features

Nearly 40 km of cavern passages have been explored in the Caves Branch. The majority of these represent epiphreatic and vadose trunk conduits 20-30 m wide transporting allogenic water from the non-carbonate highlands through the karst to the lowlands and coast. Second in known lenght are large (to 300 m length) isolated collapse chambers, probably of phreatic origin, that appear to be randomly intersected by the trunk conduits. Those caves produced entirely by rainfall falling directly on, and routed through, the karst, tend to be small (< 1 meter diameter), short, and often phreatic. In contrast to the large cobbles transported in the trunk conduits, these latter caves contain little clastic material.

The allogenic trunk conduits appear to be the foci of cave development and integration. Through lateral passage abandonment and vertical incision, nearly all have archieved extremely low gradients (< 1 m/km). The conduits tend to parallel regional fault patterns and observed photo-lineations as could be expected from the near-total absence of bedding planes and the extreme brecciation of the bedrock.

Over 10 km of large trunk passage parallel the surface course of the Caves Branch River. At one time it took the entire flow of the river: extreme infilling blocked the original ponor entrance causing both paragenesis in downstream portions of the caverns, and development of numerous small conduits pirating surface river water back to the trunk cave conduits (Fig. 1).

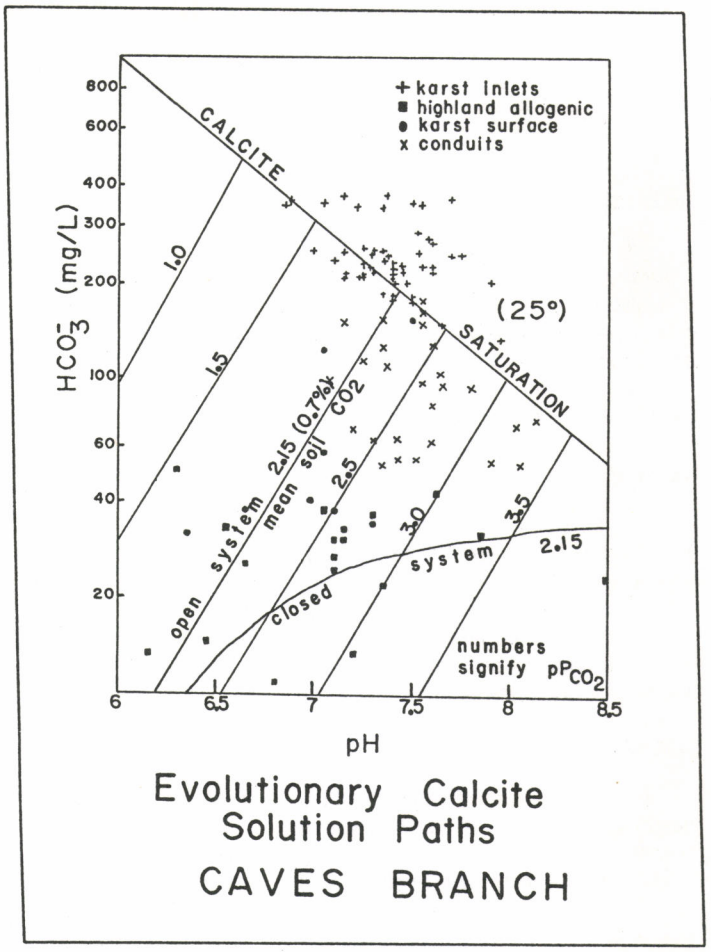
Integration of the small channels (karst inlets) transporting runoff from the karst surface appears to have occured subsequent to full development of the trunk conduits. Radiometric dating gives a minimum age of 102 (+/– 4) k.y. B.P. for this.



Hydrology

The geomorphic events which led to the development of the caverns have also created an anomalous hydrochemical response in the allogenic conduits with resulting total hardness/discharge correlation dependent upon seasonally specific restrictions. The conduit was monitored at a karst window called the Boiling Hole (Fig. 2).

Waters that fall directly upon the karst emerge as high-hardness springs in the trunk conduit. They are morphologically distinct from the channels that progressively pirate water from the Caves Branch River sufrace channel in the polje. Dry season *hydrologic* restraints upon the karst inlet springs contribute to a «normal» situation where solute concentration is inversely related to instantaneous flow. In the wet season, *hydraulic* restraints upon the other spring-type (water pirated from the surface river) permit it to be overwhelmed during storm-induced pulses of the cockpit-source water. These phenomena allow construction of a mixing-



model whose predicted hydrochemical output is excellently correlated with that actually recorded. Throughout the flow range of 0.6 to 10 m^3/sec, the mixing model developed for this phenomenon had a statistically significant R^2 of 0.86.

Aquifer Interior

Analysis of the baseflow data from the Boiling Hole and from the karst inlet springs enabled inferences to be drawn about the interior of the karst aquifer. A pronounced delay in flow response at the start of each wet season was determined to be the result of replenishment of 4.5 × 10^6 m^3 of water storage depleted during the dry season. This gave minimum estimates of 0.5-0.7 % for the porosity of the aquifer, with actual values probably closer to 2-3 %.

Soil CO_2 measured in the area had average values of 0.6-0.7 %, considerably lower than the 1.1 % mean PCO_2 observed in the karst inlet springs. The large porosity of the aquifer could explain much of this disparity as due to open system evolution within the karst (Fig. 3); the excess is probably due to intra-aquifer production of CO_2 from decay of organic debris commonly flushed into the karst aquifer from the rainforest.

The mean discharge-weighted total hardness for the karst inlet springs was ~190 mg/L, and with the calculated annual runoff gives a solution removal rate of 90 $m^3/km^2/yr$.

Summary

The hundreds of water samples analyzed from the Caves Branch have contributed to a clearer understanding of karst solution processes in the tropics. Physical exploration of 40 km of cavern pasage in the area was crucial to comprehension and modelling of the aquifer.

First contribution to the Knowledgment of the hydrogeology of the Sagada karst area (Mountain Province-Philipphines)(1)

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RESUM

Durant l'expedició espeleològica «Sagada 85» es dugueren a terme una sèrie d'investigacions hidrogeològiques i hidroquímiques per a definir les direccions del fluxe hídric a l'interior de l'aqüífer càrstic i per a estudiar possibles interconexions entre les coves d'aquesta regió.

En el present treball es fa una relació dels primers resultats aconseguits, acompanyats d'un esquema hidrogeològic de l'àrea càrstica de Sagada.

RESUMEN

Durante la expedición espeleológica «Sagada 85» se llevaron a cabo observaciones hidrogeológicas e hidroquímicas para definir las direcciones del flujo en el interior del acuífero kárstico y para probar las posibles interconexiones existentes entre las cuevas de esta región.

En el presente trabajo se relacionan los primeros resultados y se exhibe además un esquema hidrogeológico del área kársitca de Sagada.

SUMMARY

During the speleological expedition «Sagada'85» hydrogeological and hydrochemical observations were carried out in order to define the flow directions inside the karst aquifer and to test the possible interconnections existing between the caves of this region.

In the present paper the first acheived results are reported and a hydrogeological scheme for the Sagada karst area is also put forth.

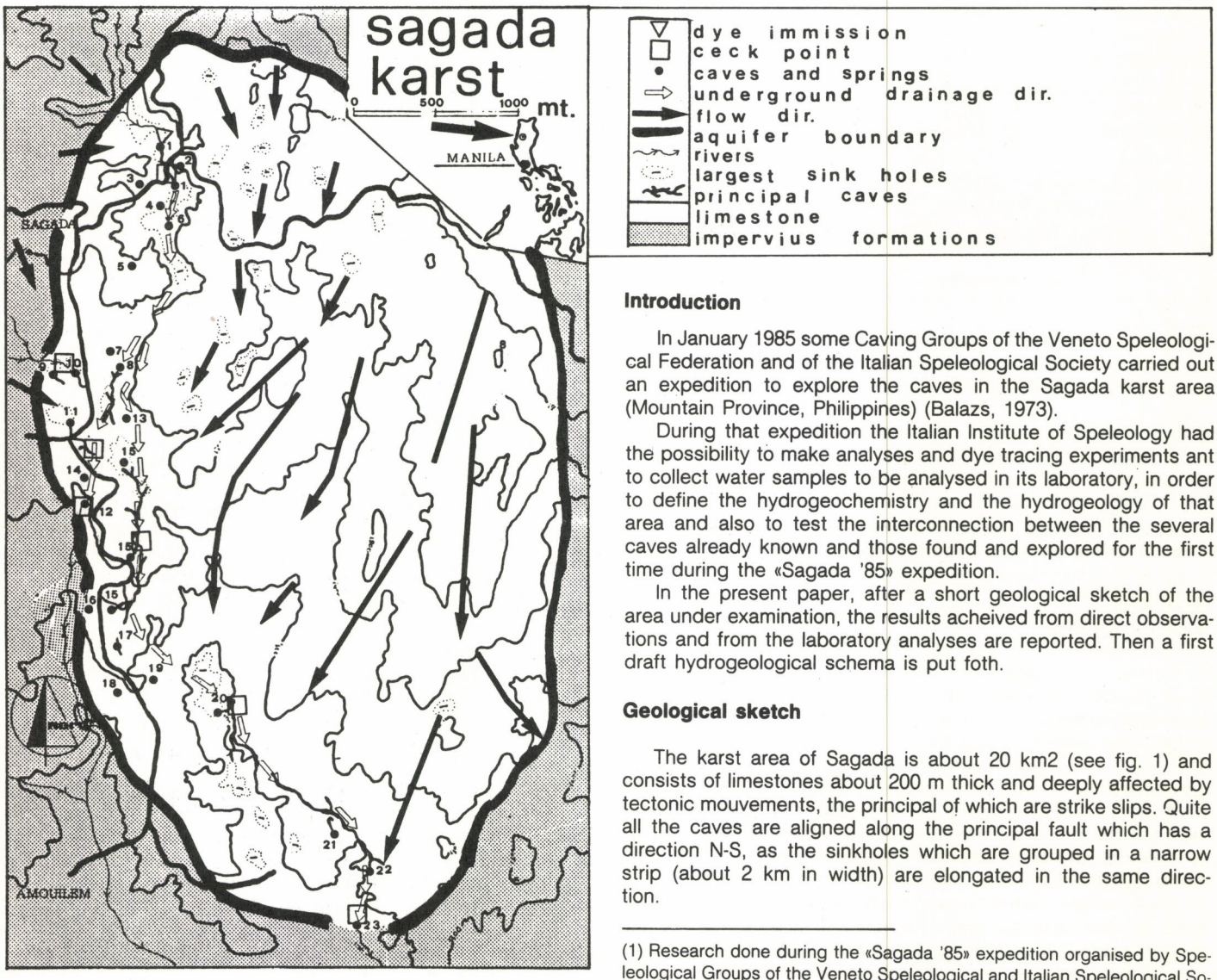


Fig.1 Hydrogeological sketch of the Sagada karst aquifer

Introduction

In January 1985 some Caving Groups of the Veneto Speleological Federation and of the Italian Speleological Society carried out an expedition to explore the caves in the Sagada karst area (Mountain Province, Philippines) (Balazs, 1973).

During that expedition the Italian Institute of Speleology had the possibility to make analyses and dye tracing experiments ant to collect water samples to be analysed in its laboratory, in order to define the hydrogeochemistry and the hydrogeology of that area and also to test the interconnection between the several caves already known and those found and explored for the first time during the «Sagada '85» expedition.

In the present paper, after a short geological sketch of the area under examination, the results acheived from direct observations and from the laboratory analyses are reported. Then a first draft hydrogeological schema is put foth.

Geological sketch

The karst area of Sagada is about 20 km2 (see fig. 1) and consists of limestones about 200 m thick and deeply affected by tectonic mouvements, the principal of which are strike slips. Quite all the caves are aligned along the principal fault which has a direction N-S, as the sinkholes which are grouped in a narrow strip (about 2 km in width) are elongated in the same direction.

(1) Research done during the «Sagada '85» expedition organised by Speleological Groups of the Veneto Speleological and Italian Speleological Society.

The high karstification degree along this fault suggest the existence of a principal underground river in which all the waters of the karst aquifer were collected. Moreover, the limestone outcrops bend towards the fault, thus supporting this hypothesis.

Authors (Deharveng, 1980) suggested that limestones represent a syncline structure, but we partially desagree with this opinion, because the whole karst area underwent rigid stresses which caused the high fracturation degree of the limestones, while no evidence was found of plastic deformations.

Moreaver no horizontal strata have been observed along the fault line.

Phisico – Chemical analyses

During the expedition, due to the very difficult conditions in which we have to operate, only few analyses had the possibility to be carryed out in the field

In fact only Temperature, pH, EH and conductivity measurements have been done (see tab. 1).

Tab. 1 Data taken in the field. Number before the cave names are the samo of those in fig. 1

Caves	Temperature °C	pH	EH mV	Conductivity siem/cm
1 Latan	20.5	8.07	275	157
8 Tangeb	17.5	7.62	220	250
8 Tangeb 2	18.5	7.52	227	189
10 Demang 2	17.0	8.05	194	239
11 Agoio ige	18.5	7.94	270	202
12 Ambasing	18.3	7.90	203	200
14 Sumagin	17.3	8.00	243	237
19 Tatatia an	21.5	7.05	250	356
23 Balangagan	21.5	7.43	210	351

Samples of water have been taken from all the principal check points and then they were fully analised in the laboratory of the Italian Istitute of Speleology at the end of the expedition (see Tab. 2).

Tab. 2 – Chemical analyses of he water samples collected during the «Sagada 85» expedition. Numbers before the cave names are the same of those in fig 1. Concentrations in meq/1.

Caves	Ca++	Mg++	Na+	K+	Cl–	S04=	HC03-	N03-
1 Latan	1.5	0.	0.78	0.05	0.06	1.0	1.5	0.015
12 Ambasing	1.9	0.4	1.09	0.06	0.10	1.5	2.3	0.012
15 Sumagin	2.6	0.2	0.74	0.05	0.06	1.5	2.7	0.010
20 Tataia an	3.7	0.1	1.46	0.15	0.20	2.4	3.4	0.015

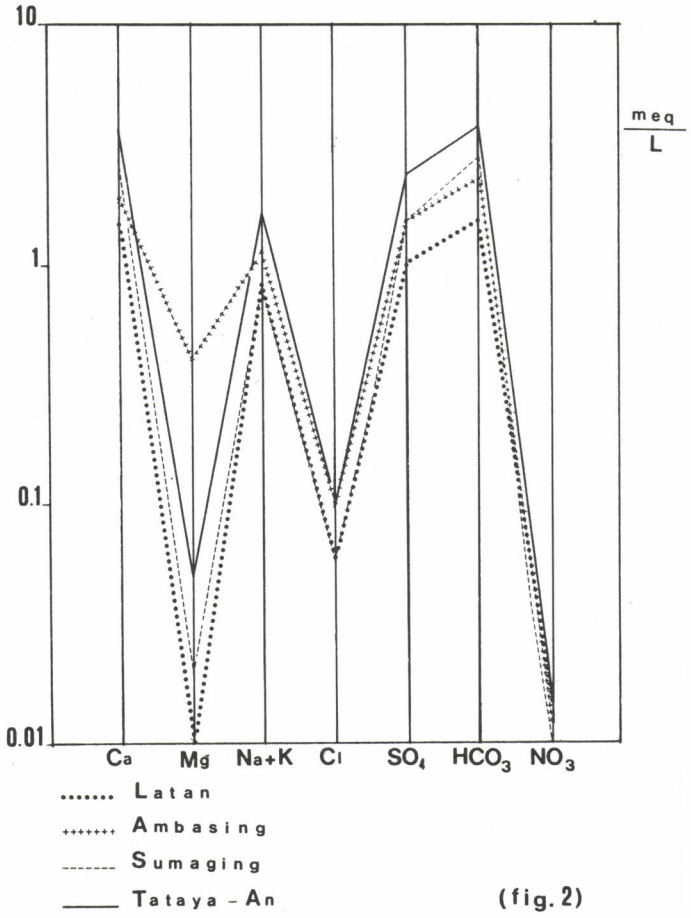
The results were plotted in a Schoeller diagrams (see fig. 2) to visualize the chemical behaviour of these waters, which seem to be similar each other.

Dye tracing test

To test the hypotesis of the existence of a single principal underground river linking all the different caves of the area a tracing experiment was carried out, dissolving 5.2 kgs of Uranine in the water sinking (about 45 l/s) near Latan (1 in fig. 1), while active coal have been placed in Sumaging, Tataia ann and Balanagan caves (15, 20 and 23 respectively in fig. 1).

About 34 hours after the its immission, the dye was clearly visible in the Ambasing spring (12 in fig. 1) where the rice-fields were completely flooded by the tracer, and in the river inside the Agoio Inge cave (11 in fig. 1)

Coal samples from Sumaging, Tataia ann and Balanagan were collected after a week and all proved to be positive, the dye content lowering from Sumaging to Tataia ann and to Balanagan. The hydrological connection of all the caves of the Sagada karst area was thus demonstrated.



(fig. 2)

Schoeller diagrams for the sampled waters from Sagada Karst area

Discussion

The tracing test clearly indicates that all the Sagada karst area is drained by a principal subterranean river directly connects all the caves along the N-S faults. The presence ot the uranine both in the Ambasing and Balanagan springs suggest the presence of a diffluence in the subterranean river between Latan and Ambasing. Infact the water springing in Ambasing do not have the posibility to reach for a second time the karst aquifer because, due to the structural and geological settlement of the area, an impervious boundary is placed just between the Ambasing river and the karst aquifer (see fig. 1). This is confirmed also by the remarkable differences in chemical composition of the waters of the Ambasing river and those of Sumanging (12 and 14 respectively in fig. 1): in particular the Mg content is very higher in Ambasing and this difference cannot be explained if the Sumanging water was partially derived from that of Ambasing. The high Mg content of the Ambasing spring with respect to all the other analysed waters can be justified by the fact that to the Ambasing spring contibute also two small river flowing over marls and clays which allow magnesium concentration.

Flow rates inside the aquifer are sufficiently high so that the presence of large storage basins or semipermeable sills can be rejected, as that of sand or clay interstrata: quite all the water sinking in Latan flows in a subterranean river, which we actually know only for some short paths, to reach the Ambasing and Balangang springs.

The difference in the observed tmeperatures have to be related to local inlets of waters from the sruface which more or less affect the temperature of the underground stream. The same can be said of the pH and the EH which are deeply influenced by the humic acids and other organic substancies brought inside the system by metheoric waters.

The calcium carbonate content, as that of Sulfates, fallow a normal trent of increase from the sinking to the spring, while the conductivity shows differencies probably due to the same factors affecting temperatures, pH and EH values.

The low nitrate content found in all the analysed waters proves that actually no deep pollution problems arise even if it is still normal to bury the deasd just in the cave entrance and often in direct contact with the flowing water.

Conclusions

The expedition «Sagada 85» allowed the definition of the boundaries of the karst aquifer, which showed to be single. Moreover the result of the tracing test has been very usefull to define the hydrodynamic of the system and the flow directions inside the aquifer.

On the other hand the chemical analyses, even if usefull, cannot be suficient to describe fully the chemical behaviour of the Sagada karst aquifer.

Therefore in the next future we have the intention to make sytematic chemical analyses in order to solve also this problem.

Aknowledgment

The authors will thank to Valentina Reyes and her family for ther fundamental support given during the expedition.

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Les échanges carboniques au niveau du drainage karstique majeur – Comparaison entre les rivières souterraines des Vitarelles (Lot, France) et de Remouchamps (Liège, Belgique)

Philippe Renault et Camille Ek

RESUM

L'any 1982, Renault va presentar un model de transferències carbòniques endocàrstiques entre la superfície i l'aqüífer. Ell considera que la superposició d'una zona pedològica productora de CO_2 amb una zona seca amb contenidors elevats del Lot i d'altres cavitats situades a un nivell superior de l'aqüífer (zona de contacte i intercanvis entre l'atmosfera subterrània i l'aqüífer) determina dos tipus de perfils de les variacions de la pCO_2 a les galeries recorregudes per un riu subterrani corresponent a un major drenatge: (1) les pCO_2 a nivell del riu subterrani són inferiors a les pCO_2 de la zona seca subjacent quan aquesta última està mal ventilada (per exemple els rius subterranis del Lot); (2) pCO_2 decreixents, aigües avall del riu subterrani, i superiors a la mitja de la zona seca a l'exterior i, en el segon cas, una aportació de CO_2 per part de l'aqüífer. Es tracta de situacions tipus, resultants dels caràcters del sistema càrstic local, interpretable en funció del sistema d'observació, a partir de l'estructura morfosedimentària del massís i del sistema meteohidrològic corresponent.

RESUMEN

Anteriormente ha sido presentado un modelo de transferencias carbónicas endokársticas entre la superficie y el aquífero (Renault, 1982). Él, considera la superposición de una zona pedológica productora de CO2, de una zona seca con contenidores elevados en el Lot, y cavidades a un nivel superior del acuífero donde el régimen de cambios en el contacto atmósfera subterránea acuífero, determina 2 tipos de perfil de variaciones de la pCO2 en las galerías reseguidas por un río subterráneo correspondiente a un mayor drenaje: (1) los pCO2 a nivel del río subterráneo son inferiores a los pCO2 de la zona seca subyacente, cuando esta última está mal ventilada (por ejemplo ríos subterráneos del Lot) (2) pCO2 decrecientes hacia el tramo aguas abajo del río subterráneo, y superiores a los promedios de pCO2 de la zona seca subyacente. En primer caso hay transferencia de CO2 de la zona seca al exterior y en el segundo caso, aporte CO2 por el acuifero. Se trata de situaciones–tipo resultantes de los caracteres del sistema kárstico local, interpretable, en función del sistema de observación, a partir de la estructura morfo–sedimentaria de macizo y del sistema meteohidrológico correspondiente.

RESUME

Un modèle des trasferts carboniques endokarstiques entre la surface et l'aquifère a été présenté antérieurement (Renault 1982). Il considère la superposition d'une zone pédologgique productrice de CO_2, d'une zone sèche à teneurs élevées dans le Lot, et de cavités au niveau supérieur de l'aquifère où le régime des échanges à l'interface atmosphère souterraine/aquifère dètermine 2 types de profil des variations de la pCO_2 dans les galeries suivies par une rivière souterraine correspondant à un drainage majeur: (1) les pCO_2 au niveau de la rivière souterraine sont inférieures aux pCO_2 de la zone sèche sus–jacent, lorsque cette dernière est mal ventilée (par exemple rivières souterraines du Lot), (2) pCO_2 décroissantes vers l'aval de la rivière souterraine, et en moyenne supérieures aux pCO_2 de la zone sèche sus–jacente. Dans le 1° cas il y a transfert du CO_2 de la zone sèche vers l'extérieur, et, dans le 2° cas, apport de CO_2 par l'aquifère. Il s'agit de situations–type résultant des caractères du système karstique local, à interpréter, en fonction du système d'observation, à partir de la structure morpho–sédimentaire du massif, et du système météohydrologique correspondant.

10104

Structural, lithologic and hydrologic controls on cave development at Friars Hole System, West Virginia, USA

S.R.H. Northington

RESUM

El Frias Hole System, amb 67 km. de galeries, és el sistema de coves més llarg que es coneix a la serralada dels Apalaches. La cova s'obre en una seqüència de calcàries de 200 m. de gruix amb capes més petites d'esquists i dolomies, que cabussen suaument cap el N.O. Distingirem tres tipus genètics de galeries a la cova. Les galeries de l'entrada presenten una inclinació descendent i es van formar a la zona vadosa. Les galeries d'enllaç comuniquen les entrades amb els drenatges principals i són normals a aquests darrers. Els drenatges principals estan orientats segons les fractures, amb poca inclinació i desenvolupats justament a sota la superfície piezomètrica. Hom les troba sovint en el punt d'intersecció d'una falla invertida amb un o dos dels plans d'estratificació de la calcària basal. La zona de fractura de les falles ha modificat els models de dissolució, originant àmplies cavitats, que suposen el 30 % del volum de la cova. Els sediments silici-clàstics dels sòls dels corredors impedeixen la dissolució de nivells inferiors, de tal manera que la circulació queda relegada a una zona molt per damunt de la superfície piezomètrica.

RESUMEN

El Frias Hole Sistem, con 67 km. de galerías, es el sistema de cuevas más largo conocido en los Montes Apalaches. La cueva está desarrollada en una secuencia de calizas de 200 m. de grosor con espesores menores de esquistos y dolomias, que buzan ligeramente hacia el Nor-oeste. Se reconocen tres tipos genéticos de galerías en la cueva. Las galerías de entrada presentan gran inclinación hacia abajo y se formaron en la zona vadosa. Las galerías de enlace unen las entradas con los drenajes principales y son normales a estos últimos. Los drenajes principales están orientados según las fracturas, con escasa inclinación y desarrollados justo debajo de la superficie piezométrica. Se les encuentra frecuentemente en el punto de intersección de una falla inversa, y uno o dos planos de estratificación de la caliza basal. La zona de fracturación de las fallas ha modificado los modelos de disolución resultando amplias cavidades que suponen el 30 % del volumen de la cueva. Los sedimentos siliciclásticos en los suelos de los corredores impiden la disolución en niveles inferiores, de tal modo que la circulación queda colgada muy por encima de la superficie piezométrica.

SUMMARY

Friars Hole System, with 67km of passage, is the longest known cave system in the Appalachian Mountains. The cave is developed in a 200m thick sequence of limestones, with minor shales and dolomites, which dip gently to the north-west. Three genetic types of cave passage are recognised. Inlet passages are high-gradient, downdip, and were formed in the vadose zone. Linking passages integrate the inlets with the main drains, and are normal to the latter. Main drains are strike-oriented, low gradient, and developed just below the piezometric surface. They are frequently found at the intersection of a thrust fault and one of two bedding planes in the basal Union Limestone. *Breakdown on thrust faults has disrupted solution patterns, resulting for several large voids which account for 30 % of the cave volume. Siliciclastic sediments on passage floors inhibit downward solution, causing streams to be perched far above the piezometric surface.*

1081

Les systèmes karstiques des Alpes Ligures (Italie Occidentale)

Gilberto Calindri
G. S. Imperiese CAI

RESUM

Exposició sintètica dels carsts dels Alps Ligurs: hi destaquem els caràcters litològics i tectònics, el paper de les glaciacions quaternàries i la morfologia càrstica actual.
Es tracta de definir una tipologia dels sistemes hidrològics càrstics en funció del seu grau d'organització, de les condicions d'alimentació i, especialment, de les dades hidroquímiques. Mesurem també, particularment, les taxes de disolució total.

RESUMEN

Exposición en síntesis de los karsts de los Alpes Ligures: se destacan los carácteres litológicos y tectónicos el papel de las glaciaciones cuaternarias y morfología kárstica actual.
Se trata de definir una tipología de los sistemas hidrológicos kársticos en función del grado de organización, de las condiciones de alimentación y especialmente de los datos hidroquímicos. Particularmente se miden las tasas de disolución total.

RESUME

Exposé synthétique des karsts des Alpes Ligures: ont souligne les caractères lithologiques et tectoniques, le role des glaciations quaternaires et l'actuelle morphologie karstique.
On essaye de dégager une typologie des systèmes hydrologiques karstiques en fonction du degré d'organisation, des conditions d'alimentation et surtout des donneés hydrochimiques. En particulier ont fait l'objet de mesures les taux de dissolution totale.

10128

Le problème des fontaines intermittentes précisé dans une perspective systémique.

Philippe Renault

RESUM

Les intermitències càrstiques van intrigar els naturalistes fins el segle XIX, per esdevenir més tard simples curiositats, episòdicament estudiades arran d'algun estudi hidrogeològic.
L'explicació de les intermitències sempre ha tingut com a referència una màquina hidràulica simple (sifó, presa d'aire, campana baromètrica,...), però l'existencia d'aquests dispositius no ha estat mai observada, funcionalment, en el transcurs de cap exploració de la xarxa subterrània, riu amunt. Les recents descripcions espeleològiques de la zona seca i de la zona inundada, porten a la revisió d'aquest fenomen, dins d'una perspectiva sistemàtica.
Els caràcters hidràulics i geomorfològics de les sorgències intermitents, obliguen a una anàlisi dels fenòmens de contacte entre les zones seca i inundada, a partir de les variacions del cabal i del ritme d'emisió de les bosses d'aire que solen acompayar–los freqüentment.

RESUMEN

Las intermitencias kársticas han intrigado a los naturalistas hasta el siglo XIX, después fueron consideradas como simples curiosidades, episódicamente estudiadas a propósito de un estudio hidrogeológico.
La explicación de las intermitencias, siempre se ha referido a una máquina hidráulica simple – sifón, toma de aire, campana barométrica ..... –, pero la existencia de estos dispositivos no ha sido jamás observada, funcionalmente, en el curso de una exploración de la subterránea rio arriba. Las recientes descripciones espeleológicas, en la zona seca y en la inundada conducen a una revisión de este problema dentro de una perspectiva sistemática. Los caractéres hidráulicos y geomorfológicos de las surgencias intermitentes inducen a un análisis de los fenómenos de contacto entre zona seca e inundada a partir de las variaciones de caudal y del ritmo de emisión de las bolsas de aire que las acompañan frecuentemente.

RÉSUMÉ

Les intermittences karstiques ont intrigué les naturalistes jusqu'au XIXº siècle, puis furent considérées comme simples curiosités, épisodiquement étudiées á propos d'une étude hydrogéologique.
L'explication des intermittences s'est toujours référée à une machinerie hydraulique simple, –siphon, prise d'air, cloche barométrique,...–, mais l'existence de ces dispositifs n'a jamais été observé, fonctionnel, au cours d'une exploration du réseau souterrain amont. Les descriptions spéléologiques, dans la zone sèche et plongée, conduisent á revoir ce problème dans une perspective systémique. Les caractères hydrauliques et géomorphologiques des émergences intermittentes induisent une analyse des phénomènes d'interface entre zones sèche et noyée á partir des variations de débit et du rythme d'émission des bulles d'air qui accompagnent le plus souvent celles-ci.

10106

Recent geohydrological studies at Crowsnest Pass, Alberta, Canada

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RESUM

Crowsnest Pass és una profunda fractura a través de carbonats massius del Paleozoic Superior. El drenatge de direcció, orientat cap a la collada, ressorgeig en dues sorgències principals (Crowsnest Spring i Ptolemy Spring) i en vàries sorgències menors. La coloració inicial indica velocitats de trànsit molt més accentuades cap a Crowsnest Spring que no pas cap a Ptolemy Spring (100 m/h i 16 m/h, respectivament). Malgrat tot, i paradoxalment, la variació diurna de la descàrrega és molt superior en l'última sorgència. Les característiques de l'aqüífer es troben en fase d'investigació, utilitzant-se, a tal efecte, fluorometria, hidrologia d'isòtops, química de l'aigua i variacions de la descàrrega.

RESUMEN

Crowsnest Pass es una profunda fractura a través de carbonatos masivos del Paleozoico Superior. El drenaje de dirección orientado hacia el collado, resurge en dos surgencias principales (Crowsnest Spring y Ptolemy Spring) y en varias surgencias menores. La coloración inicial ha revelado velocidades de tránsito mucho mayores hacia Crowsnest Spring que hacia Ptolemy Spring (100 m/h y 16 m/h. respectivamente), sin embargo, paradójicamente la variación diurna en descarga es mucho mayor en la última surgencia. Las características del acuífero están siendo investigadas normalmente, usando fluorometría, hidrología de isótopos, química del agua y variaciones de la descarga.

SUMMARY

Crowsnest Pass is a deep breach through massive Upper Paleozoic carbonates. Strike-oriented drainage towards the pass resurges at two major springs (Crowsnest Spring, Ptolemy Spring) and at several minor springs. Initial dye tracing has revealed much higher flow velocities to Crowsnest Spring than to Ptolemy Spring (100m/hr and 16m/hr respectively), though, paradoxically, the diurnal variation in discharge is much greater at the latter spring. Aquifer characteristics are currently being investigated, using fluorometry, isotope hydrology, hydrochemistry and discharge variations.

10277

Diffuse flow and conduit flow in the Greenbrier Limestone at Locust Creek, West Virginia, USA

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RESUM

Les dades recollides diàriament al col–lector càrstic de Locust Creek, han estat analitzades i han demostrat que els corrents ràpids constituïen el 68 % de la descàrrega anual. Es va deduir que l'acumulació de la circulació de base de la zona difusa havia de ser 900 vegades més gran que el volum dels conductes submergits, mentre que l'acumulació a la zona vadosa era 75 vegades més gran.

Els cálculs efectuats han fixat una capacitat d'emmagatzement de la zona difusa de 0,028 i una transmisivitat de 457–2139 m^3 segons el grau de pressió superficial. Els cálculs sobre la conductivitat hidràulica de la zona difusa han donat uns valors de l'ordre de 22–97 m. per dia o bé de 88 – 412 m. per dia, segons si considerem una conductivitat hidràulica constant a l'interior de l'aqüífer o bé que aquesta va disminuint de forma exponencial amb la profunditat. Es va calcular un factor de fricció de 63, a partir de la cavitació i de les dades referents a la circulació del veí sistema de Friars Hole. Això ha permés de fer estimacions sobre la importáncia relativa de la circulació per conductes i de la circulació difusa de l'aqüífer. Val a dir que la circulació per conductes comprèn del 80 % al 90 % del cabal total.

RESUMEN

Los datos enviados cotidianamente del colector kárstico de Locust Creek, se analizaron y mostraron que las circulaciones rápidas constituían el 68 % de la descarga anual. Se estimó la acumulación de la circulación de base en la zona difusa ser de 900 veces el volumen de los conductos sumergidos, mientras que la acumulación en la zona vadosa era 75 veces mayor que la última. Los cálculos han dado una capacidad de almacenaje de la zona difusa de 0,028 y una transmisibilidad de 457–2139 m^3 por día, según el nivel de presión de la superficie. Los cálculos de la conductibilidad hidráulica en la zona difusa han dado 22–97 metros por día o bien 88–412 metros por día, según se considera una conductibilidad hidráulica constante en el interior del acuífero o que esto disminuya de forma exponencial con la profundidad. Se calculó un factor de fricción de 63 a partir de la cavitación y las medidas de circulación partiendo del vecino sistema de Friars Hole. Esto permitió hacer estimaciones sobre la importancia relativa de la circulación por conducto y difusa en el acuífero, con conductos que comprenden 80 a 90 % del caudal total.

RÉSUMÉ

Les donnés envoyées quotidiennement, du collecteur karstique de Locust Creek furent analysées, et ont montré que les écoulements rapides composaient 68 % des envois annuels. L'accumulation de l'écoulement de base dans la zone diffuse se révéla être 900 fois le volume des conduits submergés, tandis que l'accumulation dans la zone «vadose» était 75 fois égale à la dernière. Les calculs ont donné une storativité de la zone diffuse de 0.028 et une transmissibilité de 457–2139 m^3 par jour, selon le niveau de pression de la surface. Les calculs de la conductibilité hydraulique dans la zone diffuse ont donné 22–97 metrès par jour ou 88–412 mètres par jour, selon que l'on considère un conductibilité hydraulique constante a l'intérieur de l'aquifère ou que cela diminue de manière exponentielle avec la profondeur. Un facteur friction de 63 fut calculé à partir des vagues d'erosion et les mesures d'écoulement à partir du proche système de Friars Hole. Ceci permit que des estimations soient faites sur l'importance relative de l'ecoulement conduit et diffus dans l'aquifiere, avec des conduits comprenant 80 à 90 % du débit total.

10299

Some recent advances in karst water tracing in the Canadian Rockies

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RESUM

S'ha dut a terme un programa de coloració de l'aigua dels aqüífers càrstics de les Canadian Rockies amb el propòsit d'identificar l'estructura de l'aqüífer. S'han utilitzat mètodes d'hidrologia física, fluoresceïna, isòtops i coloració termal, que s'han fet servir per a generar estructures aqüíferes hipotètiques que puguin ésser emprades en el desenvolupament de models de base física.

RESUMEN

Se ha efectuado un programa de coloración del agua en los acuíferos kársticos de las Canadian Rockies con la intención de identificar la estructura del acuífero. Se han empleado métodos de hidrología física, fluoresceína, isótopos y coloración termal y se han utilizado para generar estructuras acuíferas hipotéticas que pueden ser empleadas en el desarrollo de modelos de base física.

SUMMARY

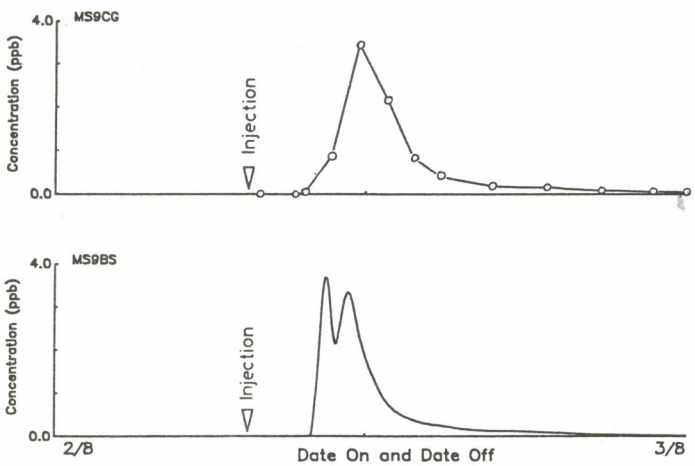
A programme of water tracing in karst aquifers of the Canadian Rockies has undertaken with the intent of identifying aquifer structure. Physical hydrology, fluorescent tracing, isotopic tracing and thermal tracing have been employed, and have been used to generate hypothetical aquifer structures which may be used the development of physically based models.

Introduction

Karst groundwater flow is predominantly controlled by the form of the conduit network which is unique to each karst aquifer. Techniques allowing the identification of the conduit network are therefore fundamental to the study of karst hydrogeology. A programme of water tracing has been initiated in the Canadian Rocky Mountains with studies made in the Castleguard Karst of Banff National Park (Ford 1983), and the Maligne Karst of Jasper National Park (Brown 1972) in the Canadian Rocky Mountains, and also in Glacier National Park in the Columbia Mountains (Ford 1969). These aquifers are suitable for such an investigation because they are dominated by conduit flow, have very rapid groundwater velocities, and great variations in flow regime over a short season.

Methods used were primarily physical hydrology and fluorescent tracing, with isotopic tracing, hydrochemistry and thermal tracing as minor methods. Regular diurnal floods with short term storm events superimposed on a six month melt season allows efficient application of flood pulse methods (eg. Ashton 1966). Fluorescent tracers were those recommended by Smart and Laidlaw (1977). Samples were collected by automatic water sampler or were analysed directly using continuous flow fluorometry. The tracer breakthrough curves were evaluated on the systematic basis proposed by Smart and Ford (1982). In order that this scheme may be applied, other processes must be insignificant. In particular, the tracer must be truly conservative and the breakthroug curve defined without error. Measurements of Rhodamine dyes were corrected to a standard temperature, and all traces were standardised to a one kilogramme injection.

P. Smart (1981) has demonstrated the need for replicate tracing, not only to confirm the reliability of the breakthrough curves, but also to document changes in system performance under different flow conditions. Twelve traces were made at Castleguard to a sample of six springs out of some 80, along with measurements of discharge, carbonate and deuterium ratios. In a continuation of this work, four traces have been made at Maligne to 15 springs to supplement previous work by Brown (1972), and Kruse (1980). Not only does discharge effect tracer results, but short term changes in discharge are also important. The Cascade Karst System in Glacier Park has very rapid groundwater velocities and diurnal flow variations, and 57 traces were made here to study the effect of unsteady flow. The Castleguard results have been most fully interpreted, while the Glacier Park and Maligne data remain preliminary.

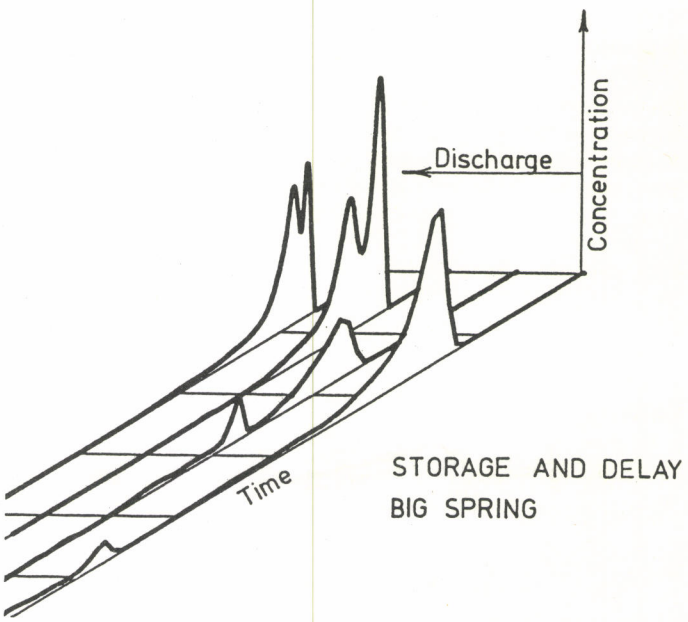


1. Breakthrough curves defined by grab sampling and continuous flow fluorometry on closely related springs. The bimodal breakthrough curve has not been detected in the first case.

Results

Improvements in field fluorometric techniques are a major outcome of these studies. The rapid travel times of tracer dyes in alpine karst have led to the adoption of high precision, continuous flow fluorometry as the preferred means of analysis. Figure 1 shows the loss of information caused by an inadequate sampling frequency. In Glacier Park, both Rhodamine Wt and Fluorescein were used in simultaneous traces, with groundwater velocities of some two kilometres per hour. Continuous fluorometry was essential, but two fluorometers and chart recorders were necessary. The records of the 57 traces then had to be digitised from several tens of meters of chart paper, an inefficient process. Most recently, at the Maligne karst, a data logger has been attached to a continuous flow fluorometer. This allows precise calibration, very high frequency sampling and averaging, automatic temperature correction, digital data storage and electronic recovery of the breakthrough curve data. These advantages are only at some cost; the instruments are expensive, and logistically demanding. Routine point-to-point tracing, or aquifers with more normal flow-through times are best approached with more conventional techniques.

As an example of the development of underground linkages, figure 2 shows a series of traces from Castleguard which suggest a bifurcation in the flow route becoming more strongly differentiated as discharge falls. Under the lowest flow conditions, tracer dye has been stored in one route until it is flushed out on a subsequent trace. P. Smart (1981) treats this condition more fully. However, further traces under similar conditions failed to produce the expected bimodal breakthrough curve, suggesting that this is actually an unsteady flow phenomenon.



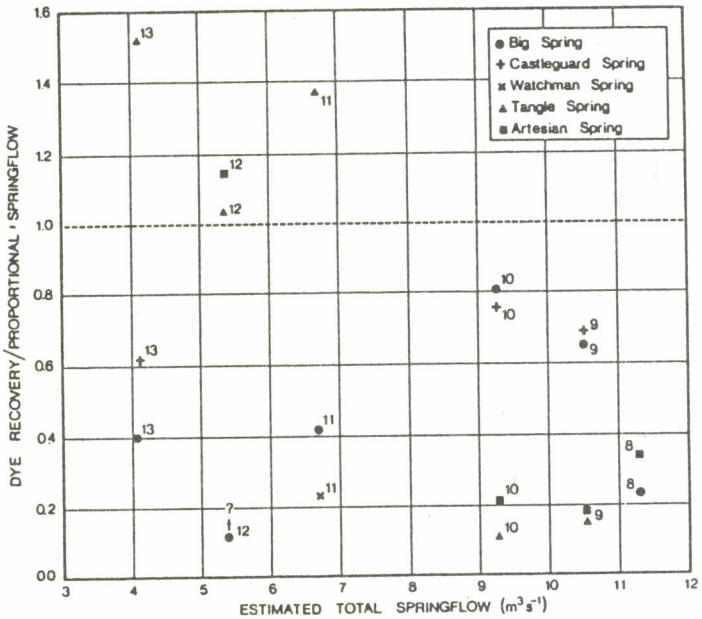
2. Breakthrough curves from a single spring under four different flow conditions show progressive separation of two peaks.

Castleguard and Maligne karsts both exhibit numerous springs, all of which are distributaries to a major system. Breakthrough curves at these springs show a spatial auto-correlation which reflects the network of distributary conduits feeding them. Springs draining a single conduit show similar breakthrough curves, while less closely related outlets have different breakthrough curves. A means of differentiating spring «families» is to evaluate the following function and to plot it against system discharge:

$$R = \frac{\frac{\int C_i\, Q_i\, dt}{M}}{\Sigma \frac{\int Q_i\, dt}{\int Q_i\, dt}}$$

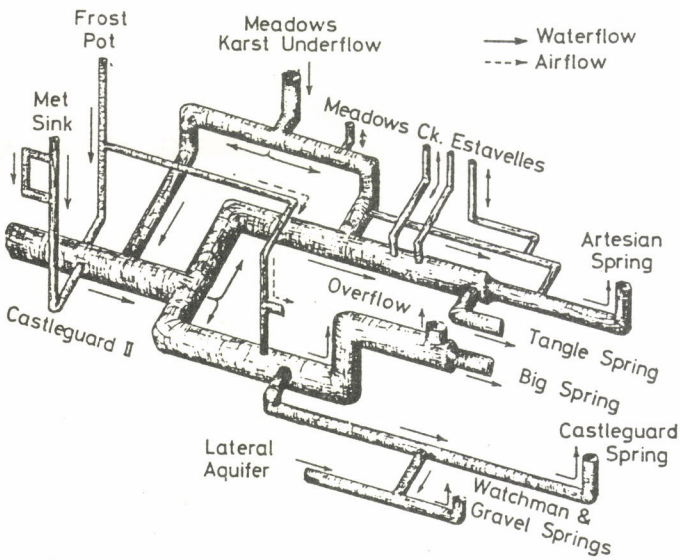
R is the dimensionless Distribution index
$\int C_i\, Q_i\, dt$ is the tracer mass recovered at spring i,
M is the mass of tracer injected,
$\int Q_i\, dt$ is the volume of discharge at a single spring (i) over the breakthrough period
$\Sigma \int Q_i\, dt$ is the total volume of discharge of the system over the breakthrough period.

Flow conditions should be steady during the test, in which case the average discharge may be used rather than the integrals. Figure 3 shows a rough plot of R versus system discharge at



3. Dimensionless tracer distribution index is used to indicate the distribution of tracer recovery and the relationship between distributary springs.

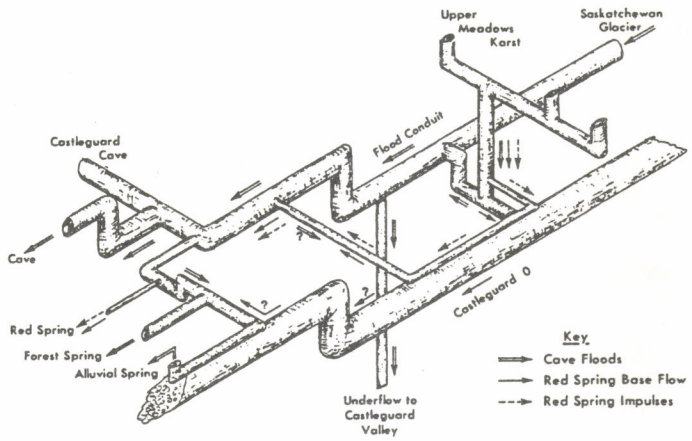
Castleguard. In a perfect distributary system with complete recovery, all the points should have R equal to one. There is poor recovery of the tracer under high flow. Either some tracer is destroyed, or a large amount passes out through an unmonitored outlet, which is quite possible given the large number of springs. Under low flow conditions, Tangle Spring and Artesian Spring show over-recovery compared to the other springs, showing that the preferential tracer route changes whith discharge.



4. A preliminary structural model of a part of the Castleguard karst aquifer, based on tracer data.

Discussion and conclusion

Space does not permit more full presentation of results, but Figure 4 shows structural interpretation of the tracer studies on a quasiautonomous aquifer lying beneath the data from Castleguard. Figure 5 shows a structural interpretation of tracer Castleguard Meadows. A full account of this work is given in Smart and Ford (1986).



5. A preliminary structural model of the Meadows Aquifer in the Castleguard Karst based on tracing, physical hydrology, and carbonate and deuterium chemistry.

The structural networks derived from field data are not to be regarded as final statements, rather they shoul be considered as intermediate hypotheses amenable to subsequent testing. This can be done both through further field work, and by the development of simulation models. In any case, the methods employed move the karst hydrologist closer to a more accurate understanding of the nature of the karst aquifer.

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Aspects of Karst erosion in the Venetian Prealps

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RESUM

El comunicat tracta d'un treball d'investigació de l'erosió química de 19 conques de sorgències càrstiques dels Pre-alps venecians (Itàlia)

Basades en dades químiques, climàtiques i hidrològiques, es valora l'escala de variacions de l'erosió química en el medi estudiat.

RESUMEN

El comunicado trata de un trabajo de investigación de la erosión química de 19 cuencas de surgencias Kársticas en los Prealpes Venecianos (Italia).

Basados en datos químicos, climáticos e hidrológicos, se valora la escala de variaciones de la erosión química en el medio ambiente estudiado.

SUMMARY

The paper deals with a research work on chemical erosion of 19 karstic springs basins in the Venetian Prealps (Italy).

On the base of chemical, climatical and hydrological data the variations range of chemical erosion in the studied environments is evaluated.

This paper describes research aiming at evaluating chemical erosion in the Venetian Prealps, on the basis of analysis of waters from some karstic springs. Until now in Italy only a few publications have illustrated research in this field, which is often only mentioned within the framework of other investigations (1).

A deeper presentation of the results of this research has already been reported elsewhere (2).

This research examined 19 springs in the Venetian Prealps between Lake Garda and Val Cellina (fig. 1). These springs, with sometimes very different average discharges ranging between 0.1 and 6000 litres/second and showing a relatively large range of water temperature values, represent a significant sample of the environmental situations most commonly encountered in the Venetian Prealps.

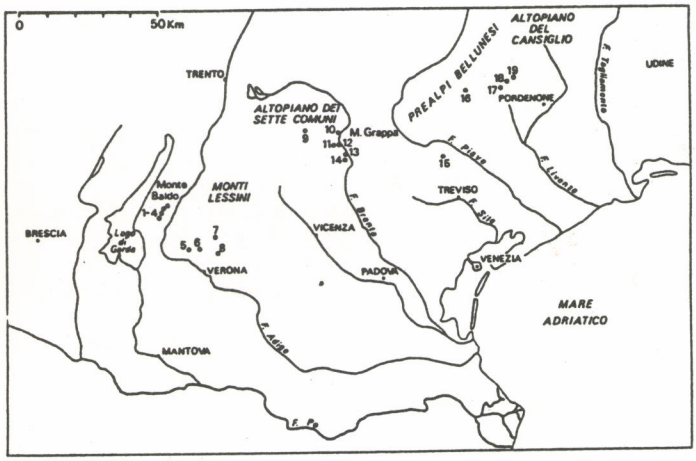

Fig. 1 –Location of the examined springs in the Venetian Prealps. The numbers are the same as in the following figures.

Data collection covered a period of about 3 years, from 1981 to 1984, during which the chemical analyses of about 500 water samples were carried out *in situ* using portable (Hach) kits. Other more complete analyses were carried out sporadically and only for some springs in the Laboratory of Physical Geography of the Department of Geography of the University of Padova, using a water analysis spectrophometer (Hach DR-EL 2).

Data from more than 200 analyses from three of the springs examined were also desumed from the literature (3, 4).

The rate of karst erosion was calculated for each basin on the basis of the data from each spring. The following simplified formula, which does not take ion and molecule concentration of rainfall water into account, was used:

$$E = \frac{R \cdot M}{d}$$

in which:

E = karst erosion in $m^3/km^2/year$

R = mean annual surplus (average depth of water subject to run-off, expressed in metres: e.g., 0.451 m)

M = mean total hardness of water, expressed as mg/l of $CaCo_3$

d = mean density of rock (e. g.: 2.5).

The values of karst erosion for the 19 springs vary between 12 and 83 $m^3/km^2/year$, with a mean of 52.3 $m^3/km^2/year$.

In order to evaluate the influence of some environmental parameters on the chemical and physical characteristics of the waters and thus on the extent of chemical erosion, possible correlations were examined. In particular, the following environmental variables were compared: median altitude of the basin; mean annual air temperature; annual precipitation; annual potential evapo-transpiration with the following water characteristics: discharge, total hardness, dissolved CO_2, mean temperature. Possible interrelations were also sought between the last two parameters.

Some climatic features of the Prealp areas examined here are illustrated in fig. 2, which shows that mean annual temperatures decrease with altitude according to a mean gradient of –0.63°C every 100 m; precipitation increases with altitude, ranging from approximately 850 mn/year at altitues of about 100 m a. s. l. to about 1600 mn/year at about 1300 m. It should be remenbered that the Venetian Prealps, as the first series of reliefs north of the Venetian plain, are often subject to orographic precipitations, which are particularly abundant at higher altitudes.

Potential evapotranspiration (calculated according to Thornwaithe's method) for the three stations chosen as representative of various altitude belts in the Prealp environment, shows values decreasing from 700 mm/year in the foothill belt to 500 mm/year at 1100 m and then to 100 mm/year at 1700 m (all approximate figures). Water surplus thus increases with altitude, as shown by the values from the three stations, i. e., about 200, 900 and 1700 mm respectively.

In order to show better the influence of climate on karst water properties, we considered not so much the actual altitudes of the springs, but the median altitudes of their drainage basins, defined on the basis of geomorphology and hydrology.

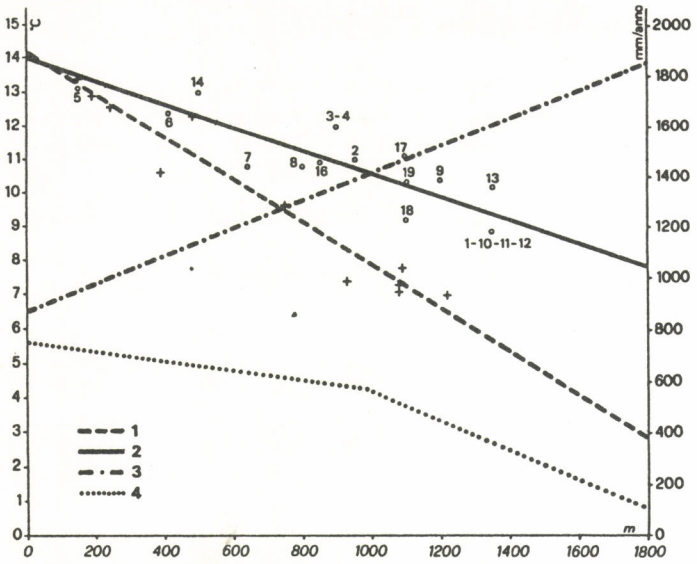

Fig. 2 –Correlation of some physical variables in the Venetian Prealps against altitude: 1) regression line of the mean annual air temperature in centigrades from the data of eleven stations (symbol +); 2) regression line of average temperature of the examined spring waters (symbol O; median basin elevation taken); 3)average annual precipitations; 4)potential evapotranspiration. For a given elevation the difference in mm between the lines 3 and 4 is the water surplus.

Fig. 2 also shows water temperatures in relation to median altitudes of the respective basins. The mean gradient turned out to be –0.34°C every 100 m– clearly less than that of the mean annual air temperature.

The variables among which interdependence was shown are briefly considered here. The mean content of CO_2 in the water turned out to depend on the median altitude of the drainage basin (it should be noted how CO_2 values decrease with increasing altitude, so that, over 1000 m, the quantity of dissolved CO_2 is reduced to about one-third)

Total hardness values also decrease from about 245 mg/l at low altitudes to about 140 mg/l higher up.

As regards chemical erosion, this clearly increases with altitude, varying from about 25 m^3/km^2/year at lower altitudes, to about 70 m^3/km^2/year higher up (Fig. 3). This variation is caused by the strong increase in surplus water with altitude, which is prevalent with respect to the reduction in hardness. Our values of chemical erosion in the Venetian Prealps agree with those in the literature for medium-latitude karst areas, both in Italy (5, 6, 7, 8, 9) and elsewhere (10, 11).

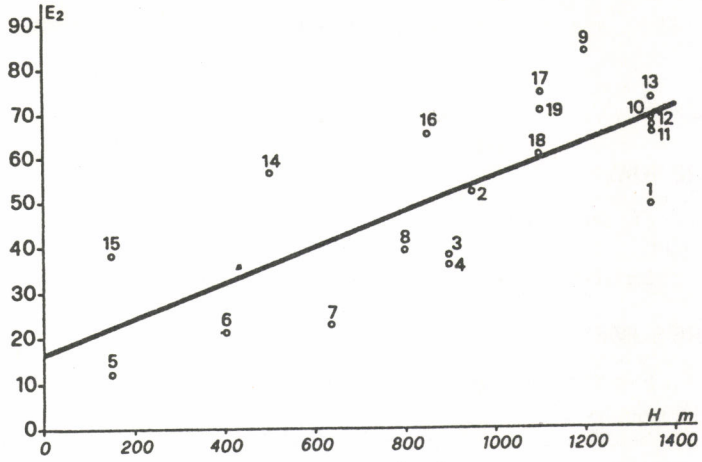

Fig. 3 –Correlation of karst erosion (E_2) in m^3/km^2/year, against karst drainage basins median altitudes (H). The equation of the regression line is $E_2 = 0{,}0392\ H + 16{,}2$.

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10270

Modeling karst aquifer response to rainfall

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RESUM

Un model d'element finit (anomenat HYDMATCH) pren dades hidrogràfiques conegudes de surgències d'aqüífers càrstics com a resposta a la pluja i genera una relació de regressió lineal de conductivitat de fractura cap al gradient potencial del sistema. L'excés de pluja en forma d'energia potencial en engolidors i subconques es consumeix com a un element puntual i sofreix una

translació cap a un element finit d'una dimensió engranatge fins a l'últim nus, el qual representa la sorgència càrstica. Una equació de circulació per fractura, derivada de l'equació de Navier-Stokes, determina la càrrega de la surgència, utilitzant conductivitats de fractura a partir de l'equació de regressió i el gradient potencial del MESA.

Aspectes que precisen d'una millora encaminada a l'obtenció d'un model més precís de circulació de l'aigua subterrània en els aqüífers càrstics són: una estimació fiable de l'excés de pluja, una millor estimació del fluxe de base i les condicions precedents de l'aqüífer càrstic. El model ha estat sotmès a un test aquí, en un petit aqüífer càrstic, però si la utilitat del model es provés en aqüífers més grans, els resultats podrien acostar-se més al percentatge-wise de les actuals descàrregues del sistema. Els models d'aquest tipus podrien ésser útils, aleshores, per a predir descàrregues d'inundació i el temps de pas de contaminants en els aqüífers càrstics.

RESUMEN

Un modelo de elemento finito (llamado HYDMATCH) toma datos hidrográficos conocidos de surgencias de acuíferos kársticos como respuesta a la lluvia y genera una relación de regresión linear de conductividad de fractura hacia el gradiente potencial en el sistema. El exceso de lluvia en forma de energía potencial en el sistema. El exceso de lluvia en forma de energía potencial de sumideros y se entra como elemento puntual y sufre una traslación hacia un elemento finito de una dimensión engranaje hacia el último nudo, el cual representa la surgencia kárstica. Una ecuación de circulación por fractura derivada de la acuación de Navier-Stokes determina la carga en la surgencia utilizando conductividades de fractura a partir de la ecuación de regresión y el gradiente potencial del MESA.

Zonas que precisan una mejora en orden a obtener un modelo más preciso de circulación de agua subterránea en los acuíferos kársticos son: una estimación fiable del exceso de lluvia, una mejor estimación del flujo de base y las precedentes condiciones del acuífero, así como el conocimiento de los límites de la cuenca del acuífero kárstico. El modelo se ha sometido a un test aquí, en un pequeño acuífero kárstico, pero si la utilidad del modelo se probara en acuíferos mayores, los resultados podrían estar más cercanos al percentage-wise a las actuales descargas del sistema. Los modelos de este tipo podrían ser útiles entonces para predecir descargas de inundación y tiempos de paso de contaminantes de acuíferos kársticos.

SUMMARY

A finite-element model (called HYDMATCH) takes known spring hydrograph data from a karst aquifer in response to rainfall and generates a linear regression relationship for fracture conductivity versus potential gradient in the system. Rainfail excess in the form of potential energy from sinkholes and sub-basins is input to element nodes and routed down a one-dimensional finite-element mesh to the last node, which represents the karst spring. A fracture-flow equation derived from the Navier-Stokes equation determines discharge at the spring using fracture conductivities from the regression equation and potential gradient in the last element of the mesh.

Areas in need of improvement in order to accurately model ground-water flow in karst aquifers are: a reliable estimate of reinfall excess, a better estimation of baseflow and antecedent aquifer conditions, and the knowledge of the karst aquifer catchment boundaries. The model was tested here on a small karst aquifer but if the performance of the model was tested on larger aquifers, the results may be closer percentage-wise to the actual discharges from the system. Models of this type may then be useful to predict flood discharges and contaminat travel times in karst aquifers.

Introduction

The hydraulic parameters (permeability and storage) of karst aquifers have been determined by applying the Theis equation to the recession curves of spring hydrographs (Tobarov, 1976). Problems using this method arise due to different linear segments of the log-log recession curve. White (1969) used the base-flow recession curve to determine drainage basin coefficients (discharge ratio, exhaustion coefficient, and response time).

Digital modeling has potencial for the evaluation of karst aquifer parameter analysis. Thrailkill (1974) adopted equivalent pipe-flow systems to predict flow directions and head distribution within a karst system using the finite-difference method. Few efforts have succeeded in simulating response of springs to recharge due to rainfall in karst areas.

The objective of this paper is to present a model simulating rainfallr-runoff and spring discharges in karst areas. Overland flow is modeled using equations approximating rainfall-runoff on a sloped surface. The characteristics of karst spring hydrographs are used to estimate the hydraulic parameters of karst aquifers. Introduction of excess rainfall and propagation of storm pulses through the fractured-aquifer system are modeled using the finite-element method. A finite-element model was constructed that determines representative fracture conductivities-- using an equation for fluid flow through a fracture-of karst aquifer by iterating fracture conductivity in the system until the hydrograph from a known rainfall event is matched. A linear regression equation is established for potential gradients in the karst aquifer system versus fracture conductivities. The model is verified by comparing known spring hydrograph discharges from another rainfall event to modeled discharges for that rainfall event.

Hydraulics of karst aquifers

Karst aquifers causing the most theoretical difficulties in paramete evaluation are aquifers which are dominated by fissures and conduits. Conduits transmitting ground water are fractures with different widths, different shapes, differing dregees of sinuosity, varying sized pools, and conduit constrictions. The composite spring hydrograph is representative of the rainfall on different area subbasins and flow through combinations of above and below ground characteristics.

Representing all these caracteristics in a conceptual model for karst aquifer response to rainfall is a problem. The soils and vegetative cover can be mapped and their effect on surface runoff towards sinkoles estimad mathematically. The below-ground water-transmitting fracutes have various shapes, lengths, roughenesses, and sinuosities which must be lumped together withina a single parameter of the subsurface flow regime. That single parameter is the representative fracture conductivity of the karst basin.

Energy in a karst Aquifer

Rainfall excess introduced into the conduit system through the sinkhole is an energy addition to the aquifer. This energy can be expressed by the Bernoulli equation as the sum of the velocity head, pressure head, and elevation head (all in units of length). The velocity head is an expression of the kinetic energy of moving rainfall excess as it travels overland and sinks into the ground at the sinkhole. The pressure head is the energy of the weight of the fluid flow depth . The elevation head is the difference in elevation between the conduit taking runoff from the sinkhole

and the spring at the base of the system. Elevation head, which affects the gradient in the system, is the most difficult to define in karst aquifers because input from the sinkhole subbasin may travel vertically downward as vadose flow for considerable distances before flowing horizontally towards the spring. Therefore, the elevation head used should not be the altitude difference between the sinkhole and the spring. Rather, make an arbitrary estimate of 20 percent or 30 percent of this value.

Equations of Flow

Hydraulic conductivities of karst aquifers include the affects of gravity and fluid friction. An accepted approach to solution of viscous flow problems is by application of the Navier-Stokes equations for laminar flow of a newtonian fluid. Fracture conductivity for the problem of steady, uniform, one dimensional, laminar, incompressible flow through a passage bounded by plane, impermeable boundaries can be determined by integrating the Navier-Stokes equation with respect to the passage boundaries. The equation for fluid discharge that results is similar to Darcy's law -- Q=KAdh/dx.

There is, however, a basic difference between Darcy's hydraulic conductivity and fracture conductivity determined by the Navier-Stokes equation. Darcy's hydraulic conductivity multiplied by the hydraulic gradient gives the seepage velocity, which is equal to the ratio of flow rate and total area normal to the flow direction and is less than the mean velocity in the pores. In contrast, the fracture conductivity equation gives mean velocity and, therefore, the hydraulic conductivity of the fracture does not charcaterize the rock but only one opening.

Karst aquifer response to rainfall

The one-dimensional finite-element model (HYDMATCH) was formulated using the Galerkin method for numerical representation of the differential equations governing the problem. The model was applied to an example karst basin to test the model perfomance. The mesh information, initial and boundary conditions, sinkhole subbasin runoff hydrographs, the given spring hydrograph, and initial arbitrary fracture conductivities are input into HYDMATCH. The model calculates potencials at each node in the mesh for each time element specified. Potential gradient for spring discharge is determined for the last element in the one-dimensional finite-element mesh.

The overland flow aspect of rainfall-runoff was modeled using Izzard's time-lag approximation for surface runoff (*in* Chow, 1959, p. 542). Izzard's equations use roughnees factor, slope, length and width of runoff plane. Overland flow discharges were converted to potential energy for input to the sinkholes using the Bernoulli equation. The results of overland flow modeling are potentials which vary with time and can be plotted on a potentiograph for input to sinchole nodes.

The initial conditions are input as potentials at each node and represent the base flow of the system. Fluxes represent the soil

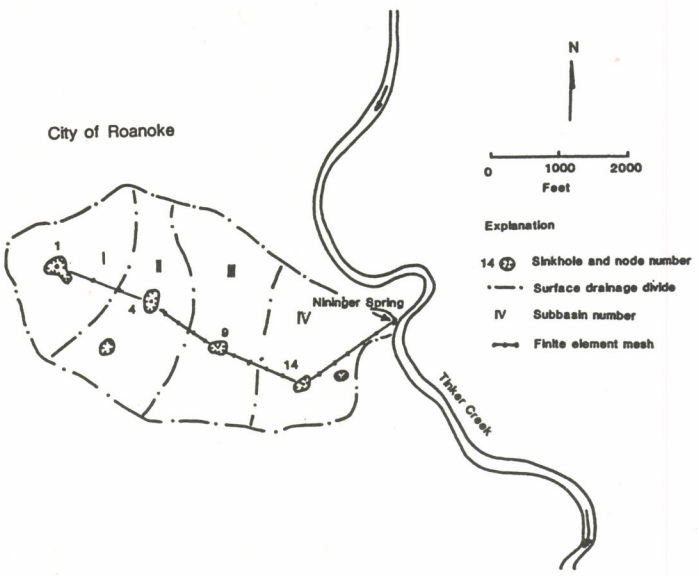

Figure 1. Finite element discretization of example basin

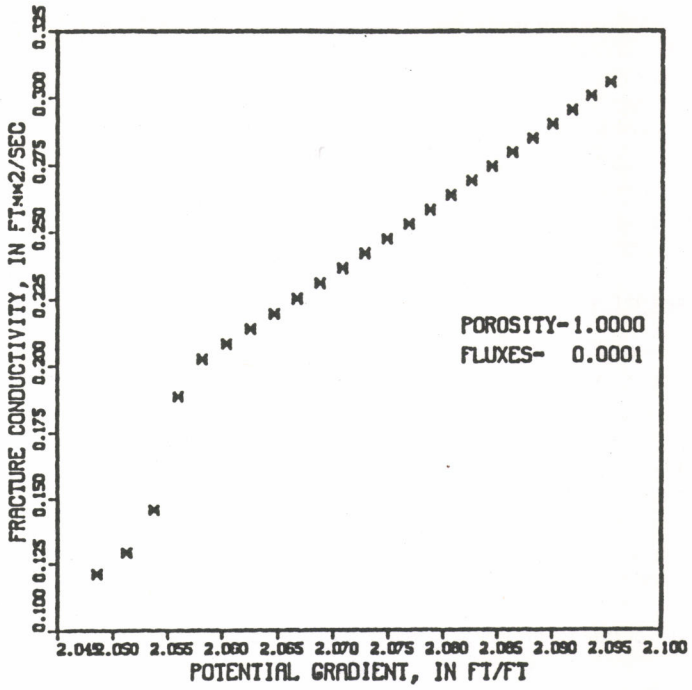

Figure 2. Potential gradient versus fracture conductivity determined from spring hydrograph data for one-half rainfall (flux units are in cubic feet per second).

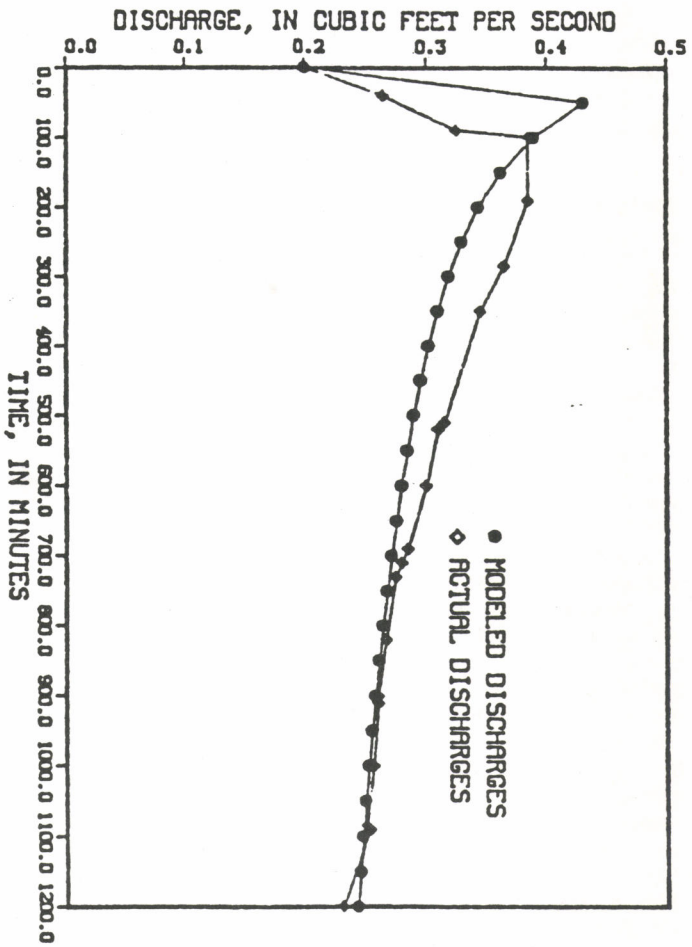

Figure 3. Modeled discharges compared to actual discharges for one-inch rainfall. Modeled discharges determined using potential gradient versus fracture conductivity relationship in figure 2.

or rock storage contribution to each element in the system. The magnitudes of fluxes, in units of cubic feet per second, affect the results dramatically. Theresfore, fluxes were varied for the verification phase to determine the best match of the modeled discharges to the observed data.

Estimates of porosity also dramatically affected the solutions. Porosity muay represent the characteristics of the fractures themselves or the characteristics of the entire basin. Porosity of a fracture will usually be equal to one (1) unless severe constrictions in the fractures prevent rapid flow. The porosityu of the basin is the volume of voids within the volume of rock in the aquifer.

HYDMATCH solves for potentials in the aquifer based on input conditions, then it matches the known spring hydrograph by determining fracture conductivities versus potential gradient in the system. HYDMATCH exits the iteration procedure of the calibration phase and reads new data for another rainfall, in this case a one-inch rainfall. New potentials are created within the system and fracture conductivities for the verification phase are selected using the fracture conductivity versus potential relationship from the calibration phase. Spring discharges are calculated by the Navier-Stokes equation.

Example karst Basin

The city of Roanoke, Virginia is built on a karst aquifer developed in the Elbrook dolomite. Discretization of the finite element mesh coniders sinkholes in subbasisn I, II, III, and IV as the input nodes to Nininger spring (figure 1). The element placements follow these sinkholes assuming that the sinkholes were caused by the existence of subsurface conduits. Other sinkholes in the sub-basins are considered as part of the runoff plane.

The results of potential gradient versus fracture conductivity for the karst aquifer are shown in figure 2. The modeled hydrograph are compared to an actual hydrograph from Nininger spring in response to a one-inch rainfall (figure 3). The results indicate that setting the porosity equal to one is most representative of spring response to rainfall. Fluxes set at much less than one produce reasonable results. This represents an accurate statement of a typical karst aquifer system: discrete fractures (porosity = 1) providing rapid transport of fracture storage in the karst aquifer.

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La karstification: processus, modeles et exemples

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RESUM

Si bé la morfologia càrstica clàssica i alguns dels procesos que originen els carsts són prou coneguts i han estat àmpliament desglossats, n'hi ha d'altres que són mal coneguts o, inclús, ignorats. Per aquest motiu, a partir de la definició hidrogeològica del carst i dels conceptes termodinàmics que li corresponen, segons les definicions de A. MANGIN, són definits els diferents procesos naturals que és necessari de considerar en la gènesi del carst.

Així doncs, a més del carst gravífic clàssic, on la gravetat i el CO_2 d'origen pedològic s'associen per a constituir el potencial de carstificació, es presenten mitjançant alguns exemples, les carstificacions relacionades amb el termalisme, amb les emanacions sulfuroses i amb les transgressions marines. Es proposa una primera aproximació als anteriors criteris de reconeixement.

RESUMEN

Si la morfología kárstica clásica y algunos de los procesos que originan los karst son bien conocidos y han sido abundantemente descritos, otros se conocen mal e, incluso se ignoran, por este motivo, a partir de la definición hidrogeológica del karst y de los conceptos termodinámicos que le corresponden, según las definiciones de A. Mangin, son definidos los distintos procesos naturales que es necesario considerar en la génesis del karst.

Así además del karst gravífico clásico en el que la gravedad y el CO_2 de origen pedológico se asocian para constituir el potencial de karstificación, se presenta mediante algunos ejemplos las karstificaciones relacionadas al termalismo, a las emanaciones sulfurosas y a las trasgresiones marinas. Se propone una primera aproximación a los anteriores criterios de reconocimiento.

RESUMÉ

Si la morphologie karstique classique et certains des processus de mise en place des karsts sont bien connus et ont été abondamment décrits, d'autres sont mal connus, voire même ignorés; c'est pourquoi, à partir de la définition hydrogéologique du karst et des concepts thermodynamiques qui lui sont associés, et tels que les a définis A. MANGIN, sont définis les différents processus naturels envisageables dans la genèse de karst.

Ainsi, à côté du karst gravifique classique dans lequel la gravité et le CO_2 d'origine pédologique s'associent pour constituer le potentiel de karstification, les karstifications liées au thermalisme, aux émanations sulfurées et aux transgressions marines sont présentées, avec des exemples. Une première approche des critères de reconnaissance est alors proposée.

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Diffuse flow and conduit flow in the Greenbrier Limestone at Locust Creek, West Virginia, USA

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RESUM

Es van analitzar dades referents a la descàrrega diària de la zona càrstica de Locust Creek i aquestes indicaren que la circulació ràpida representa un 68 % de la descàrrega anual. L'emmagatzematge o fluxe de base de la zona difusa va resultar ésser 900 vegades el volum dels conductes submergits, mentre que l'acumulació a les zones vadoses era 75 vegades més gran que aquest darrer. Els càlculs van donar una zona d'acumulació difusa de 0,028 i una transmisivitat de 457-2.139 m^3/dia, depenent del nivell de la superfície piezomètrica. Els càlculs sobre la conductivitat hidràulica de la zona difusa donaren uns valors de 22-27 m/dia o bé de 88-412 m/dia, depenent de si un d'ells assumeix una conductivitat constant dins de l'aqüífer o bé presenta una disminució exponencial amb la profunditat. Es va calcular un factor de fricció de 63 de la cavitació i s'efectuaren mesures de corrent des del veí sistema de Friars Hole. Això ha permès de fer estimacions sobre la relativa importància de la circulació per conductes i de la circulació difusa dins l'aqüífer, amb conductes, la circulació dins dels quals constitueix el 80-90 % de la descàrrega total.

RESUMEN

Se analizaron datos de descarga diaria tomados de la zona kárstica de Locust Creek e indicaron que la circulación rápida se calcula en un 68 % de la descarga anual. El almacenaje o flujo de base en la zona difusa resultó ser 900 veces el volumen de los conductos sumergidos, mientras la acumulación en las zonas vadosas era 75 veces mayor que la última. Los cálculos dieron, zona de acumulación difusa de 0,028 y transmisividad de 457-2.139 m^3/día, dependiendo del nivel de la superficie piezométrica. Los cálculos de conductividad hidráulica en la zona difusa dieron 22-27 m/día o bien 88-412 m/día, dependiendo de si uno de ellos asume una conductividad hidráulica constante dentro del acuífero o presenta una disminución exponencial con la profundidad. Se calculó un factor de fricción de 63 de la cavitación y las medicioones de corriente desde el vecino sistema de Friars Hole. Esto permite hacer estimaciones sobre la relativa importancia de la circulación por conductos y circulación difusa en el acuífero, con conductos cuya circulación constituye el 80-90 % de la descarga total.

SUMMARY

Daily discharge data from the karstified Locust Creek catchment were analysed, and showed that quickflow accounted for 68 % of annual discharge. Baseflow storage in the diffuse zone was found to be 900 times the volume of submerged conduits, while storage in the vadose zone was 75 times as great as the latter. Calculations gave diffuse zone storativity of 0.028 and transmissivity of 457-2.139 m^3/day, depending on the level of the piezometric surface. Calculations of hydraulic conductivity in the diffuse zone gave 22-97 m/day or 88-412 m/day, depending on whether one assumes a constant hydraulic conductivity within the aquifer or one decreasing exponentially with depth. A friction factor of 63 was calculated from scallop and flow measurements from the nearby Friars Hole System. This enabled estimates to be made of the relative importance of conduit and diffuse flow in the aquifer, with conduits accounting for 80-90 % of total discharge.

10300

The Hydrogeomorphic Implications of a conduit aquifer model

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RESUM

Un model d'aqüífer càrstic pensat, més per a una millor compresió que no pas per a predir la descàrrega, es basa en un simple conducte de volum constant. La recàrrega es produeix a partir d'uso corrent captat, el qual originarà un augment del cabal d'aigua del conducte i una rèplica instantània de la descàrrega de la font. Els petits conductes individuals es desbordaran freqüentment a la superfície durant les crescudes i la probabilitat d'excedència del fluxe a través de l'aqüífer i per sobre de la superfície es defineix com una funció de la distribució del fluxe i de la forma de l'aqüífer. La probabilitat de fluxe superficial és un índex del tipus d'evolució del paisatge. Aquesta probabilitat pot estar relacionada tant amb el tipus de la probabilitat d'excedència del fluxe com amb la forma de l'aqüífer, de tal manera que evoluciona independentment del temps. Això proporciona un model de l'evolució del paisatge càrstic al marge del temps, amb diferents nivells de relleu càrstic i vàries magnituds de reccàrrega.

RESUMEN

Un modelo de acuífero kárstico pensado para aumentar la comprensión mejor que para predecir la descarga, se basa en un simple conducto con volumen constante. La recarga es desde una corriente captada que ocasiona un aumento del caudal en el conducto y una réplica instantánea en la descarga de la fuente. Los pequeños conductos individuales se desbordarán frecuentemente

en la superficie durante las crecidas y la probabilidad de excedencia del flujo a través del acuífero y por encima de la superficie se define como una función de la distribución del flujo y la forma del acuífero. La probabilidad de flujo superficial es un índice del tipo de evolución del paisaje. Esta probabilidad puede estar relacionada tanto con el tipo de la probabilidad de excedencia del flujo como con la forma del acuífero, de modo que evoluciona fuera de tiempo. Esto proporciona un modelo de la evolución del paisaje kárstico fuera de tiempo con diferentes niveles de relieve kárstico y varias magnitudes de recarga.

SUMMARY

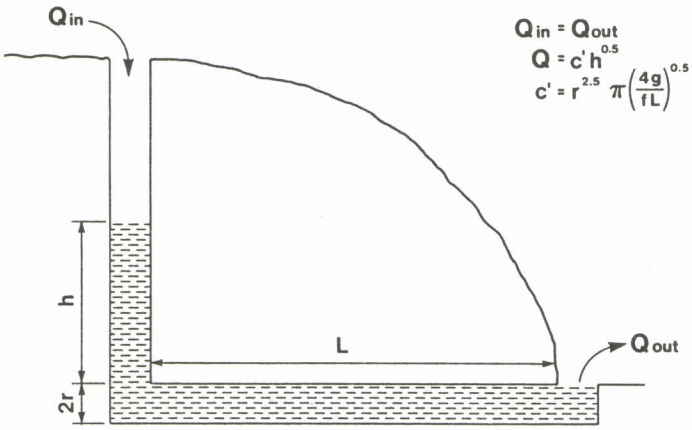
A model of the karst aquifer designed to enhance understanding rather than predict discharge is based on a simple conduit with constant volume. Recharge is from a single sinking stream which causes a rise in head in the conduit and an instantaneous response in spring discharge. Small single conduits will frequently overflow at the surface during floods and the exceedance probability of flow through the aquifer and over the surface is defined as a function of the inflow distribution and the form of the aquifer. The probability of surface flow is an index of the style of evolution of the landscape. This probability can be related to both the form of the inflow exceedance probability and the form of the aquifer, so that it evolves over time. This provides a model of the evolution of karst landscapes over time with different levels of karst relief, and various magnitudes of recharge.

Introduction

It is the purpose of this paper to present a simple model for a conduit karst aquifer, and to explore the link between the hydrological behaviour of the aquifer and karst landscape evolution.

The Model

The aquifer model employed is a simple abstraction, but this is sufficient for the present work which attempts to understand general principles rather than predict the flow of a particular aquifer. The simple conduit aquifer (Figure 1) consists of a



1. A diagrammatic representation of the simple conduit model.

horizontal phreatic pipe which conveys water between a vertical shaft at one end and the spring at the other. A stream of discharge Q enters the shaft, and the head developed in the shaft drives water through the system. To retain computational simplicity, the shaft is considered volumeless. Flow is governed by the Darcy-Weisbach equation for steady uniform turbulent flow through a pipe of circular section (eg. Giles 1977 p.99):

$$Q = h^{0.5}\, r^{2.5} \left(\frac{4\,g}{f\,L} \right)^{0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

where Q = pipe discharge (m^3/s)
A = pipe cross-sectional area (m^2)
h = head at the shaft intake with respect to the spring outlet (m)
r = pipe radius (m)
g = gravitational aceleration (9.81 m/s^2)
f = Darcy-Weisbach friction factor
L = conduit length (m)

L is set at one kilometre. Fully developed turbulent flow and constant relative roughness are assumed so that f is arbitrarily taken to be constant at 0.33.

Application of the Model

In the short term, head is the only variable controlling spring discharge. There is a fixed relationship between head and discharge so that if the distribution function for discharge is known, then the distribution for head may be calculated. A convenient way of expressing the long term distribution of discharge is through the exceedance probability of particular flows. As a first approximation this is an exponential distribution, which allows for computational simplicity. The exceedance probability of head may thus be expressed as:

$$p(h \geqslant H) = \exp\,(-K\ C'\ H^{0.5}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

where h is a random value of head
H is a reference head level
K is a parameter of the exceedance probability of discharge given by the reciprocal of the mean flow.
C' is a collective form parameter including all of the right hand variables in the Darcy–Weisbach equation except for h.

There is an upper limit to the head which can be developed on a karst conduit. This may correspond to an internal overflow, or to the available relief of the karst aquifer. This maximum head will be termed the «thickness of the aquifer, H_a», recognising that it may depend on other factors. When the head required to drive water through the aquifer is greater than H_a, then surface runoff will occur. The probability of surface runoff is given by the probability of discharge equalling or exceeding the flow through the aquifer under head, H_a, which is given by:

$$p(\text{surface overflow}) = \exp\,(-K\ C'\ H_a^{0.5}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Implications of the model

There are several ways of interpreting the overflow condition. For example, it implies that there is a finite maximum flow expected from the spring, with a probability of occurrence equal to that of surface overflow. There is no upper limit to the expected flow on the surface.

It is possible to extend this reasoning to estimate the geomorphic work done by underground flow and surface flows. The simplest way of expressing this it to consider the probability of surface runoff. Thus a very high probability of surface runoff implies a fluvial landscape, and a low probability implies a fluviokarst, and as the probability approaches zero, so there is a true holokarst. Assuming that the exceedance probability of flow over time does not vary, then the factors controlling the landscape form in this model are clearly those that evolve over long time periods: the length of the conduit, the friction factor, and conduit radius. It is possible to envisage numerous ways in which natural geomorphic evolution of a karst conduit may be represented through these variables. For example, capture may

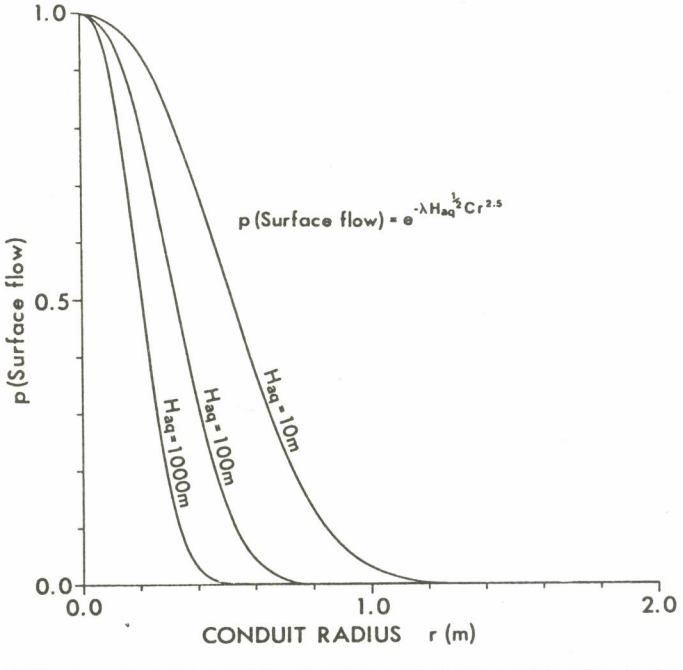
shorten a conduit, or collapse may increase the friction factor. However, by far the most powerful single variable is conduit radius, and for this reason it will be investigated here.

Once a karst system has genuine conduit flow, then the conduit radius will increase through time, at a rate generally depending on the square of the saturation deficit rather than on discharge (Palmer 1981). As the conduit radius increases, the value of de C' will increase to the 2.5 power, and the probability of surface overflow will decrease according to:

$$p(\text{surface overflow}) = \exp(-K\ C\ r^{2.5}\ H_a^{0.5} \quad \ldots\ldots 4$$

where $C = C' / r^{2.5}$

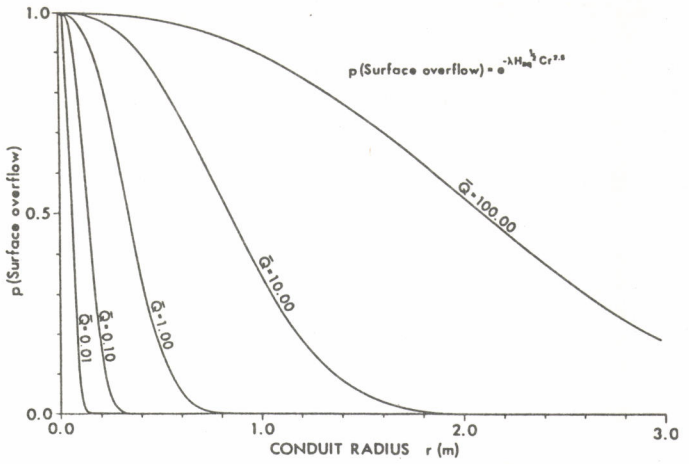
This function is drawn in figure 2 for a mean inflow discharge of 1 m^3/s, and several different values of H_a, the «aquifer thickness». This diagram demonstrates that the evolution of a landscape from the fluvial to the holokarstic condition may be regarded as a function of time. The «thicker» aquifer absorbs the majority of floods, and becomes holokarstic earlier than the «thinner» aquifer. It is difficult to apply a time axis to the abscissa, although Palmer (1981) implies that for recharge of uniform chemistry, the conduit radius will be a linear function of time. Applying Palmer's (1981) theory, the time to reach a 1m radius varies between 4×10^3 to 4×10^7 years for saturation deficits of 1 and 100 ppm., respectively. Figure 2 is valuable in that it



2. The decrease in the probability of surface overflow with conduit radius (ie. time) and aquifer thickness (available relief).

places the different karst landscapes in an evolutionary continuum, and provides a clear indication of why holokarst depressions frequently retain an inherited dendritic pattern (eg. Miller 1981).

While it is clearly possible to add numerous qualifying complexities to this model, for now only one other significant variable will be considered; the mean discharge of the sinking stream. This determines the parameter, K in equation 4. Large streams are more likely to overflow than small streams for a given size of conduit. Figure 3 illustrates this concept for streams with a mean discharge over 4 orders of magnitude, and an exponential distribution of flow exceedance. An aquifer «thickness» of 100 m is assumed. Tiny streams very soon become entirely karstic, and will not develop extensive fluvial forms. Such a stream will not



3. The decrease in the probability of surface overflow with conduit radius as a function of the mean discharge of the surface stream.

develop the valley network necessary to expand its catchment area, and is unlikely to develop large caves. Larger streams, either allogenic or autogenic will develop as parts of more extensive fluvial valleys before becoming entirely karstic. The very largest streams are likely to flood over the surface with great frequency, regardless of the size of conduit developed, forming fluvial valleys even when flanked by holokarst. These are the rivers which form the well-known karst gorges.

Further work and conclusions

It is not possible to develop other aspects of the model here, the main reason being that greater verisimilitude requires that higher order assumptions must be made and the model becomes less general. For example a further application might be the simulation of climatic change. The difficulty is not so much in running the model, but in quantifying the climatic and geomorphic effects of climatic change.

In conclusion, the value of an abstract model of this kind is that it clearly increases and formalises understanding of how karst aquifers operate. While the assumptions are unrealistic, they are at least explicit, and of general applicability. The major unrealistic assumption is that of constant volume over time. This could be overcome by developing several levels of conditional probability, but there are no data on which to base this. Alternatively, the problem may be tackled in the time domain, an approach which has already produced interesting findings (Smart 1983).

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Characterisation of Carbonate Aquifers: A Conceptual Base

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RESUM

Els tres atributs fonamentals que regeixen el comportament dels aqüífers carbonatats són: la recàrrega, l'emmagatzematge i la transmissió. Al desestimar-se el reconeixement de la seva naturalesa independent s'ha creat una notable confusió bibliogràfica. Nosaltres proposem un model en el qual aquests tres atributs són classificats entre membres finals que donin un camp tridimensional, en el qual s'hi puguin situar els aqüífers carbonatats. Per a la recàrrega, els membres finals a considerar estan concentrats i les entrades, disperses. Per a conductes de transmissió i circulació difusa, així com per a emmagatzement alt i baix, retenció total. Les implicacions d'aquest model estan considerades respecte als recursos aqüífers, desenvolupament i protecció, i es tracten exemples d'aqüífers carbonatats del Regne Unit.

RESUMEN

Los tres atributos fundamentales que rigen el comportamiento de los acuíferos carbonatados son: recarga, almacenaje y transmisión. El fracaso de reconocer su naturaleza independiente ha representado una considerable confusión en la bibliografía. Proponemos un modelo en el cual los tres atributos son clasificados entre miembros extremos que den un campo tridimensional en el cual se pueden situar los acuíferos carbonatados. Para la recarga los miembros finales considerados están concentrados y las entradas dispersas. Para conductos de transmisión y circulación difusa y para almacenaje alto y bajo, retención total. Las implicaciones de este modelo están consideradas con respecto a los recursos acuíferos, desarrollo y protección, y se tratan ejemplos de acuíferos carbonatados del Reino Unido.

SUMMARY

The three fundamental attributes governing the behaviour of carbonate aquifers are recharge, storage and transmission. Failure to recognise their independent nature has resulted in considerable confusion in the literature. We propose a model in which all three attributes are ranged between end members giving a 3 dimensional field into which carbonate aquifers may be plotted. For recharge the end members considered are concentrated and dispersed inputs; for transmission conduit and diffuse flow and for storage high and low total retention. The implications of this model are considered with respect to water resources development and protection, and examples of carbonate aquifers from the UK discussed.

Introduction

There is a substantial body of literature concerning the hydrology of carbonate areas, however its utility is limited for two reasons. First; there has been confusion over the processes controlling spring behavior which, due to the lack of a clear conceptual base has hindered the understanding of aquifer function. Second; differences in nomenclature have prevented adequate integration of results from different areas.

Some of the major problems associated with karst hydrological studies are highlighted by the literature published in the late 1960's and early 1970's. Much of this considered aquifers either in terms of the proportion of conduit to diffuse flow present (Shuster & White 1971), or the quantity of swallet to percolation water entering the aquifer (Newson 1971). Further, Pitty (1966) introduced the terms autogenic and allogenic to describe water that had risen on carbonate or non carbonate rocks respectively. These three approaches were all derived from studies of springs with essentially similar behavior, thus resulting in confusion between the independent processes of flow and recharge.

More detailed studies in the late 1970's started to recognise the importance not only of flow and recharge but also of storage, however there remained considerable uncertainty as to which of these was dominant in controlling spring response (compare Aley 1975 and Atkinson 1977). Further, the association of swallet recharge with conduit flow and low storage was almost universal, even after White's (1969 & 1977) conceptual model which stressed their essential independence. The distinctions between the three variables is thus emphasised here, and they are suggested as the basis for a model representation of carbonate aquifers.

Recharge

Recharge is ranged between concentrated and dispersed end members, the former being characterised by large inputs at discrete points, and the latter by smaller inflows at a much larger number of sites. The distinction between autogenic and allogenic recharge made by Gunn (1985) is not employed here, as we place emphasis on the mode of entry into the aquifer rather than the source of water. The continuum of recharge types is shown in Figure 1. The most important property used to define the position of individual inputs on the spectrum is the discharge. Because some sites such as subcutaneous drains remain dry for long periods of time, and therefore have apparently low values (Friederich 1981), the most satisfactory measure of discharge is the maximum value. This emphasises their high capacity during wet periods, which is of most significance for recharge.

In the case of surface flows major stream sinks represent the most concentrated inflows and are unmatched in magnitude by subsurface sources. We differentiate between these and loosing streams (Aley 1975), where recharge may be more distributed, losses occuring gradually along the stream, particularly when unconsolidated sediments form the bed. Finally we recognise that in many bare limestone catchments or those where significant

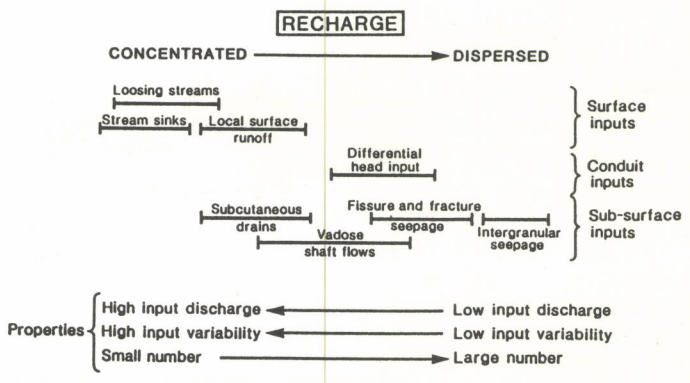

Figure 1. Range of recharge types and their properties as used in the model.

concentration of runnof can occur, for instance on impermeable soils or caprocks, recharge may occur directly into fissures and shafts (Gunn 1981).

The hydrological response of local surface runoff is similar to that of subcutaneous drains in the subsurface zone which may also have a comparable capacity. At times of high recharge water accumulates in the permeable subcutaneous zone because of the limited capacity of vertical discharge routes in the underlying unsaturated zone of lower permeability. Water therefore flows laterally in the subcutaneous zone to discharge via high capacity routes developed by preferential solution at geologically favorable localities such as the intersection of major joints or open bedding planes (Friederich 1981, Williams 1983). The capacity of these routes may be matched by that of vadose and shaft flows (Figure 39, Friederich and Smart 1982). These result from the integration of smaller seepages and flows. The essentially morphological distinction between shaft and vadose flows is not usefull because hydrologically they behave in an identical manner. In low porosity carbonates the most dispersed recharge is via fissures and tight fractures which have very low discharges but are often numerous. In more porous limestones such as the Chalk of South East Britain, intergranular seepage can also occur.

In aquifers where conduit flow is developed (see below) recharge to the saturated zone can occur as a result of head differentials between the conduit, whose response to storm rainfall is rapid, and fissures in the adjacent rocks, which respond more slowly (Onder 1985). There is a growing body of evidence in support of this mechanism (Atkinson et al 1973, Dodge 1985), but the emphasis has been on the role of surface inputs. Given the rapid response that is possible in subcutaneous drains which also directly feed the conduit system, we beleive that such emphasis may be misplaced and this recharge process may also be important where surface inflows are absent. However to date no quantitative estimates of the importance of this process to aquifer recharge have been obtained.

Flow

We follow the general consensus that flow in carbonate aquifers varies between conduit and diffuse end members (Atkinson and Smart 1981, Shuster and White 1971, White 1977), as shown in Figure 2. Conduit flow occurs in large open channels with relatively high velocities giving rise to turbulent flow. Diffuse flow is confined to tight fractures and pores with small openings; velocities are low and flow is laminar obeying Darcy's law. Diffuse flow can occur either as intergranular flow in porous limestones or as fracture flow in dense limestones with low primary porosity. The latter are similar in behavior to fracture flow aquifers developed in igneous rocks, and are wholly characterised by laminar flow.

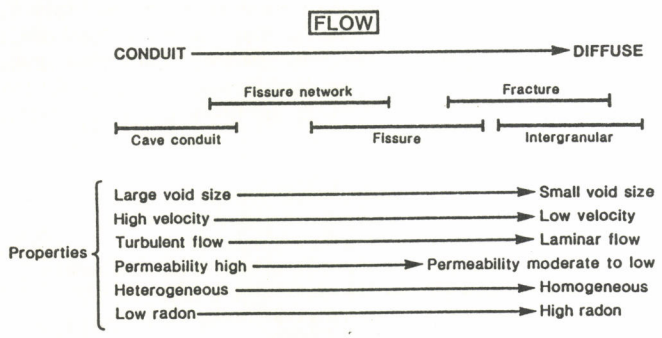

Figure 2. Range of flow types and their properties as used in the model.

Through time solutional modification of voids will occur. Where massive limestones are involved this may result in the development of cave conduits. These have high transmission capacities which dominate flow through the aquifer, even though large zones of diffuse flow remain between the conduits. In contrast where more densely fractured carbonates are involved there is a tendancy for more uniform solutional development, especially where these carbonates are associated with dispersed rechage (Palmer 1984). Fissures (width – cm) are thus developed from the initial fractures (width – mm) but flow does not become concentrated. In some areas however zones of enhanced fissuration occur giving rise to bands of dense fissure networks separated by less developed areas. Atkinson (1985) has suggested they form a separate flow type, but here we prefer to consider them intermediate between fissured aquifers and those with cave conduits. They are characterised by high general transmissivities, but have much less spatial variability than conduit aquifers.

The simplest methods of characterising flow type are by use of tracer experiments, but hydrological modelling is needed to produce quantitative estimates of the flow proportion in diffuse and conduit routes (Atkinson 1977). Chemical properties and the variability of discharge have also been used to characterise flow types (Shuster and White 1971), however because they are also dependent on the recharge process they may give ambiguous results. Recent work suggests that radon concentrations in spring waters may give an indication of the void size through which transmission occurs.

Storage

The representation of storage in the model is problematic because there is no consensus of opinion on the end members to be employed. If a similar approach is adopted to that used for recharge and flow, the continuum may be arranged in terms of storage type from unsaturated to seasonally saturated to permanently saturated storage (Figure 3). Such a scheme will be usefull for resource development and permits the clear differentiation of perched and saturated aquifer types. It also corresponds in a general manner with a trend towards increasing total volumes of storage (vertical axis of Figure 3). This is desirable because in some cases essentially similar hydrological responses may be derived from totally different storage zones, a factor which has probably been responsible for the underestimation of storage in the unsaturated zone of karstified aquifers. Unfortunately the relationship is not universal, and it could be argued that a continuum from high to low storage would be more usefull. However because storage is cummulative over several different locations in the aquifer this scheme does not permit a simple physical interpretation, and is therefore at varience with our general aim. Finally it is important to recognise that storage depends as much on the topography and geology of the aquifer system as on the flow type occuring (White 1969 and 1977). Thus the separation of transit (conduit flow) and storage (diffuse flow) water of Aley (1975) is not adopted here.

Individual components of storage are arranged on the continuum according to their dominant state. Thus unsaturated zone stores which may be partially air filled for much of the year ranged near the unsaturated end member, with seasonally saturated storage in unconfined aquifers occupying the central zone, and permanently saturated storage as the other end member. Deposits overlying the limestone prove a particular

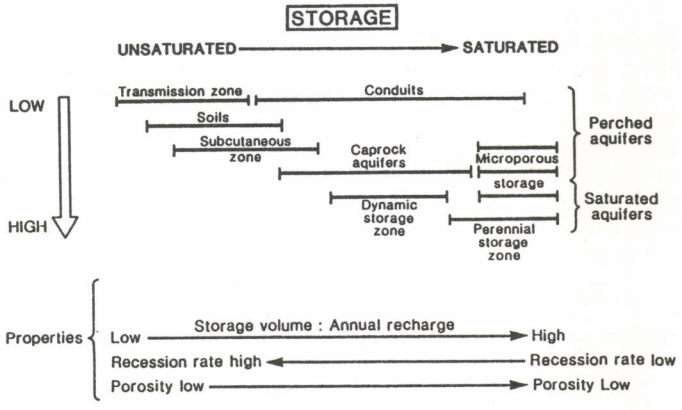

Figure 3. Range of storage types and their properties as used in the model.

problem in this arrangement. They range from thin limestone soils throung thick unconsolidated deposits to *in situ* caprocks such as sandstone and shale. For simplicity these have been subdivided into soils with essentially unsaturated storage which may reach field capacity during the wet season, and caprock aquifers which are capable of developing a true saturated groundwater body, and therefore have a greater storage capacity.

There has recently been an increasing awareness of the importance of the unsaturated zone storage in karstified aquifers (Friederich 1981, Gunn 1985). The majority of this storage occurs in the subcutaneous zone, which may be up to 10m thick and have a greater effective porosity than the saturated zone. This zone is seasonally saturated and a perched water body may develop in it because of the lower permeability of the underlying rocks. This underlying part of the unsaturated zone is termed the transmission zone, and is associated with fissure, fracture and intergranular seepage with low storage. The storage in unsaturated conduits is also low. Perched aquifers include all the types of storage discussed above but have no significant saturated storage. This distinguishes them from confined and unconfined aquifers where a true saturated zone is present.

In the saturated zone two important sub divisions are recognised: Dynamic storage occurs above spring level in unconfined aquifers. The water drains freely under gravity and is responsible (together with any unsaturated storage) for maintaining spring flows. Perenial storage occurs below spring level in unconfined aquifers and throughout confined aquifers. The volume of water in storage may be large, but changes in head yield small amounts by elastic release processes (aquifer compresion and water expansion). The volume of water in storage may be large, but changes in head yield small amounts by elastic release processes (aquifer compresion and water expansion). The appropriate storage coeficient is thus the storativity which is generally very low. It must be emphasised that considerable groundwater flow may occur in the perenial zone both by conduit and diffuse processes, thus the term static storage is avoided. Perenial storage may provide a significant source of water supply, because dewatering by pumping yields much greater volumes of water by gravitational drainage.

A final storage type recognised is microporous storage. This term is used to denote water retained at high tensions in bedrock voids in both the saturated and unsaturated zones after cessation of gravitational drainage. It is of most significance in carbonate aquifers with well developed microporosity such as the Chalks of South East England. Whilst microporous storage is of limited significance in affecting the dynamic response of the aquifer, it has a role in controlling water quality and is therefore included.

Storage is best measured in terms of the ratio of the storage volume to the annual recharge. This eliminates the effect of catchment size and emphasises the role of the confined zone which has a very significant effect on spring response. Conventional groundwater techniques may be used to determine storage and recharge volumes, but recession constants may give a usefull indication of relative magnitudes.

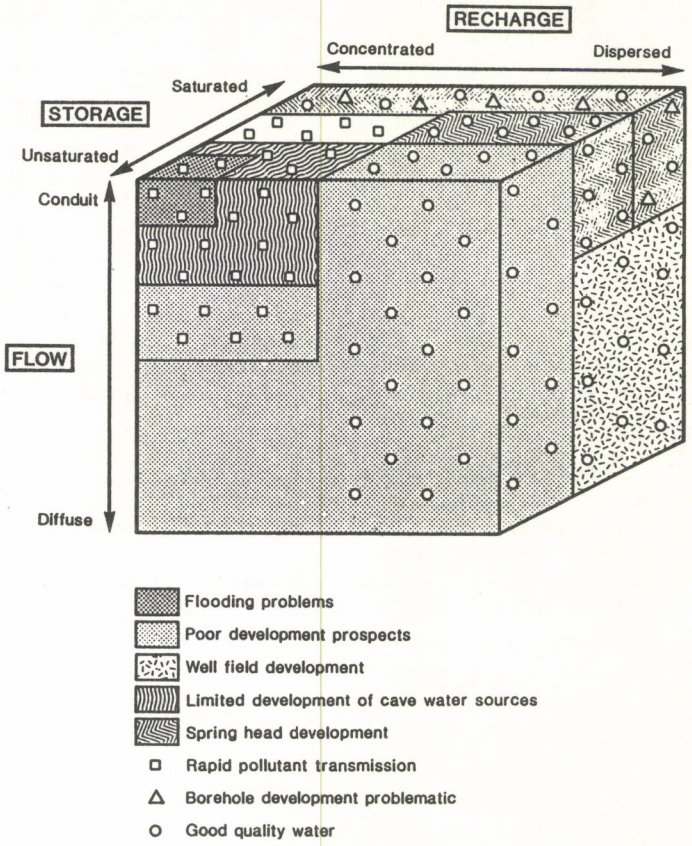

Figure 4. Three dimensional representation of the proposed model showing the influence of different typess of recharge, flow and storage on aquifer development prospects.

Discusion

Perched aquifers with little or no saturated storage have poor potential for the development of significant supplies irrespective of the nature of the recharge process (Figure 4). However, where conduit flow occurs in these aquifers water may accumulate in cave pools and be accessible directly througn the cave system (Waltham et al 1985). These supplies will however have a small yield as they rely on unsaturated zone storage for replenishment.

Where significant perennial storage is present, resource development may be via boreholes providing that conduit flow is absent. In fracture flow aquifers, borehole yields will generally be low and a large number of wells will be needed to provide a regional supply, but where fissures and particularly fissure networks occur, well yields may be very high. The great heterogeneity of conduit flow aquifers introduces an unacceptable degree of uncertainty into aquifer development by boreholes, and in this case abstraction at springs and resurgences will be more practical. This however limits storage to that in the saturated and dynamic zones. Development of the perennial storage zone of conduit flow aquifers whilst being highly desirable remains problematic.

Karstified aquifers are frequently of the conduit flow type with concentrated recharge and limited storage. This gives very rapid response to storm rainfall which can result in severe flooding by ponding of conduits and property damage downstream of springs (Crawford 1984, Newson 1973). Where conduits or conduit networks occur and recharge is concentrated, then there is a high risk of groundwater pollution from surface sources. However, where storage is large, residence times increase, resulting in dilution and attenuation of polutants. Water quality will thus be generally good. Dispersed recharge will similarly attenuate pollutant transmission, even if conduit or fissure network flow is developed.

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10293

The prediction method of the principal directions of drainage in karst

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RESUM

El mètode descrit ha estat probat amb èxit en diferents calcàries d'Espanya i a les geleres de Spitsbergen.

El mètode es basa, a més, en dues simples hipòtesis de treball, en l'aplicació de tècniques d'estructura geològica i en la projecció estereogràfica.

Aquest és un instrument de predicció simplement càrstica, que proporciona un grau de precisió superior al 95 % en els onze casos en què s'ha aplicat.

Té moltes possibilitats d'utilització en el camp de l'enginyeria geològica.

Donada la quantitat d'hipòtesis en què es basa aquest mètode, l'autor proposa nous camps d'aplicació, alguns dels quals encara no han estat assajats.

RESUMEN

El método descrito ha sido probado con éxito en distintas calizas de España y en los glaciares de Spitsbergen.

El método se basa además en dos simples hipótesis de trabajos en la aplicación de técnicas de estructura geológica, así como también en la proyección estereográfica.

Este es un instrumento de predicción meramente kárstica, que proporciona un grado de precisión superior al 95 % en los once casos en que ha sido aplicado.

Tiene muchas posibilidades de utilización en el campo de la ingeniería geológica.

En vista de la cantidad de hipótesis en que se basa este método, el autor propone nuevos campos de aplicación, algunos de los cuales no han sido probados todavía.

SUMMARY

The described method has been successfully tested in Spain limestones and in Spitsbergen glaciers.

The method is not only grounded on two simple work hypotheses but also on the application of structural geological technics as well as on the stereographic projection.

It's a prediction tool purely karstic giving an accuracy degree superior to 95 % in the eleven cases, in which it has been applied.

Its possibilities of application comprise large fields of the geological engineering.

Seen, the amplitude of the hypotheses on which is based this method, the author proposes new application fields. Some of them have still to be tested.

1. Introduction

The drainage in karstic and classical aquifers is very different. In karst, permeability occurs because there is a fissures interconnection whose circulation involves rock dissolution.

For that reason, both are qualitatively different.

In karst, the dissolution resulting from water circulation brings about an enlargment of holes or interconnected fissures, decreasing consequently, its pressure drop. So, in consequence, the hydraulic gradient of water flow grows, increasing the water circulation and so, successively.

By means of a feed-back effect, onyl the fissures which receive a stronger water circulation flow, get larger, to the detriment of the others.

The result of that phenomenon is a tridimensional conducts net which explains the high transmissivities as well as both directional and discrete characteristic of karstic aquifers.

When, the external conditions involve an hydraulic gradient decrease, the system evolves towards paleokarst which is characterized by a general tendency of conducts fillings. In the case of hydrothermal karst, a lot of ore minerals have the same origin, between them, we find a great number in Central Europe.

Dam building in karstic regions, where dam site offers excellent conditions, in civil engineer's point of view, presents frequenly, serious likeage problems. Their corrections are resulting so expensive as unforeseeable.

The aquifers, highly vulnerable to pollution and frequently, used as water supply for towns as well as endorreic drainages of some coastal karstic aquifers discharging directly into the sea etc., explain the high socioeconomic costs involved for using this bit of nature, into man's benefits.

For all these reasons, some contribution which is an advance in the karst knowledge, will bring an improvement of solutions in its practical application.

After a lot of decades and 5 years of contrasting and testing, we think that this method gives an advance in the knowledge of karst, for this motive, we proceed to its diffusion.

2. Methodology

The method is based on two hypotheses, the first one is qualitative and the second one is quantitative.

1) Karst is predetermined by tectonic conditions suffered by the rock massif. So, it determines the disposition of the tridimensional net of drainage conducts, according to its geological history.

2) The most probable drainage directions are organized inside plans which have the maxium component (1) and the intermediate component (2) of each stress ellipsoid. In consequence, they are perpendicular to the minor component (3) of each respective ellipsoid.

Work field investigations were limited to the application of structural geological techniques and also to the definition of stresses suffered by the massif, giving Grolier, 1976), (Ragan, 1980), (John 1962), (Park, Schot, 1968), (Shainin, 1950), (Stagg-Zienkiewicz, 1970), (Tjia, 1967).

A better solution is the microtectonic analysis, So. it's only necessary, to classify tectoglyphs conjunctions which, we shall use to define the searched ellipsoids. (Arthaud, 1969), (Arthaud, Choucrune, 1972), (Arthaud, Mattauer, 1969), (Capote, 1975), (Choukroune, 1969), (Eraso, Herrero, Saint-Aubin, 1983), (Grillot, Guerin, 1975), (Guerin, 1973), (Hudson, Priest).

These conjunctions are principally:

- Stylolite – Veine (E-V).
- Stylolite – Fault (E-F).
- Veine – Fault (V-F)
- Conjugated Faults (F-F)

By applying the stereographic projection, we shall resolve for each case, the ellipsoid in Wulff's net. (Philips, 1975).

By applying the second work hypothesis, we shall determine the drainage plan.

In practice, it's more interesting to work with the greatest number possible of tectoglyphs conjunctions to determine the probability degree of each defined mode.

For representing them, we shall apply the stereographic projection, but in this case, using Schmidt's net.

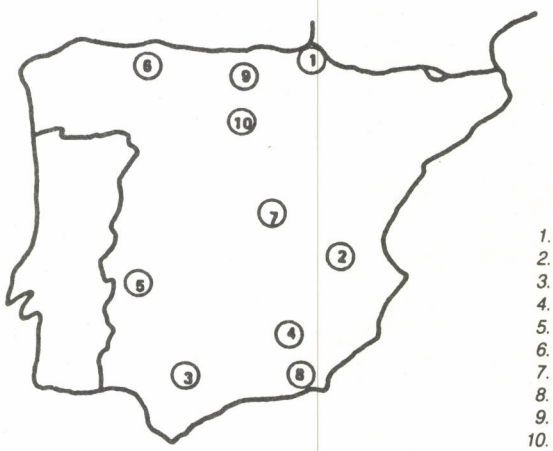
The result is a tridimensional polimodal with a quantified probability percentage for each of its modes giving the principal directions of the subterranean drainage. This result is valid for predictions.

To make easier field data processing, the method is available with three computer programs:

- GEORED: In which, we see Wulff's stereographic net (equiangular) as well as Schmidt's net (equiaral) for some angle of inclination and also for several parallels and meridians densities.
- GEODRE: In which, the position of the ellipsoid component (1,2,3) as well as the drainage plans for each respective conjunction are calculated and drawn by plotter.
- GEOPOL: In which, for a determined plans or poles family, the areas of equal concentration, for each wished are percentage, are calculated and drawn by plotter.

3. Results

The method successfully in eleven examples, ten were carried out in very different geological conditions of Spain karstic regions (figure 1).and the eleventh was carried out into ice karst of the Svalvard Archipelago Glaciers. (Eraso, 1983), (Eraso, 1986a), (Eraso, 1986b).



1. *Larra*
2. *Tous*
3. *Libar*
4. *San Clemente*
5. *Canchales*
6. *Soto de Ribera*
7. *Alcorlo*
8. *Beninar*
9. *Miera*
10. *Ojo Guareña*

Figure 1. Location of the Spanish examples

Its accuracy degree is very high, superior to 95 % in the cases, in which, it was possible to quantify (9 of them).

The purposes of the study of the Spanish examples were: The contrast in the case of large caverns nets whose topography were possible to carry out; the leaks prediction in dam building; the pollution progression in aquifers; the subterranean discharge of fresh water into the sea etc...

The examples were chosen in order to bring a great variety into the sampling. they were carried out into the «Macizo Pirenaico», the «Cornisa Ibérica», the «Cordillera Bética» and they were located in the most various calcareous outcrops from the Cambrian to the Tertiary (Table 1).

The prediction given by the method has been confirmed in the majority of cases by means of coloration with fluoresceine, which has been used in some cases to modify the original engineering projects, in order, to adapt them to the actual situation.

The method contrast in the case of having available the topography of large subterranean nets, can be carried out by means of the polimodels shown in the figure 2, in this particular case in two dimensions.

If we apply Kolmogorov's test to the accumulated curve, we shall be able to quantify statistically, the validity of the described method.

Table 1. Validity of the prediction method

EXAMPLE		LOCATION		PURPOSE	COMPARISON BEET WEN PREDICTION AND REALITY	DEGREE OF SUCCESS	
No.	Karst	Geographical	Geological			Cualitative	Cuantitative
1	Larra	Navarra Francia	Cretaceous	Checking of the method in limestone	Direct a priori	Very high	< 5%
2	Tous	Valencia	Cretaceous	Water lost in dam	Directly	Full	< 2%
3	Livar	Málaga	Jurasic	2nd. Cycle thesis	Direct a priori	Full	< 1,5%
4	San Clemente	Granada	Subbetic Prebetic	Hyperreservoir	Direct a posteriori	Full	< 1%
5	Lacara	Badajoz	Cambrian	Tegulation Dan	Indirect in Mineral veins	Concordant	–
6	Soto de Ribera	Asturias	Carboniferous	Thermal power plant	Direct a posteriori	Full	< 1%
7	Alcorlo	Guadalajara	Upper Cretaceous	Irigation dam	Indirect by Kriging	Concordant	–
8	Beninar	Almería	Alpine Trias	Dam and tunnel for water suply		Full	< 2%
9	Rio Miera	Cantabria	Lower Cretaceous	Pollution progression	Direct a priori	Full	< 1%
10	Ojo Guareña	Burgos	Upper Cretaceous	Checking of the method in limestone	Very high	< 3%	
11	Werens Kiold	Svalvard	Glacier	Checking of the method in ice mass	Directly	Full	< 2%

4. Conclusions

At first. the described method is appicable to the following fields:

– Knowledge of the karstic drainage net.

– Study and operation of karstic aquifers. (Kordk, Eraso, 1985).

– Pollution progression and contamination in karstic aquifers.

– Leakages prediction in dams located in karstic regions.

– Carrying out of diaphragm walls and grouting curtains for the impermeabilization in civil engineering jobs, in karstic regions.

– Detection of fresh water leakages in coastal karstic aquifers and submarine springs.

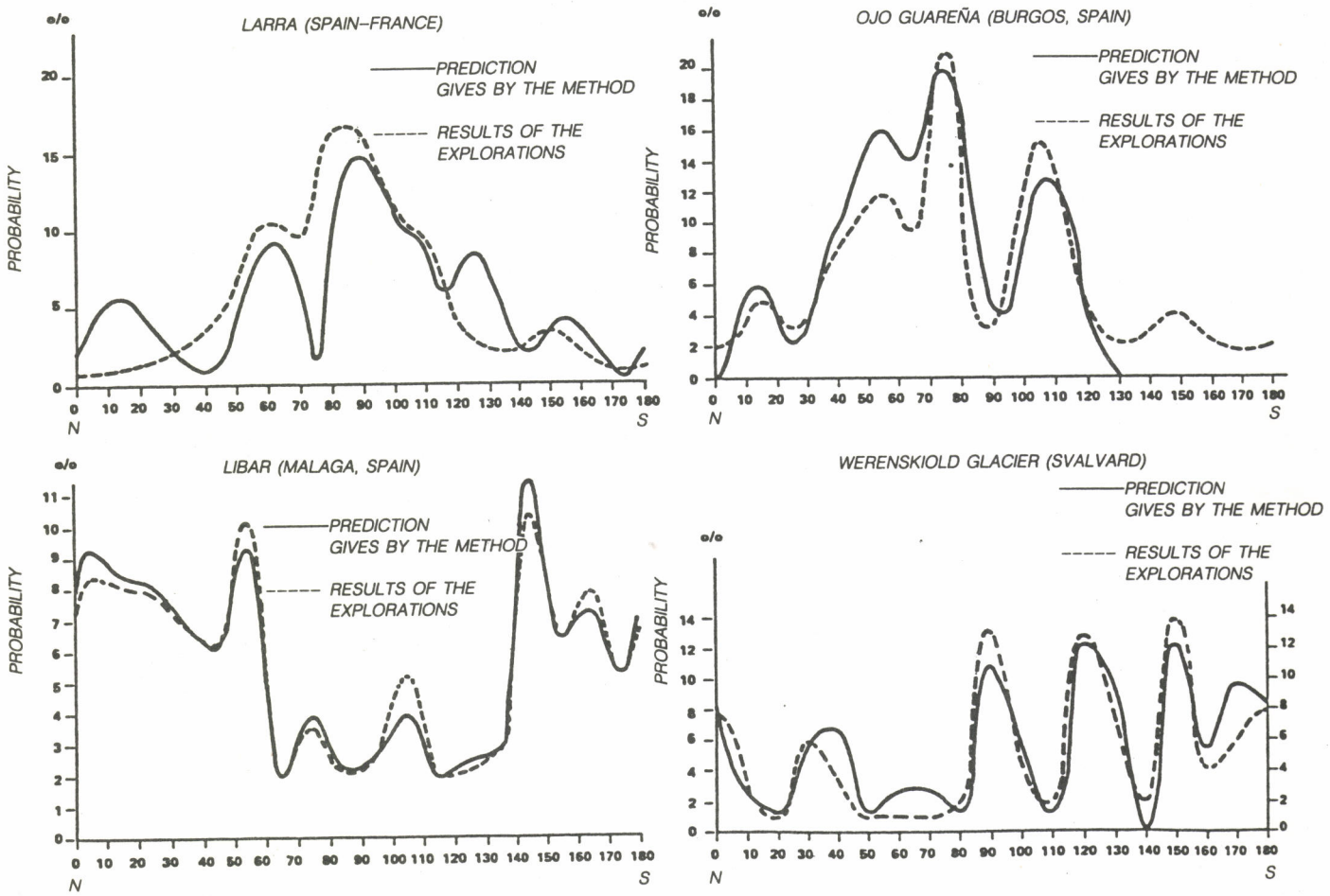


Figure 2. Comparison between both directional probability polimodals in several examples

– Saline intrusion in coastal karstic aquifers due to overworking.

– Prediction of the mineralization directions interrelated with paleokarst.

– Water intrusion in open pit mines located in karstic regions.

– Excavation under the water table in karstic aquifers.

And is generally, also used for the quantitative estimation in the directional aspect of both karstification potential and validity, in the theorical studies of karst.

The karstification process is very important and is not exclusively limited to a specific type of rocks. It has been observed not only, in carbonatic rocks but also in quarzites of the Sarisarcinama region (South part of Venezuela)–. We should be able to use this nature phenomenon as work hypothesis, thinking that nature has had enough time, during 600 millions of years, to carry it out, but it's not enough...

If as work hypothesis, the concept of dissolution is amplified to the concept of solid likeage, for instance: colloidal dispersion or state change due to fusion then, it's possible to use the same posings for the following aspects (Eraso, 1973), (Eraso, Pulina, 1985):

– Piping in clays core of earth dams.

– Lavic tubes produced in some volcanic rocks.

– Ice karstification in Subpolar Glaciers and its practical consequence, the fresh water supply, for bases located in the Antarctic periphery.

It has been tested sucess in the Arctic Circle. (Eraso, 1985b), (Eraso, 1985c).

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The karst hydrogeology of Lukwi caves, Papua New Guinea

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RESUM

Les coves de Lukwi es troben a la província occidental de Papua Nova Guinea. Les coves van ésser explorades i estudiades l'any 1985, a petició d'OK Tedi Mining Limited, ja que s'obren a la part final d'una presa. Alguns quilòmetres de galeries subterrànies varen ésser descoberts en la calcària de Warre, en una zona càrstica d'uns 2 km², amb complexes sistemes de cavitats i amb una

gran varietat morfològica. La calcària de Warre pertany al Miocè Mitjà, i només s'ha pres en consideració i ha estat explorada per a estudiar el desenvolupament del carst durant un curt període. El desenvolupament del carst és ràpid, ja que l'àrea està recoberta de selva tropical i el carst de Lukwi reb, aproximadament, 8 m. anuals de precipitacions. S'han dut a terme estudis geològics, geomorfològics i de la composició química de l'aigua de la superfície i del subsòl, a fi i efecte de poder establir una seqüència en el desenvolupament de les coves de Lukwi.

RESUMEN

Las cuevas Lukwi están en la Provincia occidental de Papúa Nueva Guinea. Las cuevas fueron exploradas y estudiadas durante el año 1985 a petición de OK Tedi Mining Limited ya que se encuentran dentro de la parte final de una presa. En la caliza Warre fueron encontrados algunos kilómetros de galerías subterráneas en una zona kárstica de unos 2 km^2. Hay complejos sistemas de cavidades que contienen una soprendente variedad de morfologías de galerías. La caliza de Warre es del Mioceno Medio, sólo se le ha dado valor y ha sido explorada para el desarrollo del karst durante un corto período. El desarrollo del karst es rápido ya que el área se cubre con selva tropical y el karst de Lukwi recibe aproximadamente 8 m. anuales de lluvia. Se han efectuado estudios geológicos, geomorfológicos, hidrológicos y de la composición química del agua de la superficie y del subsuelo. Ello se utiliza para presentar una secuencia para el desarrollo de cuevas en Lukwi.

ABSTRACT

Lukwi Caves are in the Western Province of Papua New Guinea. The caves were explored and studied during 1985 at the request of Ok Tedi Mining Limited as they lay within a proposed tailings damsite. In the Warre Limestone several kilometres of cave passage were found in a karst area of some 2 km^2. Within this small karst area there are complex cave systems and these contain a surprising variety of cave passage morphologies. The Warre Limestone is Middle Miocene and it has only been uplifted and stripped for karst development for a limited period. Karst development is rapid as the area is covered with tropical rainforest and the Lukwi karst receives approximately 8 metres of rainfall annually. Studies of the surface and underground geology, geomorphology, hydrology and water chemistry have been made. These will be used to present a sequence for the cave development at Lukwi.

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L'evolution paleohydrologique et morphologique des Pyrenees Centrales: l'exemple du massif karstique d'Arbas (France)

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RESUM

Aquest massís, prou conegut pels espeleòlegs, gràcies al «réseau Trombe de la Coume Ouarnède», està constituit per vàries desenes de quilòmetres de cavitats i és un exemple remarcable per l'esglaonament de les formes càrstiques i fluvials que presenta. Les causes d'aquest fenomen han estat analitzades per a reconstruir l'evolució paleohidrològica i morfològica d'aquesta part dels Pirineus Centrals. L'evolució d'aquesta regió des del Terciari, permet una millor comprensió de la carstificació i una millor definició dels factors que intervenen en el potencial de carstificació.

RESUMEN

Este macizo, bien conocido por los espeleólogos gracias al «Réseau trombe de la Coume Ouarnède», está consitituido por varias decenas de kilómetros de cavidades, es un ejemplo remarcable por el escalonamiento de las formas kársticas y fluviales que presenta. Las causas de este escalonamiento han sido analizadas para reconstruir la evolución paleohidrológica y morfológica de esta parte de los Pirineos Centrales. La evolució de esta región desde el terciario permite una mayor comprensión de la karstificación y una mejor definición de los factores que intervienen en el potencial de karstificación.

SUMMARY

Ce massif, bien connu des spéléologues grâce au réseau Trombe de la Coume Ouarnède, est constitué de plusieurs dizaines de kilomètres de cavités; c'est un exemple remarquable par l'étagement des formes karstiques et fluviatiles qu'il présente. Les causes de cet étagement ont été analysées afin de reconstituer lévolution paléohydrologique et morphologique de cette partie des Pyrénées centrales. L'évolution de cette région depuis le Tertiaire permet ainsi de mieux comprendre la karstificaction et de mieux définir les facteurs intervenant dans le potentiel de karstification.

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Karst in Catalonia: geomorphological and hidrogeological aspects

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RESUM

Aquest treball és una síntesi preliminar de les grans àrees kàrstiques de Catalunya. Es sistematitzen els karsts segons s'hagin desenvolupat en: roques carbonàtiques, detrítiques (conglomerats i gresos) i evaporítiques (guixos,...). I es faciliten dades dels exemples de karsts i/o sistemes kàrstics que per les seves característiques geomorfològiques (espeleològiques) i/o per la seva hidrogeologia són més remarcables.

RESUMEN

Este trabajo constituye una síntesis preliminar de las áreas kársticas más importantes de Catalunya. Se sistematizan los karsts según se hayan formado en: rocas carbonatadas, detríticas (conglomerados y areniscas) y evaporíticas (yesos,...). Y se facilitan datos relativos a los ejemplos de karsts y/o sistemas kársticos que por sus características geomorfológicas (espeleológicas) y/o por su hidrogeología son más remarcables.

SUMMARY

This is a preliminary synthesis of the wide karstic areas in Catalonia. Karsts are being systematized according to their development in either carbonatic rocks, clastic rocks (conglomerates and sandstones) or evaporitic rocks (gypsum,...). Data proceeding from karst examples and/or karstic systems which are remarkable for their geomorphological (speleological) characteristics and/or for their hydrology, are also supplied.

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Evolution and dynamics of a karst in the Pyrenees: Arañonera, Alba and Guells de Jueu

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RESUM

En aquest treball s'analitzen les característiques de tres àrees kàrstiques de la zona pirenaica: Karst d'Arañonera (Serra Tendeñera, riu Ara), karst d'Alba (Maladeta, riu Essera) i karst dels Güells de Jueu (Maladeta-Artiga de Lin, riu Garona). Primerament es discuteixen aspectes relatius a l'evolució d'aquests karsts, remarcant el seu caràcter polifàsic, a partir d'observacions realitzades en les xarxes espeleològiques pretèrites i, d'aspectes geomorfològics més generals i, a continuació, es facilita una síntesi de la dinàmica actual dels sistemes estudiats basada en dades, essencialment hidrogeoquímiques.

RESUMEN

En este trabajo se analizan las características de tres áreas kársticas de la zona pirenaica: karst de Arañonera (Sierra Tendeñera, río Ara), karst de Alba (Maladeta, río Esera) y de Güells de Jueu (Maladeta-Artiga de Lin, río Garona). En primer lugar se discuten aspectos relativos a la evolución de dichos karsts, destacando su carácter polifásico, a partir de las observaciones realizadas en las redes espeleológicas pretéritas y en aspectos geomorfológicos más generales y, a continuación, se facilita una síntesis de la dinámica actual de los sistemas estudiados basada en datos, esencialmente hidrogeoquímicos.

SUMMARY

In this work the caracteristics of three karstic areas from the Pyrenees are analyzed: Arañonera karst (Sierra Tendeñera, river Ara), Alba karst (Maladeta, river Esera) and Guells de Jueu karst (Maladeta-Artiga de lin, river Garona). On the one hand, aspects of relating to the evolution of these karst are discussed, specially stressing their poliphasic traits, according to the observation carried out in, ancient speleological networks and in more general geomorphological aspects. On the other hand, a synthesis of the modern dynamics of the studied systems is provided, based on essentialy hydrogeochemical data.

10116

Flood statistics, extreme flood events, and their importance to cave development in the Green River basin (Mammoth Cave Area)

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RESUM

El Green River, amb una conca de drenatge de 7.200 km². per sobre de la mesura de Brownsville, és el curs nivell base per als amplis sistemes de cavitats del National Park, prop de Mammoth Cave. El Green River discorre per una vall estreta amb un canal situat a uns 6-10 m. per sobre de reompliments sedimentaris de Wisconsin. El drenatge dominant dels sistemes de cavitats són eixos de gradient baix, alineats en sèries des del nivell d'embassament del pis inferior fins a 60 m. per sobre del nivell d'embassament del pis superior, amb nivells principals separats tant sols de 20 m. Degut a l'estretor de la vall, les inundacions del Green River van acompanyades de grans crescudes del riu, inundant-se la major part de les galeries subterrànies compreses dins la zona d'inundació. Les anàlisis, fruit de seixanta anys de presa de dades, indiquen que un llarg retorn periòdic de les inundacions (100 i 1.000 anys) té lloc a galeries subterrànies normalment seques, en intervals poc freqüents. L'anàlisi des inundacions extremes prediuen que les taxes mitjanes de cada 100 i 1.000 anys, són, respectivament, de 3,0 i 4,0.

RESUMEN

El Green River, con una cuenca de drenaje de 7.200 Km². por encima de la medida de Brownsville, es el curso nivel de base para los amplios sistemas de cavidades en el National Park y cerca de Mammoth Cave. El Green River discurre por un valle estrecho con un canal colgado a unos 6-10 metros por encima de rellenos de sedimentos de Wisconsin. El drenaje dominante en los sistemas de cavidades son ejes de gradiente bajo, alineados en serie desde el nivel del embalse del piso inferior hasta 60 m. por encima del nivel del embalse del piso superior, con niveles principales separados solamente por 20 metros. Debido a la estrechez del valle las inundaciones en el Green River van acompañadas por grandes crecidas del río con inundación de la mayoría de las galerías subterráneas que están comprendidas dentro del rango de inundación. Los análisis de sesenta años de recolección de medidas muestran que un largo regreso periódico de las inundaciones (100 y 1.000 años) acontecen en galerías subterráneas normalmente secas en intervalos poco frecuentes. El análisis de las inundaciones extremas predice que las proporciones promedio de 100 años y promedio de 1.000 años son 3,0 y 4,0 respectivamente.

SUMMARY

Green River, with a 7.200 Km² drainage basin above the Brownsville gage, is the base level stream for the large cave systems in and near Mammoth Cave National Park. Green River flows in a narrow valley with a channel perched on 6 - 10 meters of Wisconsin sedimentary filling. The master drains of the cave systems are low-gradient trunks arrayed in tiers from below pool stage to 60 meters above pool stage with major levels separated only by 20 meters. Because of the narrow valley, floods in the Green River are accompanied by large rises in river stage with accompanying flooding of many caves passages that lie within the flood range. Analysis of sixty years of gage records shows that long return period floods, 100 and 1000-year, result in flooding of normally dry cave passages at infrequent intervals. Extreme flood analysis predicts the 100-year/mean and the 1.000-year/mean ratios are 3.0 and 4.0 respectively.

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The Expounding Of Recession Coefficient In The Hydrography Curve Of Karst Systems

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RESUM

L'article sobre «L'explicació del coeficient de regressió en la corba hidogràfica dels sistemes cárstic» parla de tres diferents equacions de decadència de les corbes hidrogràfiques i de diferents models hidrogeològics, obtenint-se tres coeficients de regressió, respectivament. L'equació de recessió exponencial i el coeficient de regressió dels sistemes càrstics aplicada, per extensió als sistemes aqüífers càrstics té condicions estrictes. Es pot aplicar, tant sols, als sistemes d'aqüífers càrstic que s'assemblin al model de reservori; però no als medis permeables dels sistemes d'aqüífers de fisures càrstiques. Segons l'equació exponencial és quasi un prejudici, 'en gran part de situacions, explicar la variació del coeficient de regressió en «the territory of time» en els sistemes d'aqüífers càrstics indeterminats des del punt de vista dels múltiples medis d'un aqüífer. El coeficient de regressió dels sistemes d'aqüífers es relaciona, no només amb les característiques de l'aqüífer, sinó també amb la variació de les propietats dels límits de l'aqüífer.

RESUMEN

El artículo sobre «La explicación del coeficiente de regresión en la curva hidrográfica de sistemas kársticos» habla de tres diferentes ecuaciones de decadencia de las curvas hidrográficas de diferentes modelos hidrogeológicos, obteniendo tres coeficientes de regresión respectivamente. La ecuación de regresión exponencial y el coeficientee de regresión de los sistemas kársticos aplicada extensivamente a los sistemas de acuíferos kársticos,* tiene condiciones estrictas. *Se pude aplicar solamente en los sistemas de acuíferos kársticos que se asemejen al modelo de* reservorio *pero no en los medios permeables de los sistemas de acuíferos de fisuras kársticas. Según la ecuación exponencial es casi un* prejuicio *en la mayor parte de situaciones explicar la variación del coeficiente de regresión en «the territory of time» en los sistemas de acuíferos kársticos cualesquiera desde el punto de vista de los múltiples medios de un acuífero. Para el coeficiente de regresión de los sistemas de acuíferos se relaciona no sólo con las características de los acuíferos, sino también con la variación de las propiedades de los límites del acuífero.*

SUMMARY

The article of «The Expounding of Recession Coefficient in the Hydrography Curve of Karst Systems» discusses three different decay equations of hydrography curves of different hydrogeologic models, obtaining three recession coefficients respectively. The exponential recession equation and the recession coefficient of karst systems applied to karst aquiferous systems extensively have strict conditions. It can apply only in the karst aquiferous systems that likes the resorvoir model, but not in the permeable media of karst fissure aquiferous systems. According to the exponential equation, it's almost a prejudice at most situations to explain the variation of recession coefficient at the territory of time in the karst aquiferous systems everywhere from the point of view of multiple media of aquiferous body. For the recession coefficient of aquiferous systems relates not only to the characteristic of aquiferous media but also to variation of boundary properties of aquiferous body.

The research of recession characteristic in the hydrograph curve of karst systems is at present time in accord with exponential equation, which was solved by Maillet in 1905.

Maillet exponential recession equation was derived from the model of reservoir. The differential equation may be written as:

$$A\frac{dh}{dt} + \varepsilon h = 0 \quad , \quad h\Big|_{t=0} = h_0$$

Where A is the area of resorvoir, h is the water table of reservoir and $\varepsilon=Q/h$ is a constant that is related to discharge, while Q is the amount of water passing through the exit of reservoir at t time. The solution of differential equation may be obtained as follows:

$$h = h_0 e^{-\alpha_1 t}$$

where $\alpha_1 = \frac{\varepsilon}{A}$

we call α_1 the recession coefficient of the water table of reservoir.

The karst aquiferous system model near by the river is another practical hydrogeological model. Here the river penetrates all the way through the aquifers. The differential equation and its conditions of solution are expressed as:

$$\begin{cases} \frac{\partial}{\partial x}\left(h\frac{\partial h}{\partial x}\right) = \frac{\mu}{k}\frac{\partial h}{\partial t} \\ h(x,t)\Big|_{t=0} = h(x) \quad , \quad 0 \leqslant x \leqslant L \\ h(x,t)\Big|_{x=0} = 0 \quad , \quad t > 0 \\ \frac{\partial h}{\partial x}\Big|_{x=L} = 0 \quad , \quad t > 0 \end{cases}$$

Were K and μ are the hydraulic conductivity and specific yield respectively, L is the distance between recharge area and exit of groundwater flow, h(x)- the thickness of aquiferous body of karst systems at initial time.

Using the methods of separation of variables, let the solution of eq. (4) be

$$h(x,t) = X(x)\cdot T(t).$$

Therefore the first equation of (4) becomes

$$\frac{1}{X}\frac{d^2(X^2)}{dx^2} = \frac{2\mu}{T^2 k}\frac{dT}{dt}$$

Since it depends only on t on the right side of above equation, only on x on the left side, so it's a constant, Let it be $-\lambda(\lambda > o$, for practical meaning).

Thus eq. (4) becomes

$$\begin{cases} \frac{dT}{dt} + \frac{\lambda k}{2\mu}T^2 = 0 \\ \frac{d^2(X^2)}{dx^2} + \lambda X = 0 \quad , \quad X(0) = 0 \quad , \quad X(L) = 0 \end{cases}$$

The first and second equations in (5) are solved, we obtained respectively:

$$\begin{cases} T(t) = \frac{1}{C_2 + \frac{\lambda k}{2\mu}t} \\ X(x) = C_1 F\left(\sqrt{\frac{\lambda}{3C_1}}\cdot\frac{x}{v}\right) \end{cases}$$

Where C_1, C_2 are two constants of integrals,

$$v = \int_0^1 \frac{\tau\, d\tau}{\sqrt{1-\tau^3}} \approx 0.864$$

and F is defined by

$$s = \frac{1}{v}\int_0^F \frac{\tau\, d\tau}{\sqrt{1-\tau^3}} \quad , \quad (0 \leqslant s \leqslant 1 \ , \ 0 \leqslant F \leqslant 1)$$

Hence the general solution of first equation of (4) is

$$h(x,t) = \frac{C_1 F\left(\sqrt{\frac{\lambda}{3C_1}}\cdot\frac{x}{v}\right)}{C_2 + \frac{\lambda k}{2\mu}t}$$

Using initial and boundary conditions, we obtained at last that the solution of (4) is

$$h(x,t) = \frac{h_0(x)}{1+\alpha_2 t}$$

$$\alpha_2 = \frac{1.12\, k h_0(L)}{\mu L^2}$$

Eq. (7) is hyperbolical function. In the same way as eq. (3), we call α_2 the first recession coefficient of aquiferous body.

If the thickness of aquiferous body is much larger than the depth of cut of river, then the differential equation and the conditions given about hydrogeology model are the following:

$$\begin{cases} \dfrac{k H_{cp}}{\mu}\dfrac{\partial^2 h}{\partial x^2} = \dfrac{\partial h}{\partial t}, & h = H_0 - H \\ h(x,t)\Big|_{t=0} = 0, & 0 \leqslant x \leqslant \infty \\ h(x,t)\Big|_{x=0} = H_0 - H_{cp} = h_1, & t > 0 \\ h(x,t)\Big|_{x=\infty} = 0, & t > 0 \end{cases}$$

Where H_{cp} and H_0 are the thickness of aquiferous body at the river bank and the watershed respectively. H is the thickness of aquiferous body at any point along the x-axis.

Using the semi-infinite Fourier sine transform

$$\bar{h} = \int_0^\infty h \sin(\lambda x)\,dx \quad \left(\lambda = \frac{n\pi}{L},\ n = 1, 2, \cdots\right)$$

the first equation of (9) would become

$$\int_0^\infty \frac{\partial h}{\partial t}\sin(\lambda x)\,dx = a\int_0^\infty \frac{\partial^2 h}{\partial x^2}\sin(\lambda x)\,dx$$

where $a = KH_{cp}/\mu$. After integration above equation, the first and second equations of (9) would become

$$\begin{cases} \dfrac{d\bar{h}}{dt} + a\lambda^2\bar{h} = a\lambda h_1 \\ \bar{h}\Big|_{t=0} = 0 \end{cases}$$

It's a first-order nonhomogeneous linear differential equation. Its solution is

$$\bar{h} = a\lambda h_1 \int_0^t e^{-a\lambda^2(t-\tau)}\,d\tau$$

Using (11) for finding inversion of (10), we have

$$h = \frac{2ah_1}{\pi}\int_0^t \left[\int_0^\infty \lambda e^{-a\lambda^2(t-\tau)}\sin(\lambda x)\,d\lambda\right] d\tau$$

Calculating above integral by appropriate transformation, we obtained at last that the solution of (9) is

$$h(x,t) = \frac{2h_1}{\sqrt{\pi}}\int_{\eta_0}^\infty e^{-\eta^2}\,d\eta = h_1\,\mathrm{erfc}(\eta_0)$$

In the above expression

$$\eta = \frac{x}{\sqrt{4a(t-\tau)}},$$

$$\eta_0 = \frac{x}{\sqrt{4a(t-\tau)}}\Big|_{\tau=0} = \frac{x}{\sqrt{4at}},$$

$$a = \frac{kH_{cp}}{\mu} = \frac{T}{\mu}$$

Let us assume $\alpha_3 = 4kH_{cp}/(\mu L^2)$,

α_3 is called the second recession coefficient of aquiferous body. Then eq. (12) becomes

$$h(x,t) = h_1\,\mathrm{erfc}\left(\frac{1}{\sqrt{\alpha_3 t}}\right)$$

From previous discussion, we obtained three different recession coefficients of decay equation of groundwater systems with different hydrogeological models. The hydrogeologists at home and abroad have been doing a lot of work in the field about groundwater regime. In the monography, Ycrobue Øopmuupobahue u npo1h03bl ecmecmbehh010 pexuu nog3uhblx bog by B. C. Kobarebckuu in 1973, he wrote: «When aquifer structure of discharge zone is relatively uniform, while the data mesured during water table falling are used, the recession coefficient is a constant. The recession coefficient of water table in the karst aquiferous systems is liable to vary. When the water table decline at the initial stage, the groundwater flow out from cave-tube, soon after from karst fissure and then from the fine fissure and microkarst. The value of α vary also from large to small correspondingly,...» These are the most common opinion about recession coefficient and it has formed the fixed method to obtain α.

In summary, we conclude with the following points:

1. from eq. (3) and (8), we can see that the water table recession coefficient of aquiferous systems relate not only to the characteristic of aquiferous media (i. e. specific yield, transmissivity and aquiferous body geometry), but also to boundary properties of aquiferous body. Namely, the variation of recession coefficient is not necessarily due to the properties of multiple media. Some scholars have pointed out that the recession coefficient of water table in the year of raininess is less than in the dry year.

2. The water table decay equation with exponential function is obtained from the reservoir model (From the heat-conduction equation, we can only obtain the exponential function as simplified solution). Eq. (7) and (14) are the accurate solution in the field, we must utilize these two formulas as fully as posible. It must be careful to use eq. (2).

3. The method to use data of water table with the aid of exponential function to obtain the recession coefficient of aquiferous system is a means of curve fitting. People may use this method to forecast the water table or amount of flow in future, but their hydro-physics implication is not quite clear.

It is almost a prejudice at most situations to explain the variation of recession coefficient in the karst aquiferous systems everywhere from the point of view of multiple media of aquiferous body.

4. If we use the hydrogeological tests in field to obtain the parameters of karst aquiferous systems, and then utilize the formula of recession coefficient to calculate the value of α, it may be discovered that the recession coefficient obtained from using data of water table with the aid of exponential function is less than the former one.

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Principle Characteristics of Karst Hydrology in China

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RESUM

Les característiques hidròqiques del carst de les regions septentrionals de la Xina són molt diferents de les de la Xina meridional, ja que tant condicions climàtiques com l'estructura geològica, la litologia de les formacions calcàries, la geomorfologia, el sòl i la vegetació són també molt diferents.

Les condicions hidrològiques del carst de les regions meridionals es caracteritzen per un gradient longitudinal més escarpat, per la presència de conductes i de corrents àmpliament distribuïts, un elevat coeficient d'inestabilitat, una gran velocitat, una forta fluctuació de descàrrega i una alternància de les seccions superficials i sub-superficials dels cursos d'aigua càrstica.

Les característiques hidrològiques del carst de la Xina septentrional es distingeixen per un gradient hidràulic horitzontal, una xarxa de fissures i corrents que circulen per conductes, una àmplia zona de surgència de drenatge, un règim estable, un elevat contingut de compostos químics, una baixa proporció de descàrrega màxima, una mínima velocitat del corrent i un llarg temps de permanència.

RESUMEN

En condiciones de diferentes climas, estructura geológica, litología de formaciones carbonatadas, geomorfología, suelo y vegetación, las características hidrológicas del karst en China Septentrional se distinguen mucho de las del Sur.

La hidrología kárstica se caracteriza por el gradiente longitudinal más escarpado, conductos y corrientes en cavidades distribuídas ámpliamente, elevado coeficiente de inestabilidad, gran velocidad, fuerte fluctuación de descarga, nivel del agua y calidad responsable de la lluvia, alternancia de la secciones superficiales y subsuperficiales de los cursos de agua kárstica.

Las características de la hidrología del karst en China Septentrional son de gradiente hidráulico horizontal, red de fisuras y corriente por conducto, amplia zona de surgencia de drenaje, régimen estable, elevado contenido de compuestos químicos, baja relación de descarga máxima y velocidad de corriente y largo tiempo de permanencia.

SUMMARY

In the conditions of different climate, geological structure, lithology of carbonate formations, geomorphology, soil and vegetation, the karst hydrologic characteristics in North China greatly distinguish from the South.

The karst hydrology is characterized by the steeper longitudinal gradient, conduit and cavern flow broadly distributing, high unstable coefficient, high velocity, strong fluctuation of discharge, water level and quality respounsible to rainfall, alternation of surface and surbsurface sections of karst water course.

The characteristics of karst hydrology in North China is flat hydraulic gradient, network of solutional fissure and conduit flow, large spring drainage area, stable regime, high chemical compound contents, low ratioes of max.-min. discharges and flow velocity and long residence time.

Introduction

The carbonate rocks in China occupy about 3,440,000 Km^2, of which 910,000 Km^2 are exposed and inhomogeneously distribute (Fig. 1, Table 1), about 450,000 Km^2 in the southwest China including Guizhou, Guangxi, Hunan, Hubei, Sichuan and Yunnan provinces; only 79,000 Km^2 in the north and northeast China; and 270,000 Km^2 in Xingjiang, Qinghai, Xizang and Ningxia provinces.

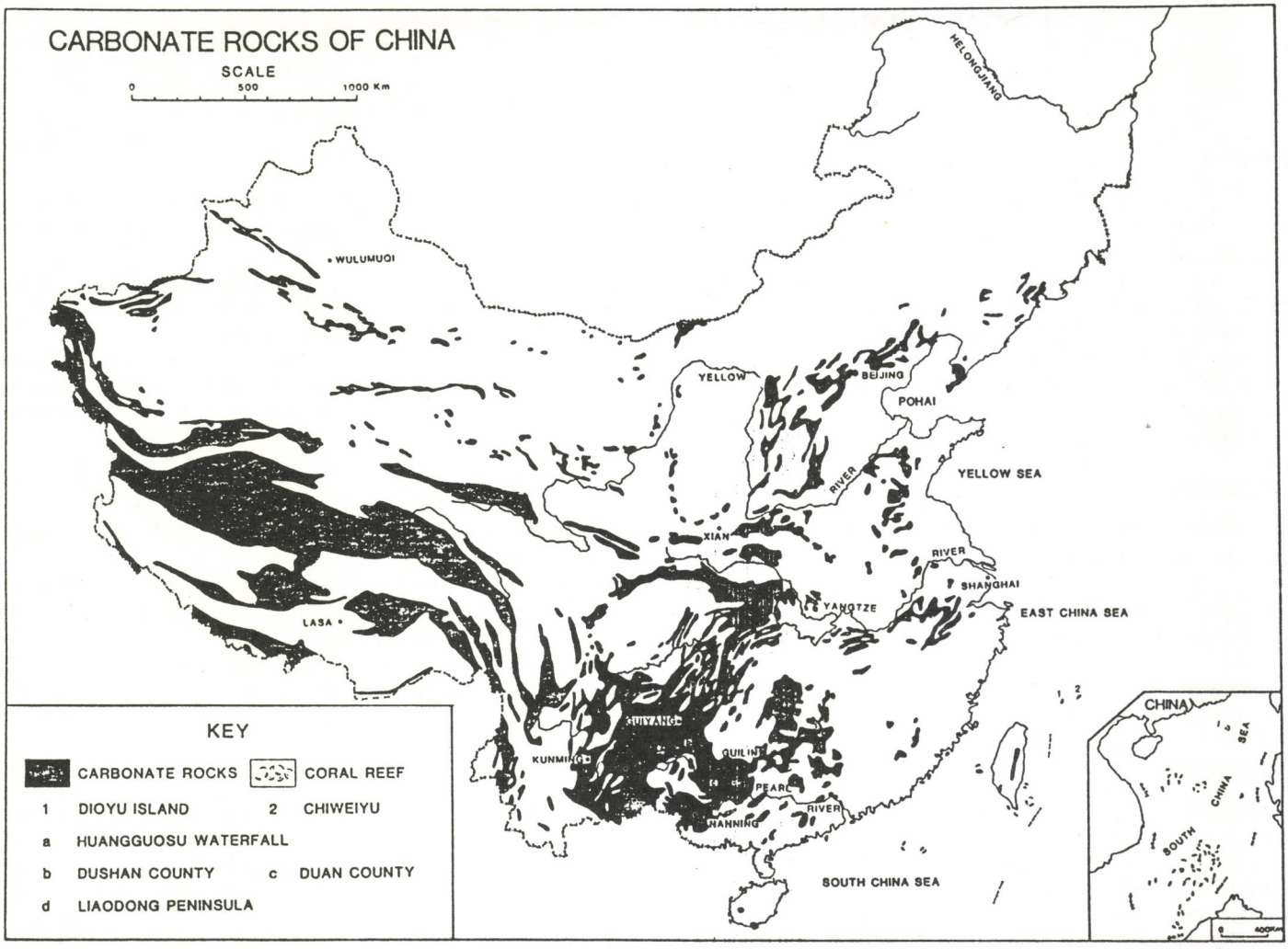
China is a typical monsoon climatic country with four distict seasons and the rainy and dry seasons. In the south, the annual average temperature may reach up to 15-25° C or more and the precipitation generally 1,000-2,000 mm; in the north and northeast China, it is about 0-13° C and precipitation 400-800 mm, while, the northwest China is a typical plateau territoriality draught climate with the annual average temperature varying in the range of 0°-12° C and the precipitation generally less than 200 mm, but in someplaces lower than 50 mm, the evaporation capacity is very high, commonly 3,000 mm a year.

The geotectonics in China is very complicated. The north China belongs the China-Korean Geoplateform with 7,000 m thickness of marble, limestone, dolomitic limestone and dolomite aged from Presinian to Mid-Ordovician Periods, but the thickness of karstified limestone just less than 1,000 m. Since the Sinian, the China-Korean Geoplateform is at the flucturative movements upward and downward. The carbonate rocks are interbedded with the sandstones and shales. During the early-middle Ordovician, the great marine transgression was taken place in north China, 200 m pure limestone and dolomitic limestone were deposited. Since then, the China-Korean Geoplateform is lack of the carbonate deposits and the earthcrusst was at the block movement with uplifting and subsidencing.

Except the Kangdian Old land, the most south China belongs to the pene-geoplateform. The carbonate rocks were deposited from Sinian to Mid-Triassic Periods, the thickness may reach up to 5,000-6,000 m. They have experienced several strong tectonic movements and intensely folded and faulted. Since Miozoic, the India Plate powerfully inserting into Asia Plate has been making the Hemalaya Mountains greatly uplifting and the south China in homogeneously uplifting too. The Xialong Gulf in Viennan is subsidencing, South Guanxi nearly stable and Yunnan-Guizhou and Qinghai-Xizang plateaus are greatly elevating. Since Quaternary, the Guizhou Plateau has been elevated about 500 m or more, while the Qingzang plateau at lest uplifting 6,000 m.

The environment of palaeography great distinguishes from south to north. Since mid-Ordovician, the north China was in the environment of warm and humid erosion and inland deposit, and there has formed the broad palaeokarst groundsurface on the mid-Ordovician limestone and accumulated the thicker solutional and weathering residual Alumyte. After that, carbonifereous and Permian sandstone and shale with coal have been deposited in the warm climatic conditions. During the Tertiary, it was warm and humid environment and karst developed very well. It came into the cool and dry stage since Quaternary.

In the south China, it was in tropic and subtropic warm and humid environment. So the Fenglin and Fengcong have been developed perfectly. As for the inhomogeously uplifting from the east part to YunGui and QuingZang Plateaus, a series of karst geomorphology patterns has been developed on the Guangxi-Guizhou-Yunnan slope.



Based on Group of Karstology, Institute of Geology, Academia Sinica, 1979

Table 1 the area of carbonate rocks in China

Province	Carbonate R. 10^4 Km^2	Formations with Carbonate R. 10^4 Km^2	Exposed Carbonate R. 10^4 Km^2	Proportion of exp. carb. R. in total province area (%)
Yunnan	24.1	19.8	9.7	26
Guizhou	15.6	14.5	8.9	51
Sichuan	36.0	17.0	8.2	15
Xizang	86.5	46.3	11.5	9
Guangxi	13.9	10.3	7.9	33
Guangdong	2.9	2.6	1.4	7
Hunan	11.3	8.2	5.8	27
Hubei	7.8	5.9	4.1	22
Henan	10.4	1.9	1.1	7
Taiwan	0.1	0.1	0.1	3
Fujian	0.2	0.2	0.04	0.3
Jiangxi	2.5	1.8	0.9	5
Zhejiang	2.2	0.9	0.4	4
Anhui	6.4	2.4	1.25	9
Jiangsu	4.5	0.3	0.2	2
Shangdong	8.7	1.5	1.0	7
Hebei	13.5	3.4	2.2	10
Shanxi	10.2	4.3	3.3	21
Nei Monggol	10.9	5.1	1.3	1
Liaoning	2.6	1.6	0.9	6
Jilin	1.0	0.9	0.3	2
Helongjiang	1.2	0.9	0.2	0.4
Shaanxi	5.1	4.1	2.1	10
Gansu	9.0	6.8	2.7	7
Ningxia	0.9	0.4	0.1	2
Qinghai	19.0	15.0	6.1	8
Xingjiang	38.2	29.8	9.0	6
Total	344.3	206.0	90.7	9.7

Table 2 Runoff character of underground drainage systems in South China

Subsurface drainage system	Area Km^2	Max. discharge m^3s^{-1}	Min. discharge m^3s^{-1}	Unstability coefficient
Disu	1,080	390	4.00	97.,5
Shantan	150	6.64*	0.55	12.5
Huanghe	460	170	1.549	110
Yaohua	194	90	0.835	108
Shuilou	82	40	0.33	121
Loutizai	35	9	0.08	113
Dalongqing	29	20	0.335	60

*** The usual discharge**

Patterns of karst water flows

According to the dimentions of water-bearing space in the medium the fracture flow (including pore water), solutional fissure flow, conduit flow and cavern flow may be classified.

The fracture flow distributes and moves very slow in the pore and fractures with 0.001-1.0 mm wide. It follows the Darcy's lamina flow law.

The solutional fissure flow mainly distributes in the solutional fissures with the width of 1.0-200 mm. The hydraulic properties is very complicated and is deponded upon the Reynolds number Re:

$$Re = \frac{\rho v d}{\mu}$$

where v is flow velocity, d is the dimention of pore or fissure. ρ is fluid density and μ is viscosity.

In the given area, the ρ and μ of the karst water is not much different, then $\rho / \mu = C$, then $Re = CVd$.

Table 3 The velocity of groundwater in South China

Subsurface drainage system	velocity ms^{-1}
Dalongqing	1,100
Xiaolongqing	1,000
Naoshuiyan	2,674
Baoyan	14,900
Shantan	3,218
Hezai	312
	1,598
Guocha	1,210
	5,098

The experiments have suggested that when Re < 2,300, the flow is laminar flow neverless how the velocity and fissure widens are. When Re ' 2,300, the flow sometime is laminar, but sometime turbular, that according to the friction of the fissure walls.

Conduit flow is the water moving in the passage with 100-1,000 mm width. The water generallly flow very fast, may reach up to ten thousands meters a day. It commonly is turbular flow including the compressed and free surface conduit flows.

Cavern flow is special conduit flow in the cavern passage with the properties of surface flow. A series of solutional and erosion features and deposit forms including terraces may be developed. So some hydrogeologists call them subsurface river.

Based on the flow distributing structure, the flow may be classified into surface flow, monoconduit flow, dendritic flow and network flow.

Principle characteristics of karst hydrology in South China

Since the late Triassic Period, the South China is in the conditions of warm and humid climate, vigourous vegetation, the soil with aboundant organic materials with active bacteriums and strong tectonic tilted movement, carbonate rocks being strongly faulted, folded and interbeded with noncarbonate rocks. The carbonate rocks have been strongly karstified. In the processes of dissolution and erosion in the carbonate rock areas, the soils on the carbonate hills have been rashed down and accumulated for several meters in the depressions. So as the soils on the hills is very thin. Karst hydrology in South China characterised as follows:

1. In a carbonate terrain, the four flow patterns especial conduit and cavern flows organistly constitute the subsurface

Table 4 Unstability coefficients of the main springs in North China

Spring	Area Km^2	Max. discharge m^3s^{-1}	Min. discharge m^3s^{-1}	Unstability coefficient
Longzici	2,300	6.18	4.0	1.52
Lancun	3,800	3.80	2.29	1.66
Shentou	2,500	9.48	6.4	1.18
Niangziguan	3,600	16.00	10.2	1.57
Helongdong	2,400	38.50	5.7	6.80

Table 5 The decay coefficients of karst springs in North China

Spring	Decay coefficient	Spring	Decay coefficient
Niangziguan Spr.	0.0011	Guangshensi Spr.	0.00099
Wangqu Spr.	0.0026	Longzici Spr.	0.0012
Yanhe Spr.	0.0027	Bai Spr., Xingtai	0.0020
Pingshang Spr.	0.0024	Helongdong Spr.	0.0028
Shentou Spr.	0.00068	Yuquanshan Spr.	0.0018
Liulin Spr.	0.002	Jinan Spr.	0.0037
Hongshan Spr.	0.0006	Wanfotang Spr.	0.012-0.069
Guozhuang Spr.	0.0016	BaiSpr. Huixian	0.0058

drainage system. As the conduit and cavern flows well developed, many hydrogeologists argue that the conduit flow and underground river are the basical characteristics in the South China. In the exposed limestone regions, the distribution geometry of conduit flow and cavern flow is generally with mono-conduit (or cavern), dendrictric and cumb system, while in the area with excellent negative landforms, the network system of the conduit-cavern flow are usually developed. In the limestone block between two levels of the large scale karst depressions or karst basins and poljes, the single conduit or cavern flow is completely formed. However, the conduit flow or cavern flow is still recharged by the fracture and solutional fissure flows.

2. The surface flow commonly become the underground flow through sinkholls, funnels and fissures. Therefore, there are a lot of water inputs in the drainage system.

3. The longitudual profile of the subsurface drainage system ordinaryly take the shape of convex, concave or stepe curve. The most subsurface drainage systems in Guangxi basin perhaps form the concave, but in Guizhou are basically with the convex or stepe curve with several knick-points. In someplaces, the ground water falls appear in the caverns, the waterfall about 30 m high in Dragon Palace, Guizhou is a good example.

4. The cavern ceilings collapsing cause the cavern flow exposed. In the quite flate area with big depressions or basins, the conduit (cavern) flows develop in the block between the depressions or basins where the surface flow well developed. Therefore, the subsurface courses of the drainage system interchange with the surface sections.

5. The subsurface drainage systems are directly fed by the meteoric water, thus the groundwater regimes are determined by and very responsible to the meteoric water. The hydrography curve is like the dog's teeth. It is very evident that the surface water strongly alternates with the groundwater and the travelling time of groundwater is quite short.

6. In the rainy seasons, the conduit predominantly discharges the conduit storage and the recharge of the surface water; in the dry seasons, 90 % of discharge, the base flow of the underground drainage systems, comes from the diffusion flow stored in the fine fractures, pore space or small fissures. The underground runoff coefficient M (Song, 1981) is about 3--4 $ls^{-1}Km^{-1}$.

7. There are the multilevels of drainage bases. The ground water in the higher level of geomorphological unit flow down to the lower level of the unit. Hence, the groundwater flows step by step from the watershed to the resurgence of the drainage system.

8. In the flood seasons, the flood peak comes very fastly and intensively. The ratios of flood discharge and lowest discharge of the subsurface drainage system are very high (Table 2). The velocity of groundwater may reach upto 800-14,900 md^{-1} (table 3).

Characteristics of karst hydrology in North China

The whole North China was homogeously uplifting during the end of mid –Ordovician to the early mid– Carbonifereous, that made the carbonate rocks strongly dissolving and the ground surface leveling. The networks of solutional fissures, conduits and caverns were well developed near the ground surface and the later two were partly filled up by the late sediments of completely destroyed.

The North China was under the conditions of warm and humid climate and erosion during the end –Triassic to end– Cretaceous, the caves and conduits and the landscape of Fenglin-plain had been well developed.

In the Tertiary with warm and humid climate and the earthcrust was continuing to blockly elevated and subsidence. The area east to the Taihan Shan was greatly lowed down to deposit very thick sediments which covered the karst landform and filled up the conduit and caverns. The Shanxi plateau uplifts and the carbonate rocks were karstified and erosed. In the exposed carbonate rock area, the conduit and caverns may continue to be developed and formed the networks.

In the Quaternary, climate became cool, but the precipitation in mid-Pleistocene was high to promote the conduit and cavern net systems developed and combined together. The most big springs have been formed since then and in some places, the cavern flows like Helongtan spring, Hepei province, Shangwolong cavern flow and Xienjiawai cavern flow in Liaoning Province have been developed.

The characters of karst hydrology in the North China are as follows:

1. The drainage area of karst drainages are generally large (Table 4), such as Niangziguan Spring drainage area about 3,600 Km^2, of which the exposed limestone occupies 1,800 Km^2.

2. The stabilized coefficients of the springs are in the range of 1.18-6.8, but most being 1.18-1.66. The max. stabilized coefficient of karst drainage is still less than 10 (He Yueping, 1982). These sugust that the storage capacity of the carbonate rocks is very high, and the decay coefficients of springs are very low (Table 5).

3. The hydraulic gradients of karst aquifer are very low, for example, Niangziguan spring drainage is 1.0-4.3 %, Blue spring 2-6 % and Longyan spring 1.18-8.0 %.

Table 6 Velocity of groundwater in North China

Spring	Velocity md^{-1}	Property of Water flow	
Niangziguan Spr.	8.8-23.9	Net of fissure and conduit flow	
Longzici Spr.	29.8	Net of fissure and conduit flow	
Guangshensi Spr.	24.3	Net of fissure and conduit flow	
Helongdong Spr.	45.6	Net of fissure and conduit flow partly cavern flow	
Xuelang Spr.	1,500		Conduit and cavern flow
Longyan Spr.	288-580	Conduit flow	
Shentou Spr.	37.6	Fissure and conduit flow	

Table 7 The principle chemical property of karst water in Taiyuan, Shanxi Province

Spring	Water temperature °C	Minerization gl^{-1}	Total hardness °G	Quality pattern	$SO_4^{=}$ mgl^{-1}	Cl^- mgl^{-1}
Kuaihuagoukou	20.2	0.80	10.48	SH-CM	364.2	13.9
Fengyuogoukou	18.5	0.72	10.20	SH-CM	345.7	13.5
Nanlao Spr.	18.0	0.60	8.94	SH-CM	266.7	15.0
Shanggouyie	24.5	1.40	21.50	S-CM	912.6	17.7
Ping Spr.	25.0	1.55	23.40	S-CM	955.8	21.3
Xiliang Spr.		2.41	34.45	S-CM	1,534.6	28.8
Xingcun Spr.		4.24	48.31	S-CM	2,415.9	273.0

4. The velocity of groundwater flow is also low even if the conduit flow or cavern flow (Table 6).

5. The regime of karst groundwater is senseless to the rainfall, for example, the max. discharge of Jingci spring is 3-5 monthes late responsible to 261 mm of rainfall in July, 1966 when the discharge was 1.655 m^3s^{-1} (lowest flow), but is started to gradually increase from October, 1966.

6. Karst aquifers have greater storage and yield capacity. The transnision coefficients calculated from the test pumping of boreholes in Wangyao, Zhangyuan and Wangfeng, Hebei are 1000-20000 m^2d^{-1}, the max. 50000 m^2d^{-1}.

7. Except the net fissure flow and conduit flow, the monogeneous conduit flow and cavern flow are well developed. The underground stream with 6 km long and lowest discharge 0.11 m^3s^{-1} in Yichun, Helongjiang has been discovered.

8. The hardness and chemical composition contents of the ground waters is quite high (Table 7). The mean water temperature is higher than the mean ground temperature, that means the karst water deeply circulating.

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Discussion of hydrological results obtained from the major resurgence at Bungonia caves, NSW, Australia

Julia M. James and D. J. Martin

RESUM

La surgència principal de les aigües de la cova de Bungònia és una cavitat (The Efflux) que ha sigut inundada per un esllavissament d'escarpament. La hidrologia d'aquest sistema ha estat estudiada a través de coloracions qualitatives i quantitatives, i mesuraments del grau de corrent de base. L'exploració, topografia i estudis geològics de les coves han ajudat també a la interpretació de la hidrologia. Aquí es presenten i comparen els resultats d'alguns experiments d'inundació i bombeig, amb la finalitat de buidar les galerias inundades. Les variacions històriques del nivell i del corrent, evidenciades a través d'aquests experiments, permeten determinar les àrees de la superfície dels dipòsits d'aigua, a partir dels diferents nivells i volums de les «freas» entre aquests nivells. Comparant les àree de superfícies de seccions conegudes del sistema amb les àrees totals, obtingudes del sifonament, es pot fer una predicció del tamany i naturalesa de les galeries inundades de la cova.

RESUMEN

La surgencia principal de las aguas de la cueva de Bungonia es una cavidad (The Efflux) que ha sido inundada por un desomoronamiento de escarpe. La hidrología de este sistema ha sido estudiada por coloraciones cualitativas y cuantitativas, mediciones del grado de corriente de base. La exploración, topografía y estudios geológicos en las cuevas han ayudado además a la interpretación de la hidrología. Se presentan y comparan los resultados de algunos experimentos de inundación y bombeo, destinado a vaciar las galerías inundadas. La historia del nivel y corriente de estos experimentos permite determinar las áreas de la superfieie de los depósitos de agua por diversos niveles y los volúmenes de las «freas» entre estos niveles. Comparando las áreas de superficies de secciones conocidas del sistema, con las áreas totales obtenidas del sifonamiento, se puede hacer una predicción de la talla y naturaleza de las galerías inundadas de la cueva detrás de The Efflux.

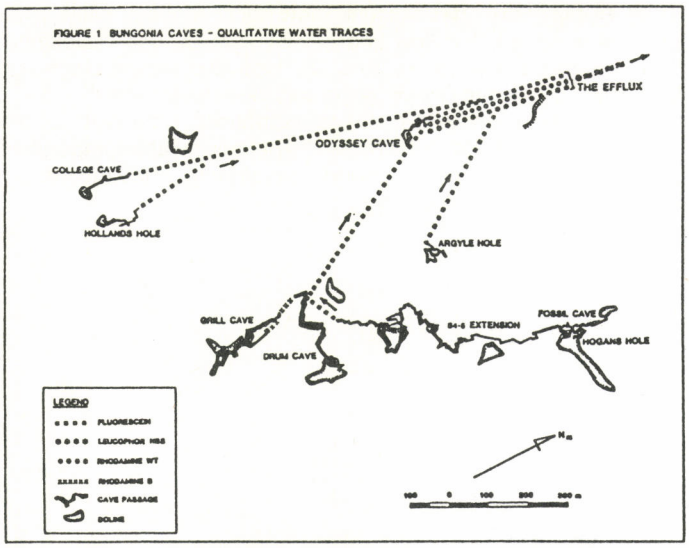
SUMMARY

The major resurgence of Bungonia cave waters is a cave (The Efflux) that has been flooded by a cliff collapse. The hydrology of this system has been studied by qualitative and quantitative dye tracing, base flow rate measurements. In addition exploration, surveying and geological studies in the caves have assisted in interpretation of the hydrology. The results of several syphoning and pumping experiments designed to drain the flooded passages are presented and compared. The level and flow time histories of these experiments allow pool surface areas for various levels and the phreas volumes between these levels to be determined. By comparing the surface areas of known sections of the system with the total areas obtained from syphoning a prediction of the size and nature of the flooded cave passage behind The Efflux can be made.

Introduction

All major caves at Bungonia drain to one spring, The Efflux. Figure 1 shows the underground connections established by water tracing. Qualitative water tracing indicates that there is a combining of waters from two separated limestone areas close to Odyssey Cave. Between Odyssey Cave and The Efflux it is believed that the combined waters follow the Folley Point Fault (James et al., 1978). The pool in Odyssey Cave responds slowly to changes in the Efflux pool level and reaches the same equilibrium level. Figure 2 shows how these two pools are related.

The Efflux Cave was blocked by a cliff collapse and buried beneath a boulder pile which was consolidated with tufa. Excavation of the Efflux blockage was started with the aim of clearing the caves of «foul air» (Bonwick, 1972). A trench was excavated to lower the water level approximately 5 m and in 1967 access was gained to a small cave with a sump. The sump was dived and it was reported that the bottom seemed to slope towards and opening surroundend by mud and loose rocks at a depth of approximately 7 m. Further cave diving was out of the question due to the loose rocks and the high probability that lethal concentrations of carbon dioxide would be encountered in any new passage. By 1967 the trench was over 30 m long and further excavation was not feasible. This left syphoning and pumping as the only alternatives for draining the flooded cave passages. A number of syphoning and pumping exercises have



been carried out to date. The most sucessful of these was in 1973 when the water level was lowered 10 m to a narrow horizontal tube too dangerous to explore because of the danger of a sudden release of wather further upstream (Bonwick, 1977).

Whilst the aims of gaining access to the passage behind The Efflux and draining the connecting caves of fould air have not been achieved these bulk water removal exercises have allowed various hydrological investigations to be carried out.

Methods

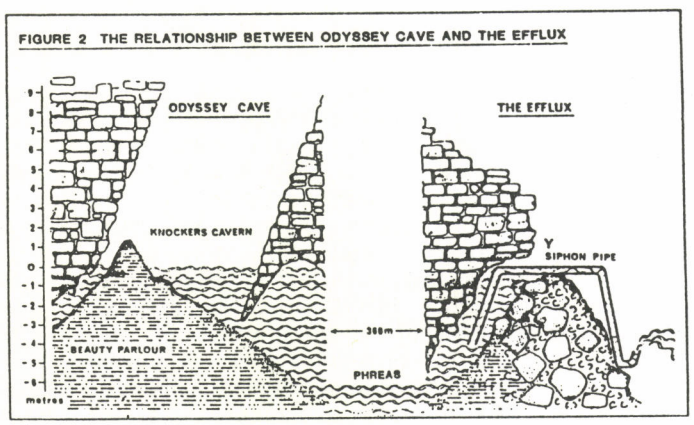
Water tracing – Rhodamine B, Rhodamine WT, Fluorescein and Leuchpor NBS have been used for water tracing. Three quantitative traces were made using 80 g and 40 g of Rhodamine WT (20 % solution) and 500 g of fluorescein. Samples were analysed on an Aminco-Bowman Fluorometer.

Syphoning – A 72 mm ID PVC syphon pipe was installed at The Efflux in March 1968. This pipe has been used to lower The Efflux spring water level (Bonwick 1972). A U bend at the outlet and extension pipes allow the flow rate to be reduced so that a desired level may be maintained without the syphon breaking.

Pumping – Submersible electric pumps have been used on several occasions to increase the rate of water removal while syphoning and to allow the pool level to be lowered below the practical limit of syphoning.

Flow rate measurement – A vertically-sliding V-notch weir was used to measure the flow in the Efflux trench before the sump was exposed. The free water surface areas of the pool behind the sump at various levels were determined by daming the weir and measuring the time rate of change in level (Bonwick, 1972 and Lambert, 1973). Syphon and pump flow rates were measured by recording the time taken to fill a 210 L drum.

Water level measurement – In the early experiments water levels were measured at various times using conventional cave survey techniques. In August 1983 a water level recorder designed and built by N.Michie was used in Odyssey Cave and The Efflux sumps. Pool surface areas were determined on the basis of time rate of change of level at known syphoning rates less the base flow and during system recharge at the measured base flow.



Results and discussion

Qualitative water traces – The results of the qualitative water traces are shown in Figure 1. These traces took times ranging from days to months. In all of these traces large quantities of dye (several kg) were used as it was believed that long retention times would lead to high dye loss. The result was that the dye could be monitored visually in the system. It was observed that the disappearence of dye from the cave pools was extremely slow as mixing is poor. The dye only disappears from the input point after a major flood has passed through the system. Because of this long dye retention at the points of input quantitative water traces in normal conditions were considered impractical.

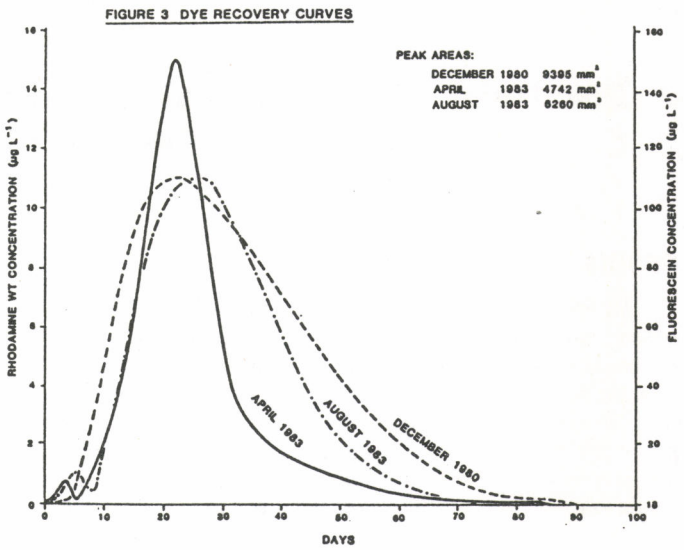


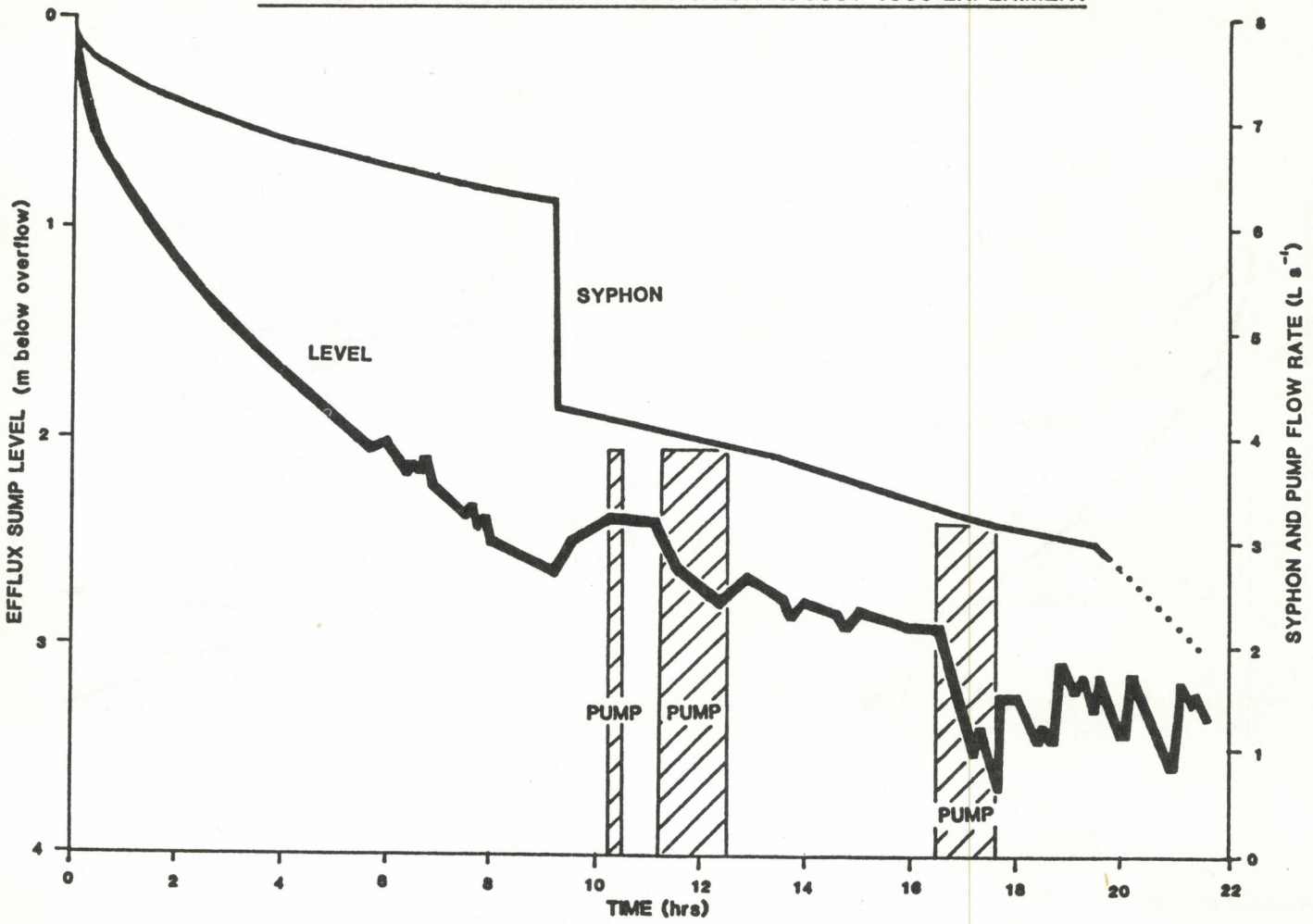
TABLE 1 WATER TRACE RESULTS

EXPERIMENT	DECEMBER 1980	APRIL 1983	AUGUST 1983
Dye	Rhodamine WT	Rhodamine WT	Fluorescein
Quantity inserted	80 g	40 g	500 g
Dye recovery	70 %	80 %	80 %
Initial base flow	2 Ls^{-1}	1.8 Ls^{-1}	1.2Ls^{-1}
Average base flow*	2 Ls^{-1}	2 Ls^{-1}	1.5Ls^{-1}
Volume removed by syphoning and pumping less base flow	250 m^3	470 m^3	270 m^3
Volume from spring before emergence of main dye peak	864 m^3	948 m^3	893 m^3
Volume from spring preceeding maximum dye concentration	4,000 m^3	4,000 m^3	3,500m^3
Volume from spring preceeding dye concentration returning to background levels	11,000 m^3	11,500 m^3	10,500 m^3

* Established from flow measurements when samples were collected

Quantitative water traces: – The flow of water at The Efflux is ten times greater than that which can be measured in Odyssey Cave. The pool in Odyssey Cave is therefore only a minor tributary of The Efflux drainage. However, it is believed that the Odyssey Cave pool is close to the main drainage conduit. It was hoped that by inserting dye at this point immediately before syphoning

FIGURE 4 EFFLUX LEVEL AND FLOWS FOR AUGUST 1983 EXPERIMENT



and pumping commenced it would quickly flow into the main conduit. Once in the main conduit, the dye would be dispersed more rapidly allowing a normal dye recovery curve to be obtained. Three such tests were carried out and the results are presented in Figure 3 and Table 1. Smooth dye concentration curves have been hand drawn as the erratic collection of samples and measurement of flow rate does not merit more detailed mathematical treatment. However, the raw data indicate that there would be a fine structure imposed on the main curve if regular sampling and flow measurements had been possible.

The dye traces are in good agreement and reproducible. The dye recovery curves are all broad. The recovery curves endorse the postulate that the more rapid entry of dye into the system allows a reasonably complete dye recovery. The broad curves and straight line sink to spring tracer velocities of 70-90 m day^{-1} indicate that water flow in the passages between Odyssey Cave and The Efflux is restricted.

Water Flow Rates and Levels

– Lambert (1973) reported a base flow range of 1.4 to 2.6 Ls^{-1}. A base flow of 1.2 Ls^{-1} was measured in August 1983. Figure 4 gives the level and flow time histories for part of the August 1983 experiment. Level oscillations occurred at the lower levels reached during this experiment. Sudden rises in level have occured before (Bonwick, 1972) and were attributed to the breaking of silt dams. The level recorder shows many of these pulses have reproducible amplitudes and frequencies. Whilst pulses can result from the breaking of dams it is suggested these are the result of the making and breaking of a syphon.

Water volumes and pool surface areas – Figure 5 gives the cumulative net volumes removed and surface areas for part of the August 1983 syphoning. The system volume between 1.14 and 3.81 m below the sump overflow level is 175 m^3 for the syphoning and 163 m^3 for recharge at base flow. The corresponding volume was 250 m^3 for the April 1983 syphoning. These levels have been chosen for comparison purposes as they comprise the most complete and meaningful data set. Prior to the August 1983 experiment the sump had been held at the −1.14 m level by the syphon.

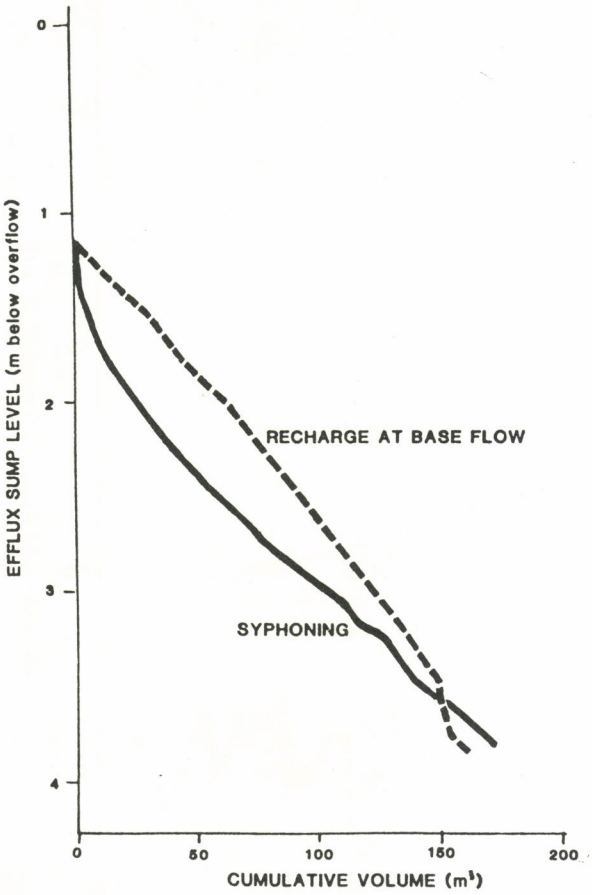
Combined dye tracing and syphoning is in some respects similar to flood pulse experiments which allow the volumes of fully submerged conduits to be determined (Smart and Hodge, 1980). The lower water levels will, however, cause a drawdown of diffuse flow water held in joints, fissures, and in this system, sediments.

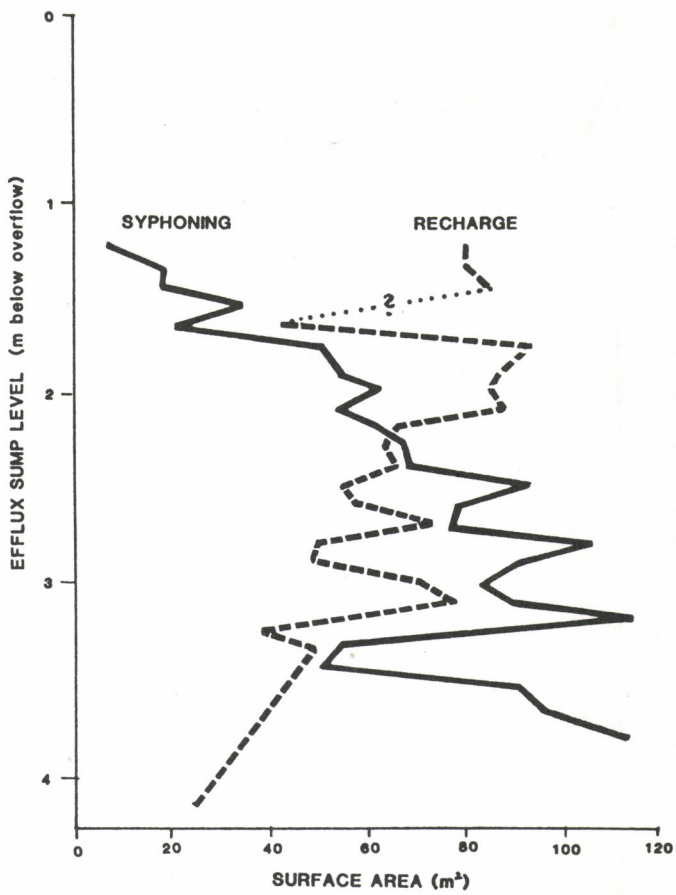
The area and volume determinations rely on the assumption that changes in level at The Efflux are reflected elsewhere in the system without appreciable time delay. Discrepancies in area and volume measurements between syphoning and recharge and the long dye travel times, even with syphoning, indicate that this assumption may not be valid. These measurements are also affected by the drawdown and recharge of the diffuse flow component. Dams and the movement of sediments in the system may explain some of the discrepancy between the April and August results.

Conclusions

Conventional flood pulse experiments and a base flow recession curve may provide more information on The Efflux system. The level recorder has allowed more detailed pool area predictions than was possible using Lambert's methods. The use of this area data for predicting passage sizes is highly speculative as the system appears to be more complex than a simple water-filled conduit.

FIGURE 5 VOLUME AND SURFACE AREAS FOR AUGUST 1983 EXPERIMENT





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Teoretičeskie i Prikladnye Pro-lemy

Теоретические и прикладные проълемы Гидрологии рарста

Gidrologii Karsta

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RESUM

La hidrologia càrstica és una ciència que tracta dels elements dinàmics del carst, regularitats de formació, influència del carst sobre el corrent del riu, el seu règim i el balanç hidràulic. La principal finalitat de la hidrologia càrstica és la d'investigar les relacions espai-temps de les aigües de superfície i subterrànies amb els procesos càrstics. La hidrologia del carst inclou els problemes d'interacció de les aigües de superfície amb les subterrànies sota les condicions dominants del carst, el règim de les aigües càrstiques, el paper hidrològic del carst i el balanç hidràulic de les zones càrstiques, així com els recursos de les aigües càrstiques i la seva utilització i protecció.

A les regions muntanyoses, la metodologia de la hidrologia de la muntanya estableix les bases metodològiques de la hidrologia càrstica, a través de les quals es posen de manifest l'essència i el caràcter d'interdependència natural del corrent amb factors zonals i regionals. A partir d'alguns mètodes ja coneguts, determinats mètodes d'hidrologia càrstica d'especial interès han estat posats al punt i aplicats amb èxit, com per exemple el mètode del «background» zonal i un mètode complex per a la determinació dels intercanvis d'aigua subterrània.

RESUMEN

La hidrología kárstica es una ciencia de regularidades de formación y elementos de dinámica del karst, influencia del karst sobre la corriente del rio, su régimen y balance hidráulico. La finalidad principal de la hidrología kárstica es investigar las relaciones espacio-temporales de las aguas de superficie y subterráneas con los procesos kársticos. La hidrología del karst incluye los problemas de interacción de las aguas de superficie y subterráneas bajo las condiciones de predominio del karst, régimen de las aguas kársticas, el papel hidrológico del karst y el balance hidráulico de las zonas kársticas; recursos de las aguas kársticas, así como su utilización y protección.

En las regiones montañosas la metodología de la hidrología de la montaña establece las bases metodológicas de la hidrología kárstica a través de las cuales se revelan la esencia y el carácter de interdependencia natural de la corriente con factores de las zonas y de las regiones. Sobre la base de métodos dados, estos importantes métodos de hidrología del karst han sido puestos a y aplicados con éxito como por ejemplo el método del «background» zonal y un método complejo para la determinación de los intercambio de agua subterránea.

SUMMARY

Karst hydrology is a science of regularities of formation and dynamics of karst matters, influence of karst upon the river runoff, its regime and water balance. The main task of karst hydrology is to investigate the space-temporal relations of surface and underground waters with karst processes. Hydrology of karst involves the problems of interaction of surface and underground waters under the conditions of karst domination, karst waters regime, hydrologic role of karst and water balance of karst areas, resources of karst waters as well as their utilization and protection.

in highland regions, methodics of mountain hydrology establishes the methodologic foundation of karst hydrology through which are revelaed the essence and character of natural interdependence of the run-off with zonal and regional factors. On the basis of the given methods such important methods of karst hydrology have been worked out and successfully applied as the method of zonal background and a complex method of subterranean waterchange determination.

Гидрология карста – это наука о закономерностях формирования и динамики карстовых вод, влияния карста на речной сток, его режим и водный баланс. Содержание гидрологии карста составляют проблемы: взаимодействие поверхностных и подземных вод в условиях господства карста, режим карстовых вод, гидрологическая роль карста и водный баланс карстовых областей, ресурсы карстовых вод, их использование и охрана / I /.

Выявление гидрологических закономерностей карста – мощного и очень своеобразного фактора стока, весьма трудная задача, которая решается лишь на общем фоне ландшафтной среды и тщательного анализа сложных переплетений физико-географических связей.

В карстово-гидрологических исследованиях на передний план выдвигается проблема подземного водообмена – самого характерного явления для интенсивно закарстованных территорий. Вследствие подземного водообмена нарушаются зональные закономерности стока и видоизменяются сочетания элементов водного баланса. Масштаб подземного водообмена определяет степень влияния карста на сток, его режим и водный баланс. Трнсформация поглощенных поверхностных вод в глубине карстового массива зависит от условий поглощения, развитости глубинного карста, расстояния и амплитуды уровней между очагами поглощения и разгрузки. Особое значение придается условиям поглощения поверхностных вод и в этой связи различаются площадная инфлюация, очаговая инфлюация и инфильтрация.

В отсутствии постоянных очагов поглощения поверхностных вод, когда нет возможности применять методы прямого определения направления движения вод, используется комплексный метод изучения подземного водообмена. Смысл этого метода заключается в следующем.

Величина стока карстового источника или подземной реки, при данных климатических условиях является лимитирующим показателем площади фактического водосбора. А четкий зональный гидрологический фон, проявляющийся в горных областях четкой зависимостью стока от высоты местности, способствует определению высотного расположения, подземного или фактического бассейна карстовых вод. Детальные морфоструктурный, литологический и гидрогеологический анализы позволяют уточнить контуры подземных водосборов.

Указанным методом удалось установить контуры, площадь и высотное расположение фактических водосборов ряда высокодебитных карстовых источников и подземных рек, в том числе крупнейшего карстового источника Кавказа – Мчишты ($Q_{ср.}$=9,3 м³сек.), питающегося из недр высокогорного Бзыбского массива. Оказалось, что подземный водосбор Мчишты более чем в шесть раз превосходит поверхностный, а по средней высоте – почти на 500 м.

Наличие больших пустот в подземном водосборе карстовой реки или крупного источника, определяет специфический характер их режима. Как известно, объемистые залы хорошо изученной Новоафонской карстовой пещеры являются регулирующими резервуарами гидродинамической системы высокодебитного карстового источника. Установлено, что в фазе развития паводка в Новоафонской пещере уровень воды в сообщающихся крупных подземных водоемах повышается более чем на 2 м за час, а в фазе спада снижается гораздо медленнее – не более чем на 0,25 м за час.

Однако, уже известно, что карст является не только регулирующим фактором режима стока. Ввиду большого разнообразия условий формирования, поглощения, подземного течения и разгрузки карстовые источники могут иметь как устойчивый, так и неустойчивый режим. Существуют периодически дебитирующие кар-

стовые источники, а также источники с сохранившимся зональным характером режима.

Вскрытие мозаичности типов режима карстовых источников и подземных рек стало возможным лишь на основании генетического анализа исследуемых водных объектов, систематизации и качественной оценки ведущих факторов, влияющих на режим стока. А что касается количественного выражения степени влияния карста на режим, то оно удается с помощью географического сравнения методами зонального фона и эталонных рек.

Генетический подход к проблеме гидрологической роли карста позволяет вскрыть главные особенности влияния карста на водный баланс и сток. Методами зонального фона и эталонных рек, а также полевыми экспериментальными исследованиями подземного водообмена осуществляется качественная и количественная характеристика влияния карста на элементы стока рек Большого Кавказа.

Установлено, что абсолютный и относительный подземный и минимальный сток карстовой реки зависит не только от знака господствующего вида подземного водообмена, но и от гидрологических признаков вод, участвующих в данном процессе. Влияние карста на подземный сток обнаруживается как по абсолютным ее величинам, так и по долевому участию подземного питания в общем стоке. Превышение абсолютной фактической величины подземного стока над теоретически ожидаемой величиной не всегда влечет за собой увеличение долевого участия подземного питания в общем стоке реки. И наоборот - занижение абсолютного фактического стока не является обязательной причиной уменьшения доли подземного питания. Именно в этом и заключается специфичность влияния карста на показатели стока, которая определяется множеством вариантов подземного карстового водообмена.

Влияние карста на норму годового стока обнаруживается либо в его увеличении, либо уменьшении. Частным случаем этих двух видов влияния является внутреннее перераспределение стока в бассейне, чего по данным наблюдений в замыкающем створе нельзя уловить.

Интенсивность подземного водообмена хорошо иллюстрируется коэффициентом подземного водообмена, который представляет отношение фактического стока к теоретическому. Теоретический сток определяется по зональному фону, который в горных областях создается связью стока с высотой. Зональным фоном для оценки степени влияния карста на изменчивость годового стока служит связь между коэффициентами вариации и средними высотами водосборов.

Выясняется, что положительный подземный водообмен не всегда обеспечивает повышение зарегулированности режима стока и наоборот, отрицательный подземный водообмен не обязательно следует считать причиной ее понижения. Определяющее значение придается режимным показателям вод, принимающих участие в карстовом подземном водообмене.

На карстовых реках, теряющих незарегулированную часть стока, наблюдается снижение высоты паводков, а при отдаче части базисного стока замечается возрастание их доли в общем стоке. На реках принимающих "чужие" паводочные воды, возрастают свои, или возникают новые пики, которые, в отсутствии карста, должны были пройти на "донорной" реке. Реки, питающиеся преимущественно зарегулированными карстовыми водами, характеризуются пониженной долей паводков в общем стоке.

Подземные реки, образованные в результате очаговой инфлюации, из-за ограниченной пропускной способности подземных русел, характеризуются сглаженными, пониженными или даже значительно пониженными пиками паводков. По синхронным записям уровней воды установлены предельные расходы некоторых подземных рек, которые удерживаются независимо от дальнейшего повышения подпорного горизонта над местом поглощения. Например, пропускная способность Дидичала-Шараульского подземного тракта составляет 28 $м^3$/сек, а Ткибула-Цзеврульского - 15 $м^3$/сек. Обе подземные реки находятся в Западной Грузии и относятся к бассейну р.Риони.

Важным звеном гидрологических исследований является расчет водного баланса. В условиях интенсивного подземного водообмена смежные территории резко отличаются друг от друга сочетанием элементов водного баланса, что создает значительные трудности в установлении территориальных закономерностей водного баланса и количественной оценки влияния карста.

Межбассейновый и внутрибассейновый подземный водообмен в горных карстовых областях определяет чередование участков с положительным и отрицательным влиянием карста на сток. Иначе говоря, по соседству с закарстованными площадями, лишенных поверхностного стока, должны быть расположены территории с повышенным стоком. Приходная часть водного баланса варьирует в зависимости от высотного положения того или иного участка исследуемого карстового массива.

Подчиняющейся вертикальной зональности структуры водного баланса в карстовой области нарушаются и они зависят от степени закарстованности площадей инфлюации и инфильтрации, развитости глубинного карста, высотного расположения линии разгрузки карстовых вод.

Линия разгрузки карстовых вод, которая соединяет очаги разгрузки поглощенной выше поверхностной влаги, разделяет область поглощения или безводную часть массива от области разгрузки или обводненной ее части. Следовательно, водный баланс карстового массива, в виду его гидрографической специфичности, следует расчитывать выше линии разгрузки, ниже нее и в целом по массиву.

Особенностью водного баланса карстовой области является пониженное, по сравнению с некарстовыми областями, испарение вследствие интенсивного поглощения дождевых и талых вод закарстованной поверхностью выше линии разгрузки. Уравнения водного баланса отдельных частей карстовых массивов содержат член - подземный сток, который качественно отличается от подземного стока в реки незакарстованных областей и не может служить показателем благоприятности структуры водного баланса.

Водный баланс в целом по карстовому массиву может не замыкаться, если часть подземных вод расходуется на питание артезианских бассейнов или же разгружается в виде субмаринных источников. Субмаринная и субаквальная разгрузки карстовых вод весьма характерные явления и наблюдаются во многих карстовых областях Земли. На Кавказе субмаринные источники отмечены у Абхазского побережья Черного моря в районе курортов Гагра-Гантиади. Оказался на дне нового водохранилища Ингурской ГЭС и превратился в субаквальный в недавнем прошлом крупный карстовый источник Легвешара ($Q_{ср.}$=0,8 $м^3$/сек).

Также, как и при картографировании элементов водного

балансе с зональным их сочетанием, в условиях господства карста требуется синтез результатов гидрологических, гидрогеологических, климатологических исследований и увязывание процессов составления карт, ибо водобалансовые карты отражают звенья единого процесса – круговорота воды. В карстово-гидрологических исследованиях особое значение придается литогенному звену круговорота, которое выступает как мощный региональный фактор стока.

Развитие народного хозяйства Грузинской ССР ставит серьезные задачи перед гидрологией карста. В первую очередь это относится к уточнению водных ресурсов рек карстовой области, что требует детального учета влияния карста на элементы стока. Исходя из методических основ гидрологии карста, никакие обобщения в оценке влияния карста на сток не допустимы и характер его определяется по конкретным проявлениям.

Важным разделом гидрологии карста является проблема собственно карстовых вод. Они характеризуются высоким дебитом и сосредоточенными очагами разгрузки. В виду того, что крупные карстовые источники Грузии, в большинстве случаев, отличаются хорошим качеством, они используются и могут быть еще использованы. Поэтому необходимо расширить масштабы изучения карстовых вод и полностью использовать их ресурсный потенциал.

За последнее время выявлено и исследовано много карстовых пещер, наиболее интересные из которых оборудуются и становятся объектами массового посещения. А все крупные карстовые пещеры представляют русла подземных рек, где возможно прохождение паводков. Безопасность эксплуатации туристских пещер во многом зависит от квалифицированного их гидрологического обеспечения.

Для карстовых областей типичны феноменальные проявления, такие как: исполинские источники, крупные подземные реки, глубокие озера, живописные водопады и т.д. Они относятся к редким природным явлениям и нуждаются в особом к ним отношении. Наиболее интересные гидрологические объекты карста привлекают большое количество посетителей и вокруг них возникают целые рекреационные комплексы. Примерами могут служить глубочайшее карстовое озеро СССР – Чирик-кель и Чегемские водопады на Северном Кавказе. Подобную перспективу имеют в Грузии: водопад Геги, исполинские карстовые источники Речхи, ущелье реки Кинчха, водопады в истоках р.Абаши, карстовый комплекс озера Амткели и т.д. В связи с этим требуется создание научных предпосылок для их разумного использования, охраны от загрязнения и истощения.

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10159

O tipach Rychlych pescernych otložemij v gorach juga evropejsmoj časti

О типах рыхлых пещерных отложений в горах юга европейской части СССР

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Пещерные отложения – уникальный источник геологической и палеогеографической информации. Именно в них запечетлевается история развития не только самой пещерной системы, но и окружающих территорий. Сказанное особенно справедливо для горных регионов юга СССР, где сколько-нибудь полные разрезы четвертичных отложений не сохраняются благодаря крутым склонам и активно протекающим процесса денудации.

Именно пещерные отложения часто оказываются особенно благоприятные для комплексного геологического и палеогеографического изучения. Как известно, пещеры нередко служили укрытием для первобытного человека и диких животных. Находки археологического материала (артефактов), костей животных в пещерных отложениях позволяют давать их датировку и более полно восстанавливать палеогеографические условия формирования толщ рыхлых отложений.

В советской литературе существует несколько классификаций типов пещерных отложений (I, 2, 3, 4, 5, 1955 и др.). Эти классификации близки между собой и несколько дополняют друг друга. Несколько большую традицию имеет изучение пещерных отложений в некоторых странах Западной Европы (Польша, Франция, Швейцария), однако и там подробная классификация пещерных отложений нам неизвестна.

Ниже приводится несколько упрощенная классификация, широко применявшаяся в пещерах горных стран на юге Европейской части СССР.

Облик пещерных отложений в значительной мере определяется их положением в пещере. С этой точки зрения в пещерах коридорного типа целесообразно выделять три основные фациальные зоны: внутреннюю, привходную и внешнюю. Границы между этими зонами, как правило, не бывают резкими, и отложения различных фациальных зон связаны друг с другом весьма постепенными переходами. Отложения гротов во многом близки осадкам привходной зоны, но обладают и некоторой спецификой, о чем будет сказано ниже.

I. Внутренняя зона (вне доступа дневного света)

Здесь господствуют условия высокой влажности и незначительных колебаний температуры. Основными источниками формирования рыхлых отложений служат:

I. Пещерные глины

При процессах растворения известняка, протекающих в карстовой системе, значительная часть карбонатов кальция и магния выносится, а среди остаточных продуктов накапливаются соединения наименее подвижных элементов: кремния, железа, алюминия. Именно соединения этих элементов (преимущественно силикатные) и составляют продукт максимального химического разложения известняков - пещерную глину. Обычно она однородна, пластична, обладает характерной красновато-коричневой окраской. Образование и накопление глин происходит во всей карстовой системе, связанной с той или иной пещерой. По системе каналов и поноров глина в конце концов поступает в полость пещеры. Порой можно наблюдать как она течет, разбавленная водой, по стенам, капает из органных труб, заполняет собой трещины в стенах и на полу пещеры.

Следует иметь в виду, что для каждой пещеры водосбором служит известняковый массив, объем которого иногда на много порядков превышает объем самой пещерной полости. Поэтому интенсивность накопления глин зависит не только от количества примесей в известняке, но и от величины известнякового массива, связанного с пещерой, а также от степени его кавернозности. По механическому составу глины из разных пещер зоны умеренных широт вполне сопоставимы друг с другом. По классификации Л.В.Пустовалова (3) их следовало бы отнести к категориям глинистых алевритов. Вообще же, чем ближе к экватору, тем интенсивнее происходит выветривание и тем тоньше (по механическому составу) становятся отложения.

2. Обломки известняков

Обрушение глыб и отдельных обломков известняка с потолка и стенок пещер - характернейший процесс внутренней зоны. При этом, вообще говоря, максимальные размеры глыб могут быть как угодно велики и контролируются только размерами свободной пещерной полости. Нередко крупные упавшие глыбы остаются на месте и образуют постаменты для сталагмитовых колонн. Частично глыбы распадаются на щебень, который затем принимает участие в построении пещерных отложений. Интересно, что процессы обваливания крупных масс известняка обычно оказываются не связанными непосредственно с землетрясениями.(Может быть здесь оказывается идеальная арочная конструкция потолков в пещерных залах и галереях, что делает их существенно антисейсмическими).

Другим и часто преобладающим процессом является отслаивание от стенок мелких обломков и щебня. Упавшие обломки попадают в жидкую (или периодически разжижающуюся) пещерную глину и смешиваются с ней в тех или иных пропорциях. Важно подчеркнуть, что до захоронения обломки, как правило, испытывают некоторое перемещение вдоль канала пещеры. Об этом свидетельствует то обстоятельство, что в большинстве разрезов обломки обнаруживают некоторые признаки ориентированности. Лишь незначительный процент упавшего материала остается на месте и не испытывает в дальнейшем никакого перемещения. Этот материал легко опознается в разрезах: обломки располагаются в глинистых толщах как бы во взвешенном состоянии. Например, могут быть обращены вниз острой гранью или вершиной пирамидальной формы.

С течением времени обломки довольно быстро сглаживаются. Одновременно с этим происходит патинизация их поверхности, а затем их грани начинают разъедаться точечной кавернозностью. По-видимому, подобный процесс первичного выветривания протекает довольно быстро, в течение немногих тысячелетий, т.к. обломки, выветрелые соответствующим образом, можно наблюдать уже в отложениях с культурой бронзового века.

В дальнейшем постепенно происходит полное разложение обломков. Время полного их разложения зависит от условий увлажнения толщи и размеров обломков. Чем меньше обломок - тем быстрее он разрагается. Судя по слоям, имеющим археологическую датировку время полного разложения обломков измеряется десятками тысячелетий. Например, в слоях, геологический возраст которых датируется Рисс-вюрмом, а по археологическим данным это архаичное мустье, отдельные обломки известняка еще сохраняют свою форму за счет тонких корочек на их поверхностях, но в руке легко превращаются в труху. Вероятный возраст их: 80-100 тыс.лет.

3. Экзотическая галька

Во многих пещерах (например, во всех известных нам пещерах Западного Кавказа) встречаются единичные гальки, представленные чуждыми для данного места породами. Обычно это мелкие (1-2 см) гальки хорошей, совершенной и весьма совершенной окатанности. Эти гальки попадают в пещеру с дневной поверхности по сложным системам карстовых ходов. Можно предполагать, что теми же путями в нее попадает и некоторое количество делювиального мелкозема, однако оценить это количество пока не представляется возможным.

4. Органогенные отложения

Преимущественно образуется за счет помета летучих мышей и местами могут достигать мощности нескольких метров. Их можно использовать для определения абсолютного возраста.

Присутствие помета летучих мышей в ряде случаев сказывается на цвете пещерных отложений, придавая им буроватый оттенок той или иной интенсивности.

П. Привходная зона (зона проникновения дневного света)

Эта зона подвержена прямому влиянию внепещерной (наружной) среды. Поэтому здесь воздействие внешних температурных колебаний и изменения влажности непосредственно сказывается на формировании отложений. Кроме того через вход в пещеру могут проникать отложения разных генетичеоких типов: аллювиальные, склоновые, эоловые и др. Последнее обстоятельство очень важно, т.к. иногда позволяет производить прямую корреляцию пещерных отложений с внепещерными. Для целей геологического и палеогеографического анализа эта зона пред-

ставляет максимальный интерес. Во-первых, именно здесь отложения наиболее чутко реагировали на изменения внешней природной обстановки. Во-вторых, именно здесь располагались стоянки первобытных людей и места обитания диких животных. Поэтому отложения зоны в наибольшей степени насыщены артефактами, органическими остатками, пыльцой, что представляет широкие возможности для датировок отдельных слоев.

Источники материала, слагающего отложения привходной зоны можно объединить в три группы.

А. Отложения, поступающие из внутренней зоны

Эти отложения были рассмотрены выше.

Б. Автохтонные отложения

I. Десквамационный щебень

Процессы десквамации, т.е. шелушения, отслаивания стенок и потолка пещеры происходят в результате температурных колебаний и особенно усиливаются в холодные периоды, в случае частого перехода температур через 0°.

Толщи десквамационного щебня - типичны для периодов оледенений, когда в горах широко распространялись перигляциальные условия. Они типичны не только для всего альпийского пояса, но наблюдаются в горных странах и несколько севернее, протягиваясь в полосе умеренных широт на восток по крайней мере мере от Средиземного моря до Байкала.

Несомненно десквамационный щебень может считаться важнейшим палеоклиматическим показателем.

2. Органогенные отложения

Органогенные отложения привходной зоны очень часто бывают связаны с деятельностью человека. Кроме того здесь могла поселяться и растительность.

Темно-бурые (до черных) гумусированные прослойки, преимущественно связанные с деятельностью людей последних столетий, наблюдаются в приповерхностных частях отложений многих пещер. В таких прослойках содержание гумуса весьма велико и может достигать I6-20%

В погребенных толщах часто сохраняются зольные прослойки, нередко содержащие и угли. В породах, вмещающих подобные прослойки, обычно можно наблюдать красноватые примазки - следы обжига. Это важный диагностический признак, указывающий, что прослойки образовались на месте, а не подвергались переотложению.

В рассеянном состоянии гумус присутствует в большинстве слоев отложений привходной зоны. Содержание рассеянного гумуса местами достигает I-I,5%, что дает возможность его извлечения путем химической обработки образцов и определения абсолютного возраста вмещающих отложений.

В. Отложения, принесенные снаружи

I. Аллювиальные отложения

Аллювий служит почти непременным компонентом отложений привходных частей пещеры в тех случаях, когда развитие последних на каком-либо этапе было связано с речной сетью. Часто аллювий располагается в основании разреза. При этом под влиянием процессов диагенеза, происходящих в вышележащей толще пещерных отложений пойменные фации аллювия могут измениться до неузнаваемости. В этом случае установить их генезис удается только с помощью химических и минералогических анализов: они полиминеральны и отличаются иным химическим составом.

2. Склоновые отложения

Склоновые отложения попадают в привходные части пещер, когда днища последних имеют обратный уклон. В этих случаях иногда удается произвести непосредственную коннексию разрезов пещерных и склоновых накоплений, что важно для целей регионального геологического и палеогеографического анализа.

3. Эоловые отложения

Во многих регионах (альпийский пояс Западной Европы, Армения, Алтай) эоловые отложения неизменно присутствуют в привходных частях пещер, причем интенсивность эолового привноса возрастала в холодные эпохи, когда происходило разреживание, а то и полное уничтожение лесов

Ш. Наружная зона (территория вне пещеры, примыкающая непосредственно к привходной зоне)

В наружной зоне пещерные отложения смешиваются со склоновыми и постепенно выклиниваются. В условиях резко расчлененного горного рельефа, однако, наружные зоны, как правило, сильно редуцируются или вообще отсутствуют.

В наружных зонах, когда таковые хорошо развиты, иногда удается обычными геологическими методами производить коннексию разрезов пещерных и внепещерных отложений.

Такова предлагаемая типологическая классификация рыхлых отложений пещер, которая проливает свет на их генезис, дает возможность более детально изучить и интерпретировать получаемые данные, включая и результаты аналитических исследований.

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A simplified approach to the evolution of the natural $CaCO_3$ -H_2O- air system by suitable methods of numerical calculus.

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RESUM

Els autors examinen el sistema natural $CaCO_3$ -H_2O-Aire, destacant les transformacions espontànies més interessants, començant per algunes condicions de no equilibri.

S'examinen, especialmente, les transformacions ocasionades per solucions aquoses de mescla d'aigües naturals amb alguns components químics i el paper de la fase gasosa per a la determinació de les condicions d'equilibri finals.

L'aproximació no és teòrica, però amb una descripció simplificada de la cinètica de l'evolució global del sistema i amb l'ús d'un ordinador personal, és possible un tractament més senzill d'aquests sistemes químics.

Per a demostrar la validesa de les simplificacions seleccionades, es realitzen algunes comparacions amb les dades teòriques i les experimentals.

RESUMEN

Los autores examinan el sistema natural $CaCO_3$-H_2O-Aire y destacan las transformaciones espontáneas más interesantes empezando por algunas condiciones de no equilibrio.

Ellos examinan especialmente las transformaciones ocasionadas por soluciones acuosas de mezcla de aguas naturales con algunos componentes químicos y el papel de la fase gaseosa para determinar las condiciones de equilibrio finales.

La aproximación no es teórica pero es posible con una descripción simplificada de la cinética de la evolución global del sistema y con el uso de una computadora personal, un tratamiento más sencillo de estos sistemas químicos.

Para probar la aptitud de las simplificaciones seleccionadas, se realizan algunas comparaciones con datos teóricos y experimentales.

SUMMARY

The authors examine the natural $CaCO_3$-H_2O–Air system and take into account the more interesting spontaneous transformations beginning from several non equilibrium conditions.

They examine, particularly, the transformations of water solutions formed from mixing of natural waters with several chemical compositions and the role of gaseous phase to determine the final equilibrium conditions.

The approach is not theoretical but it is possible, by a simplified description of the kinetics of the global system evolution and by the use of a personal computer, a more simple treatment of these chemical systems.

In order to test the ability of the chosen simplifications, some comparisons with theoretical and experimental data are performed.

Introduction

The study of karstic areas demands knowledge of the chemism of the circulating waters and its evolution, indispensable elements for a total comprehension of the various hypogean morphologies and those of surfaces. The elaboration of the chemical-physical data is usually quite complex, especially if a not oversemplified description of the system is required, one that includes relatively secondary aspects. To this end graphic methods have also been proposed. Among the most noteworthy we remember that of Roques (1972).

The theoretical approach has increasing degrees of difficulty, depending of the greater or lesser approximation to the «real» system that one wants to describe. Such elaborations provide for the same calculations tath can be carried out using personal computers, which have now become accesible to wide bands of users due to lower costs and better configurations.

Recently Y. Margaria and R. Durand (1983) proposed a program of calculus to determine the aggressive or encrusting nature of karstic water, suitable for a TI59 desk calculator or PC Apple II.

A real system is found in chemical-phisycal equilibrium only in rare cases, and being able to provide for its evolution may be very interesting; however, it can be done with a certain precision only in special cases. The kinetic equations of the main chemical reactions of the CO_2-H_2O-Carbonates system have been clarified by various Authors who have studied it both from the theoretical and experimental points of view. In its application, the use of such equations, expressed mainly in differential form, is not easy, and their validity is conditioned by certain selections of the boundary conditions. We thought, therefore, that we woult tackle the problem in a semiempirical way, carrying out the computing part on a PC with a program specially written in BASIC.

Some general considerations on the CO_2-H_2O-Carbonates system

The CO_2-H_2O-Carbonates system is usually schematized considering the various reactions which the dissolution in water of carbon dioxide and carbonates cause (fig. 1). In the first

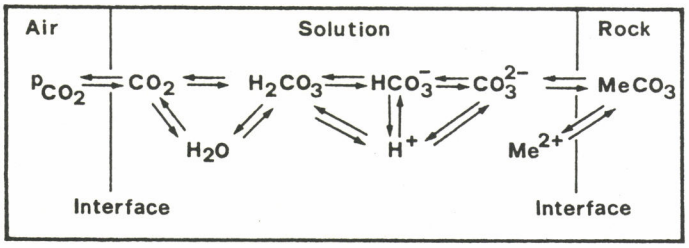

Fig. 1: Relationship between the principle species present in the threephase system Air-Solution-Carbonates (drawing: C. Grippa).

approximation the system may be considered three-phase and its evolution is conditioned by the kinetics of reaction. A fundamental role is played by the motions of the gaseous and liquid phases, as well as by the state of the solid surface, that condition the rate of exchange a great deal, especially at the interfaces. From the thermodynamic point of view, the system is monovarying: it is therefore convenient, for karstic waters, to choose couples of more easily measurable variables, to define saturation curves like those shown in fig. 2 (e.g. $[Me^{2+}]_T$/pH or $[Me^{2+}]_T$/ P_{CO2}, Roques 1964).

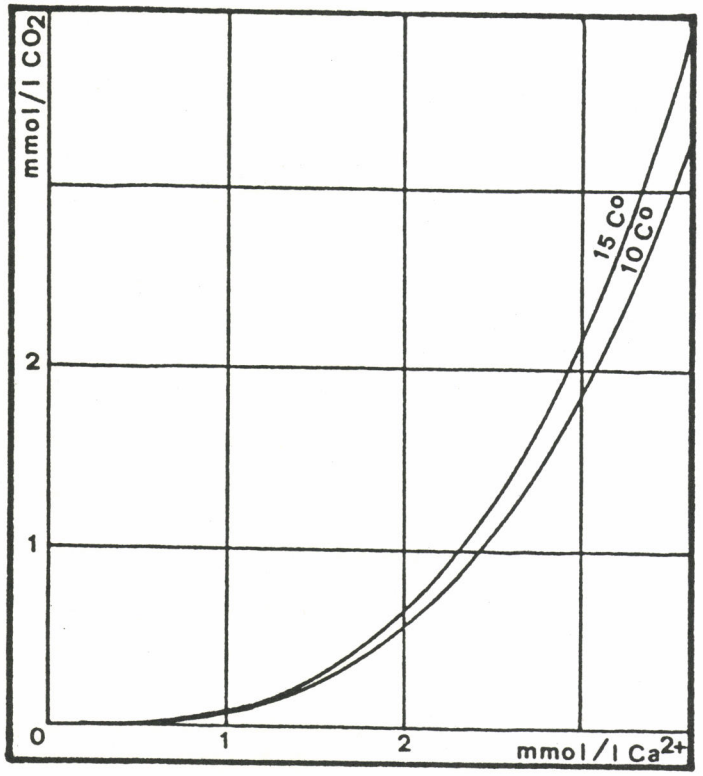

Fig. 2: Saturation curve (CO2) vs. $[Ca^{2+}]$ to 10 °C and to 15 °C, according to Roques 1964, (drawing: C. Grippa).

In the case of phreatic circulation (two-phase case), a system in thermodynamic equilibrium can exercise non corrosive or encrusting action, unless in the case of mixtures with waters with different CO_2 and/or Me^{2+} concentrations (Bögli 1964). If the system that will derive from it is not in equilibrium, the couple of concentrations will be subject to variations depending on a linear law dictated by the stechiometry of the reaction. In the case of vadose circulation (three-phase case), it is the gaseous phase that determines the conditions of equilibrium: the concentrations of CO_2 and Me^{2+} will assume values represented not by a straight line, but by curves of equations not easily definable a priori. The case of fig. 3 is emblematic:

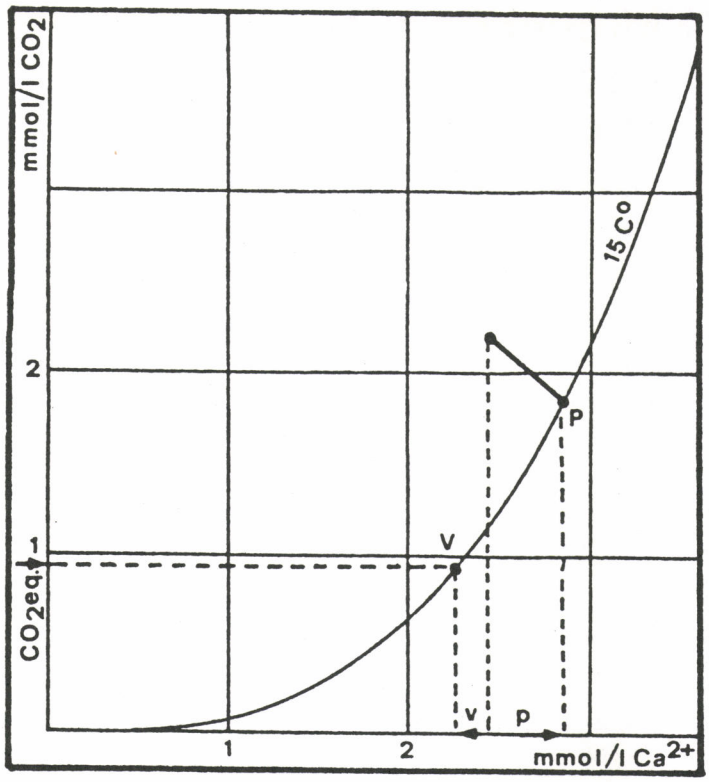

Fig. 3: Various states of equilibrium for a solution in phreatic (P) or vadose (V) circulation: in the first case, it can dissolve a greater quantity of calcium, (p), in the second, however, an excessive quantity must precipitate from it (v) (drawing: C. Grippa).

a) case of phreatic circulation: the concentrations of equilibrium are those of point P and the water is certainly aggressive;

b) case of vadose circulation: the concentrations of equilibrium are those of point V, imposed by the P_{CO2} and the water is encrusting.

The importance of considering all the phases present in the system is therefore made obvious, since the composition of the water alone can be insufficient to define its aggressive or encrusting nature.

The rate of the exchanges at the air-solution interface depends closely on the conditions of motion of the two phases, until they can be considered infinite (instantaneous mass transfer) compared to the rate of the other reactions of the «chain» (Roques 1964).

The case of laminar flow is different, with perturbations at the interface practically absent (e.g. drops with formation times above 30'), or stagnant phases where the exchanges take place by diffusion and the kinetics may be considered of the first order (Reynolds number $< 10^4$), also compared to the growth of nuclei. Such fluodynamic conditions can facilitate the conservation of metastable states even for long periods (e.g. low nucleation rate, Girou, Roques 1972). Roques (1964) and Girou, Roques (1972), studying experimentally the kinetics of precipitation of calcium carbonate, registered the variations of pH in function of time, obtaining two typical evolution curves to solution with a higher or lower degree of oversaturation (fig. 4). These Authors also related the various parts of the experimental curves to the current chemical reactions and formulated kinetic equations up to the third order, verifying their conditions of validity.

Numerical approach

In this note we propose a numerical approach of the iterative type, to be carried out on a specially programmed PC. As we have said, the most usual case is that where, besides the reaction of dissolution of the carbonate, one must also take the exchange of carbon dioxide at the air-solution interface into account.

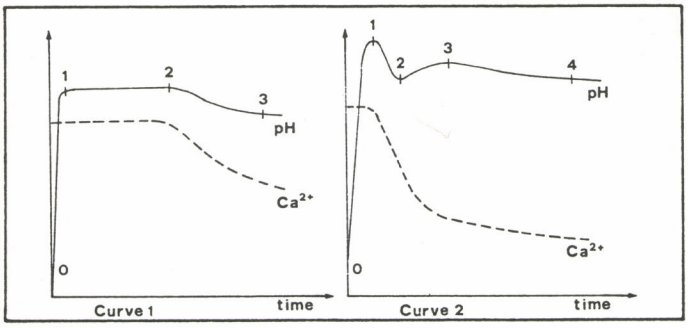

Fig. 4: Variation of pH and of the [Ca^{2+}] in function of time: curve 1, *solution with low degree of oversaturation;* curve 2, *solution with high degree of oversaturation. (drawing: C. Grippa).*

It seems simpler to consider the evolution of the system as a serie of steps, alternatively of exchange and of «reaction»[1], or viceversa. In the plan of fig. 5, two successive steps locate one point: the succesion of such points approximate the real «route» followed by the system towards the state of equilibrium. Once the equations that define the saturation curve, the kinetics of exchange and those of «reaction» having been established, only the part of calculus remains that can be done on a PC. This is, however, formally more simple in the case of the exchange. For the «reaction», the concentrations of equilibrium are located by the intersection of the said curve with the straight line of gradient (-1 mol CO_2/1/1 mol $MeCO_3$/1).

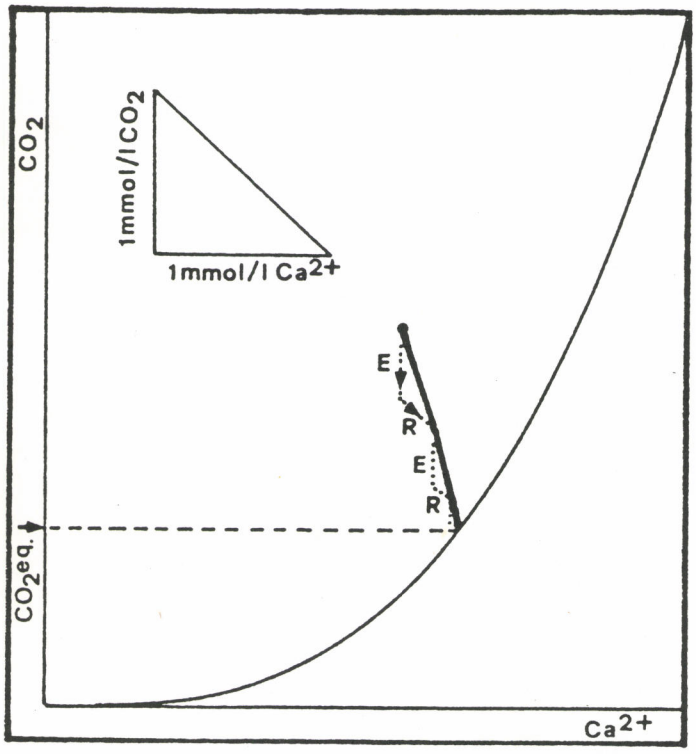

Fig. 5: Graphic representation of the steps: E=exchange, R=«reaction» (drawing: C. Grippa).

Nonetheless, the reaction of exchange will move vertically the representative point of the system and it will be necessary to make new calculations of the concentrations of equilibrium of the «reaction» every time. Formally the intersection is determined by resolving analytically the system composed of the equations of the straight and the saturation curve. As several versions can be proposed of this line (e.g. Ernst 1964, Roques 1964 etc.), every analytical solution cannot be general: for this reason we preferred to choose a numerical method of calculus which definitely converges in all cases of interest (bisection method).

To chek the quality of the program we made some tests that simulate the evolution of the system starting from a certain number of states of non-equilibrium. More precisely, states of oversaturation or insaturation that imply or exclude the exchange of CO_2 at the interface. In the pH/time plan of fig. 6, the experimental points are marked, relative to an oversaturate system of which various evolutions are simulated varying the rate constants of the kinetic equations.

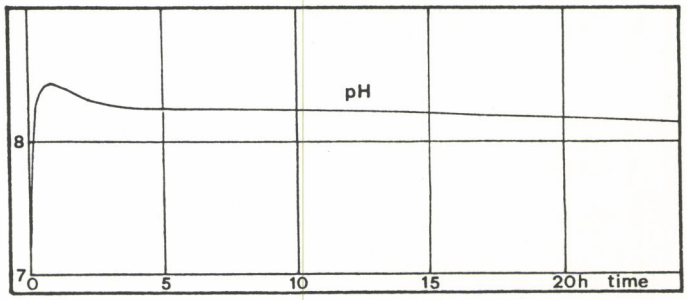

Fig. 7: Variation of pH compared to time: taken experimentally from an oversaturation system in evolution towards the state of equilibrium (from Roques 1964) (drawing: C. Grippa).

In fig. 7 we have a case taken experimentally from Roques (1964): the system, oversaturate with conditions close to those chosen for the simulation, evolves varying the pH in a very similar way to that represented in fig. 6. The equation that expresses the saturation curve by means of the $[Me^{2+}]/(CO_2)$ couple, is the following:

$$(CO_2 = \frac{4 \cdot 10^{K1-K2}}{2} \cdot [Me^{2+}]^3 \cdot f_{Me\ 2+} \cdot f_{HCO\bar{3}}$$

(Roques 1964), while the kinetic equiations (of the 1° order:

$$\frac{dC}{dt} = -K\ (C - C_{eq})\ ),$$ are suitably integrated.

The mechanism of the steps and the choice of two equations of the 1° order cannot interpret correctly the numerous reactions that really take place, but constitute an empirical semplification which allows an applicative approach to a very complex chemical-physical system. The rate constants or the possible coefficients that may be introduced and that have merely the function of adapting the simulation of the experimental data, are to be considered in the same way.

Flow chart and random test of the program

INPUT. The design of this routine provides for three phases of input, each relative to the definition of the equations necessary to the calculations: saturation curve, kinetics of exchange, kinetics, of «reaction». Each phase is conceived with a criterion of modularity, even though they are all similar in structure. In carrying out the program it is therefore possible to define the equation chosen in a predisposed set. Nonetheless it is simple to introduce new equations, operating on the level of software. So the input operations are reduced to the introduction of the foreseen numerical constants. Before the program accedes to the calculus routines, it is possible to correct the input data, that are also submitted to plausibility tests. We are also told if the system evolves from a state of oversaturation, equilibrium, or insaturation.

CALCULUS. The salient part of the program consists of the iterative routine for the determination of the concentrations of equilibrium of the «reaction» (see Numerical approach). The bisection method definitely converges with few iterations in all the cases of interest: ten interations are, in fact, sufficient to reduce the width of the interval to 1/1000 ($1/2^{10} < 10^{-3}$). This

1. By «reaction» we mean to express synthetically that which refers to the reaction: $CO_2+H_2O+CaCO_3 \leftrightarrows Ca(HCO_3)_2$.

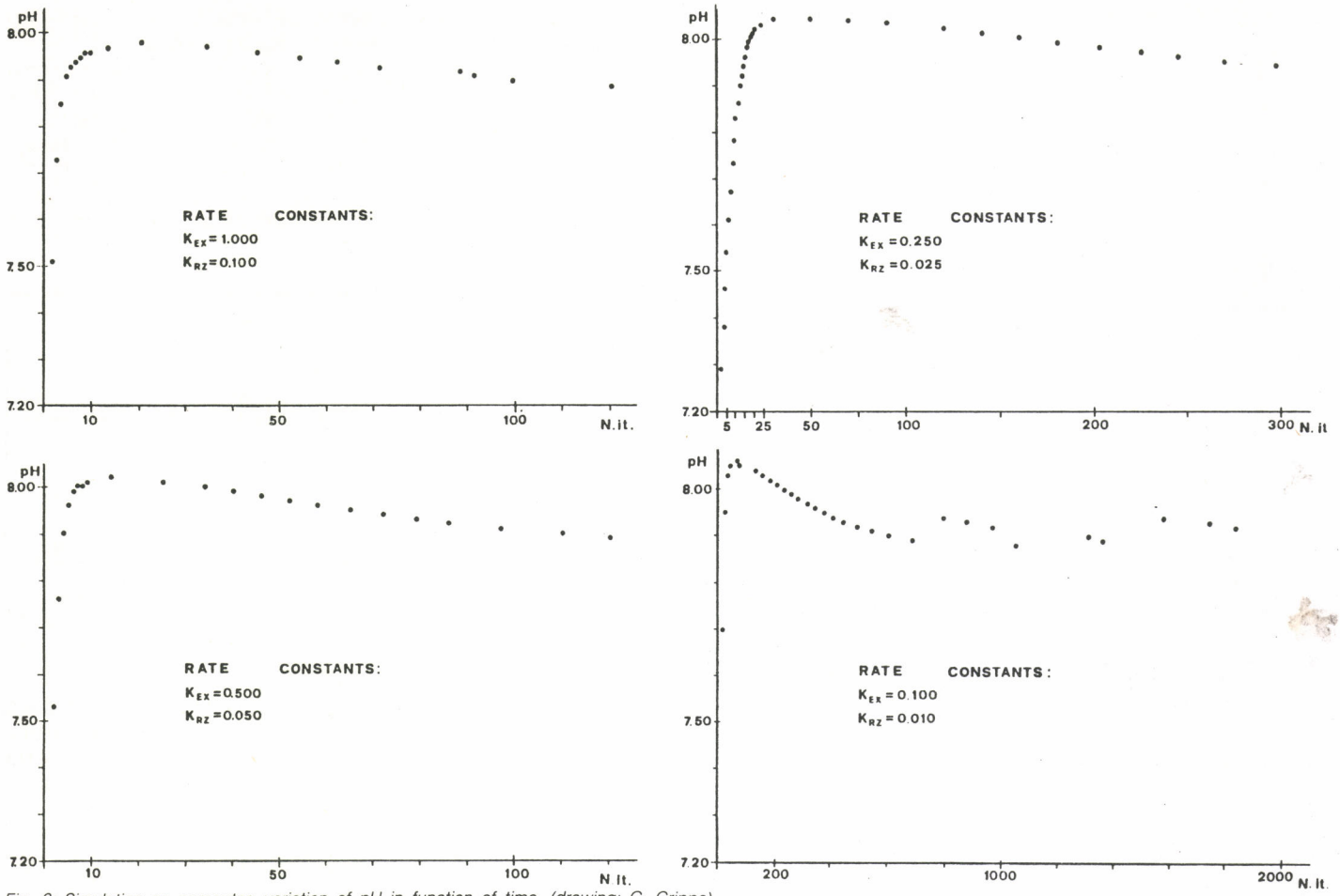

Fig. 6: Simulation on computer: variation of pH in function of time. (drawing: C. Grippa).

recursive procedure is the one that, in terms of time, absorbs most of the program, as we accede to it every time it is necessary to determine the «contribution of the reaction». The co-ordinates calculated in the two steps are collected in two vectors of 500 elements each. If the process needs a greater number of points, the program would contract the group of data to 250, cancelling every second one. Naturally samples of the new data would be stored on the new rhythm. This operation can be repeated as often as necessary, adjunsting to the new frequency of the sample.

OUTPUT. In this phase the flux of data is directioned on the printing unit or on the screen. The memorization of the data on file is also provided for, to treat them with a graphic program. This file is on a 5'' 1/4 floppy disk. In fig. 8 an essential flow chart of the program tested is shown. We also made a significant debugging test, performing a series of random tests, on concentrations chosen from a chance generation of numbers. The program, written is BASIC-80 RELEASE 5.2, Microsoft, with CP/M 2.2 operative system, occupies about 15 Kbytes of RAM memory, and to use it, one needs an OS configurated to 56 Kbytes. Naturally, the program is available in MS-DOS. The PC used is the R1 type of the Microdesign Company.

Concluding remarks

The proposed program allowed us to try every type of kinetic equation compatible with the mechanism of the steps, which gives it a marked flexibility. Starting from the experimental data, it is possible to carry out interesting comparisons between the evolutions simulated at the computer and those we arrived at experimentally. One of the potentialities that has not yet been developped is the possibility of fitting the experimental points, like those shown in fig. 6, with functions of logarythmic or polynomial type of the desired degree. Varying the rate constants, it is therefore possible to define families of polynomials, the

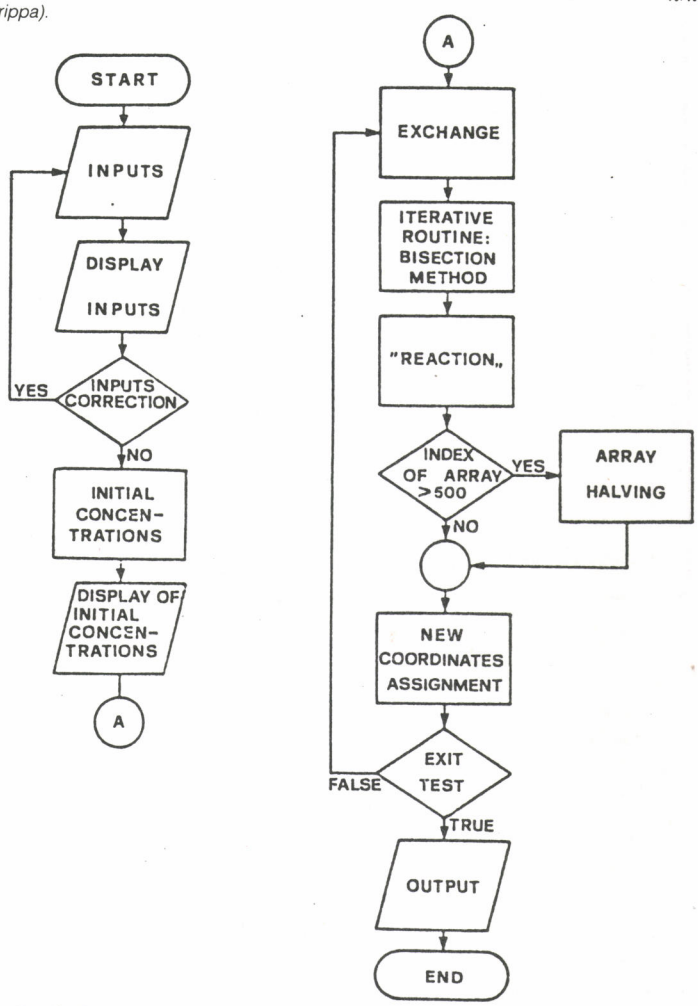

Fig. 8: Essential flow chart of the program (drawing: C. Grippa).

coefficients of which are in functional relationship with them. The choice of these constants, closely connected to the regime of flow of the system, at its degree of oversaturation etc., would allow us to calculate the «answer» easily. As a rule, the interpolation of experimental data allows for the opposite process, so we can find out in this way the value of the rate constants relative to the equations that, semiempirically, descibre the evolution of the system.

Acknowledgements

We wish to thank Dr. Maurizio Ranoisio and Dr. Massimo Raineri for their useful advice and collaboration during the preparation of the program. Our heartfelt thanks to Mr. Carlo Grippa, both for the technical assistance with certain problems with the hardware for the computer, and for having taken care of the graphic part of this essay. We are also greateful to Dott.ssa L.E. Maxwell for her brilliant translation in to English and Mrs. Cristina Oddo for having typewritten it.

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Hydrochemical data of Jósvafö springs and the problem of Magnesium

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RESUM

Durant un període de varis anys s'han estat analitzant, sistemàticament, les dades químiques d'algunes de les surgències de la zona càrstica de Jósvafö (Nord d'ongria). Normalment s'obtingué una dada per setmana, però durant les crescudes se'n recollí una cada dia.

Les dades químiques de les surgències que normalmente gairabé no presentaven variacions sofrien grans alteracions durant els períodes de crescuda d'alguns anys. La magnitud d'aquesta alteració i el valor mitjà de les dades de les surgències són característics del medi geològic de les surgències i de la zona on s'han obtingut les mostres, així com de l'estructura dels aqüífers.

Es va detectar també una relació directa entre les dades i la pol·lució.

La taxa estimada del Ca per a Mg de les roques de la superfície és inferior al nivell mitjà en l'aigua de la surgència. El descens del Mg sembla provenir del procés químic de la carstificació, p. ex. de l'índex més baix de dissolució de les roques que contenen Mg, així com també de l'alt nivell de diposició de cristalls de dolomia, respecte a la calcita.

RESUMEN

Durante un período de varios años se han analizado sistemáticamente los datos químicos de algunas de las surgencias de la zona kárstica de Jósvafö (Norte de Hungría). Normalmente se obtuvo un dato por semana, pero en las crecidas se obtuvo un dato por día.

Los datos químicos de las surgencias que normalmente casi no presentaban variaciones sufrían grandes alteraciones en los períodos de crecida de algunos años. La magnitud de esta alteración y el valor promedio de los datos de las surgencias son los característicos del medio geológico de las surgencias y de la zona de toma de muestras, así como también de la estructura de los acuíferos.

Se detectó una relación directa entre los datos y la polución.

La tasa estimada del Ca para el Mg de las rocas de la superficie es menor que el nivel medio en el agua de la surgencia. El descenso de Mg parece provenir de la química de karstificación, p. ej. de la tasa más baja de disolución de las rocas que contienen Mg, así como también del alto nivel de deposición de cristales de dolomía respecto a la calcita.

SUMMARY

Chemical data of some the springs of the Jósvafö karstic area /Nord Hungary/ have been systematically analized for many years period. One data per week were obtained usually but one data per day ot the floads.

The chemical data of springs which are usually practically unchanged have great alterations in the flood periods in some years. The magnitude of this alteration and the mean value of the data of the springs are characteristic to the geological environments of the spring and the catchment area as well as the structure of the aquifers.

Direct connection between the data and the pollution was detected.

The estimated ratio of the Ca to the Mg of the surface rocks is lower than the measured ratio of the spring waters. The loss of the Mg is lead back to the chemistry of karstification i. e. to the lower rate of solution of the rocks containing Mg as well as to the great rate of deposition of dolomitic crystals with respect to calcite.

Introduction.

The Jósvafö area of karst is one of the most studied karst in Hungary. There is no industry in the catchment area of its springs. There is two big plateau of the area, the northern and the southern one. The northern plateau crosses the Hungaryan-Czechoslowakian border. The very limited agricultural activity is at the valeys, the plateaus are mainly covered by forest or bush, their leggs are recultivated fields. The nonkarstic catchment area of the southern plateau has the greatest agricultural activity.

The rocks at the surface are triassic limestones and dolomites. The limestones containe Mg in a great amount /10-40 mole%/. There are 5 great caves on the area /longer than 1 km/ and many smaller ones. The longest cave of Hungary, the Baradla cave /25 km/, the second longest, the Béke cave /10 km/ can also be found here. Their springs the Jósva and also Barlang spring as well as the Komlós spring are within 200 m distances. Baradla cave has two independent springs.

The second greatest spring of the area is the Nagytohonya spring. It leads the water of the northern plateau and a 1 km long cave, the Kossuth cave is just at the spring. This cave terminates in a deep syphone. This spring gives also the infiltrated water of the Lófej spring, what is at the northern part of the plateau with the highest altitude amoung all of the springs investigated.

The Kistohonya spring is 2 km northern from the Nagytohonya spring just beside the Vass Imre cave /1 km/. Its permanent catchment area is cca 4.5 km^2 but it is doubled among rare conditions.

Babot-kút is a spring of dolomites. It serves as a part of the water resource for Aggtelek, the village at the ponors of spring Jósva and also Barlang.

Results.

Figure 1-4 represents the data function of four springs in the year of 1981. This year was peculiar as there were two strong floods. The data of the other years show similar characteristics with the exception of the smaller alteration of data in floads periods. The data of the other springs show similar yearly run.

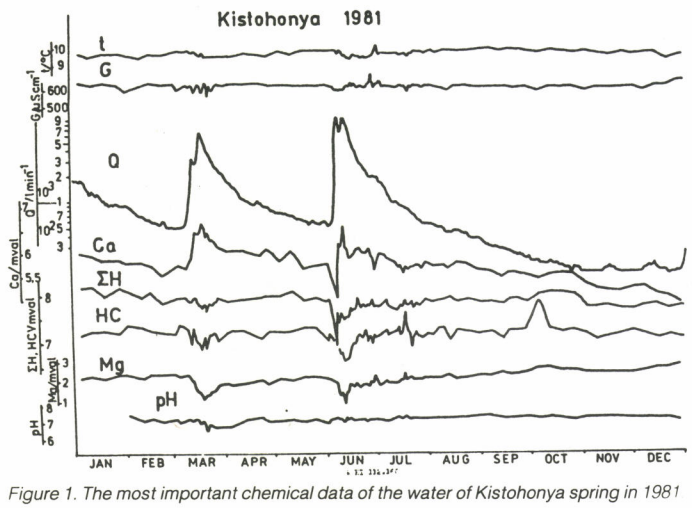

Figure 1. The most important chemical data of the water of Kistohonya spring in 1981

One part of the springs have great alteration in floads periods /Jósva and Komlós on the Figures/, the other have smaller. The former ones have open ponores thrugh what the rain or the snow-melts may run very fast to the springs. Nagytohonya and Kistohonya gives mainly water from the infiltrated waters. Lófej spring, Babot-Kút have not open ponors, too. When the catchment area of the Kistohonya spring is doubled, its water show similar properties to that of Jósva spring.

It is interesting, that the different components of the water are not running parallel. The great alteration of Ca does not correspond to that of HCO_3^-. The change in the Mg content is smaller than that of Ca. There is no big alteration also in the permanent hardnes.

The mean values of the components of many year measurements are summarized in Table I. Table II contains the upper and lower limits of same measurements carried out in 1984 when a complete analyses was done inclouding the nitrates, nitrites, chlorine and sulfate. These data of the dropping water of Vass I. cave, those of the streemlets in the Baradla cave and the rain water are included.

Table I

The mean values of the different components in the springs in mval units

spring	H	Ca	Mg	MCO_3	SO_4	Cl	pH	
Kistohonya	6.86	5.36	1.51	7.10	0.56	0.03	0.15	7.05
Nagytohonya	7.29	5.73	1.62	5.57	0.74	0.06	0.12	7.60
Lófej	7.71	5.68	2.08	7.00	0.58	0.01	0.14	7.35
Komlós	7.61	6.92	0.73	7.11	–	0.04	0.21	7.50
Jósva	6.71	5.99	0.78	5.21	0.26	0.16	0.21	7.50
Alsóbarlang	6.89	6.30	0.63	6.29	0.36	0.11	0.25	7.30
Babotkút	6.93	5.00	1.92	7.50	0.93	0.03	0.15	7.25

Table II

The extremes of the components in the water of the springs in mval units

spring	H	Ca	Mg	HCO_3	SO_4	NO_3	Cl	pH
Kistohonya	8.20	6.65	2.83	7.40	–	–	–	7.39
	7.40	5.00	1.00	6.60	–	–	–	6.49
Nagytohonya	7.21	6.13	1.73	6.54	0.27	0.07	0.12	7.3
	7.11	5.50	1.12	6.18	0.14	0.04	0.09	7.1
Komlós	7.54	6.84	0.91	6.79	0.26	–	0.39	7.5
	6.39	5.71	0.51	5.75	0.11	–	0.28	7.2
Jósva	6.75	6.13	0.91	6.25	0.23	0.19	0.24	7.3
	6.00	5.24	0.71	5.50	0.03	0.14	0.18	7.1
Alsóbarlang	7.39	6.79	0.61	7.11	0.17	0.75	0.21	8.0
	4.07	4.04	0.10	3.96	0.04	0.09	0.17	7.6
Babotkút	8.00	6.63	2.73	7.46	0.24	0.04	0.14	7.3
	6.79	4.89	1.42	6.04	0.09	–	0.05	4.3
drooping w.	6.36	6.19	0.27	5.50	0.31	0.25	0.13	7.8
	5.00	4.70	0.11	3.36	0.14	–	0.09	7.1
rain w.	3.53	2.10	–	–	0.15	0.23	0.07	6.7
	0.14	0.31	–	–	–	–	–	4.3

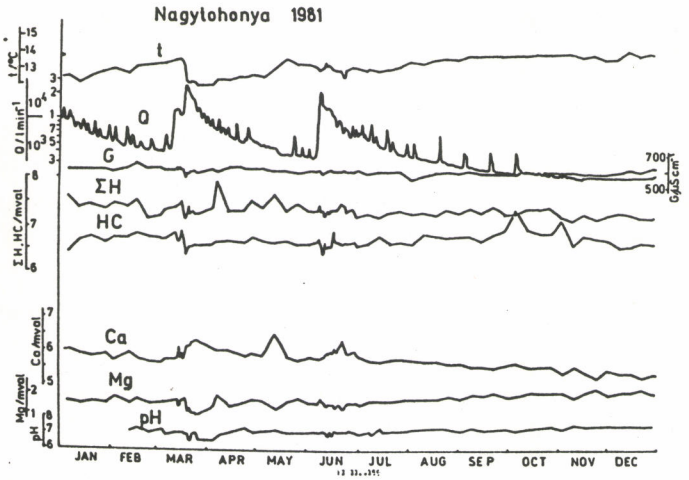

Figure 2. The most important chemical data of the water of Nagytohonya spring in 1981.

The mean value of the chemical components differ mainly only in the Mg content. The springs of the northern plateau give more Mg, than those of the southern one. In the reality, there are greater area of dolomites in north with respect to south. The mean ratio of Ca with respect to Mg is 2,5 in the springs of northern part and cca 5 in southern one.

As the rocks contain more Mg with respect to Ca, we have to state that there is loss in the mobility of Mg of this area. This contradicts to the second-solution of limestones due to their Mg content, where the waters should be more rich in Mg than the original stones /Gánti, 1957/.

The problemm of Magnesium

According to Gánti, 1957, the spring waters should containe more Mg than the original rock. Some analyzes were carried out to solve the contradiction presented above.

The Vass I. cave crosses many times dolomites. There is a syphone /Laguna/ in the middle of the to day cave. The stone is dolomite where the syphon had developed. This syphon is close for some months after floads. The water stored in the syphon is over 400 m^3 and infiltrats with a rate of 0,1 m/day in the water level. If the second-solution of Mg is true, the water should contain as much Mg than Ca, or more. We have many analytical data /Cser, 1984, Czajlik, 1961/ what indicate a very great Ca content with respect to Mg /10x/. The water of the syphon has been pumped out in this year. The pumped water floated 200 m-s along the cave and accumolated again at the

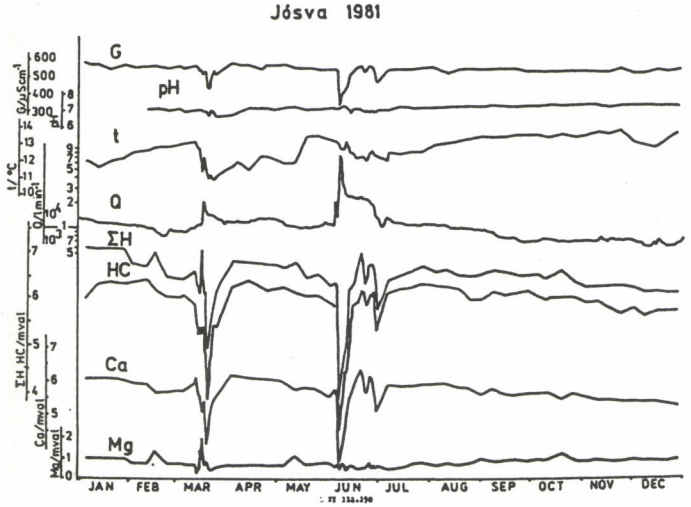

Figure 3. The most important chemical data of the water of Jósva spring in 1981.

Rockoko-gate. The analyses of the water showd a decreas in the Mg content /to its half value/ with a small increas in Ca. /Ca: 6.3 mval, Mg: 0,65 mval, Ca_2: 6.62 mval, Mg_2: 0,31 mval!/.

The bottom of the syphon is a sinter. It has been broaken and the material found there was analysed. The sinter had 57 % material solved in 10 % HC1, with a Ca/Mg =1! The sinter was a clay and small needles with equivalent Ca and Mg content. The crystallographic analyse of the minerals is in progress.

The corridor after the syphon in limestone is filled with carbonatous sand with a great Mg content.

Taking the facts into account we suppose the following mechanism:

As the solubility of the dolomite is practically the same as limestone /Hodgeman, 1061/ other parameters should be found to explaine the smaller cavernes in dolomites than in lime stones. This is the density of the dolomite, what is greater than that expected by the addition-role. The greater density causes lower rate of dissolution. The greater density may also cause a lower crytical sise of crystalline nucleus what results in smaller crystals when precipitate.

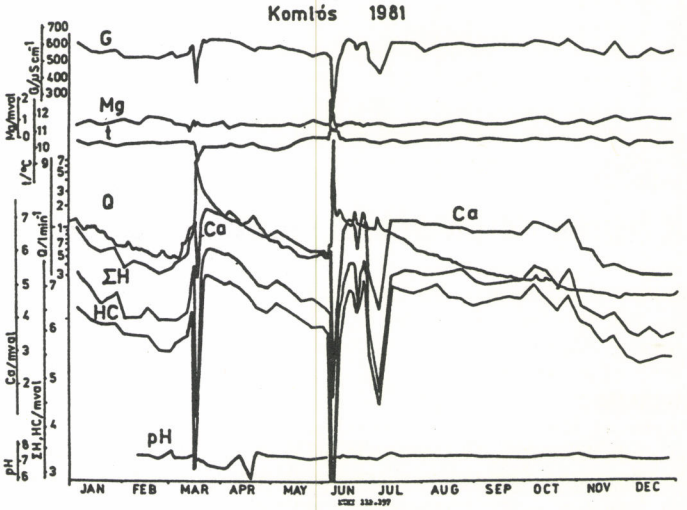

Figure 4. The most important chemical data of the water of Komlós spring in 1981.

As a consequence we suppose that at saturated condition dolomite microcrystals precipitate first and the water losses its Mg content. This precipitated dolomite can be found as a sand in the caves after the dolomite in the flow direction. Naturally, these crystals are mixed with clay. Turning the water in agressive the precipitated small crystals will be dissolved first in the turbulent streem saveing the wall in such a way. This could be the reason that there are smaller cavernes in dolomites with respect to limestone.

This is only a hypothese, we have no data to prove its validity.

Thee problem of pollution

The Tables represent the mean and the extreme values of ions in the waters. The NO_3^- the Cl^- ion are the most charascteristic to the pollution. The data do not referre to pollution. We have not found increas in NO_3^- and Cl^- in the water of springs Kistohonya, Nagytohonya, Lófej and Babotkút. This is not true for Jósva spring. Among the data measured in 1980 the drastic increase in the concentration of NO_3^- and Cl^- was found. We cuold measure 0,94 mval concentration of nitrate what is at the limit of danger. This was the indication what is at the limit of danger. This was the indication of the infiltrated /washed/ fertilizers from Aggtelek. Th Cl^- content was increased in winter periods indicating the protection of the highways from the snow. An increase in the chlorine to 1 val could be measured in Budapest in the Ferenc cave at some stalctites.

The pollution reached our caves, too, although this is one of the most protected area of Hungary.

Conclusion

The chemical data of the springs referre to the chemical processes both in the zone of infiltration both in the aquifers. The springs with very small alterations in their composition indicate, that the water comes directly from the aquifer irrespective to the presence of an open cave in its vicinity. The big caverns are formed in that time, when the erosion base was above the presence height of the corridor. The today position of the most important corridors in the aquifers should not be connected directly to those of the past.

The loss of the Mg in the process of the karstification should be investigated in more detail. The solubility data for the dolomites, for limestones with great Mg content should be measured accuratly.

The aquifers contain waters from the present as well as from the past. The pollution is not only a present danger, this effect also to the future turning the waters in aquifers unusable in the future.

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A study of chemical weathering and metal ion transport in a limestone aquifer

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RESUM

La major part de l'aigua del sistema de cavitats de Bungonia (New South Wales, Austràlia) aflora en una única surgència. Des de l'any 1971, l'aqüífer que s'estén darrera la surgència ha estat objecte d'estudis hidrològics i químics molt complets. La coloració de l'aigua, el sifonament i experiments de bombeig, han establert que l'aqüífer té una capacitat mínima de 1.500 m^3. Un mostreig d'aigües i un programa d'anàlisis químiques paral·lel als experiments més amunt detallats, han fet possible d'establir els nivells de degradació química de l'aqüífer, que corresponen a diferents nivells de cabal. Totes les mostres de l'aigua van ésser analitzades especificant els tipus d'ions, l'oxigen dissolt, indicis de metalls i el carboni orgànic total. S'ha calculat l'apreciació química en fase aquosa, els índexs de saturació dels minerals i l'equilibri de la pressió parcial del diòxid de carboni. Les pressions parcials de diòxid de carboni són molt elevades a les aigües subterrànies, mentre que les d'oxigen són baixes. La combinació d'aquests dos factors origina l'alliberament i el transport de traces d'ions metàl·lics. Aquests procesos poden ésser modificats posteriorment per la presència de microorganismes.

RESUMEN

La mayor parte del agua del sistema de las cuevas del Bungonia, New South Wales, Australia, emerge en una única surgencia. Desde 1971 el acuífero que se extiende detrás de la surgencia ha sido objeto de completos estudios hidrológicos y químicos. La coloración del agua, el sifonamiento y los experimentos de bombeo han establecido que el acuífero tiene una capacidad mínima de 1.500 m^3. Un muestreo de aguas y programa de análisis químicos durante los experimentos arriba mencionados, ha posibilitado establecer los niveles de degradación química en el acuífero, que corresponden a diferentes tasas de caudal. Todas las muestras de agua fueron analizadas para cada tipo de ión, oxígeno disuelto, trazas de metales y carbono orgánico total. Se han calculado la apreciación química en fase acuosa, los índices de saturación de minerales y el equilibrio de la presión parcial del dióxido de carbono. Las presiones parciales de dióxido de carbono son muy elevadas para las aguas subterráneas y las del oxígeno disuelto son bajas. La combinación de estos dos factores produce la movilización y transporte de trazas de iones de metales, estos procesos son modificados posteriormente por la presencia de microorganismos.

SUMMARY

Most of the water from the Bungonia Caves system, New South Wales, Australia emerges at a single spring. Since 1971 the aquifer behind the spring has been the subject of extensive hydrological and chemical studies. Water tracing, syphoning and pumping experiments have established that the aquifer has a minimun capacity of 1500 $m.^3$. A water sampling and chemical analysis programme during the above experiments has enabled the amounts of chemical weathering in the aquifer to be established for different flow rates. All water samples have been analysed for all major ionic species, dissolved oxygen, trace metal ions and total organic carbon. Chemical speciation in the aqueous phase, mineral saturation indices and the equilibrium partial pressure of carbon dioxide have been calculated. The partial pressures of carbon dioxide are very high for groundwaters and those of dissolved oxygen are low. A combination of these two factors causes mobilisation and transport of trace metal ions, these processes are further modified by the presence of micro-organisms.

Chemical Evolution of Water in Warm River Cave and Falling Spring Creek, Virginia, USA

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RESUM

En aquest treball es presenten una sèrie d'observacions físiques i químiques a fi i efecte d'explicar l'evolució de les propietats químiques de l'aigua al llarg del curs d'aigua que recorre la cova de Warm River i de Falling Spring Creek. El corrent comença a la cova de Warm River i està constituït per una mescla de dos corrents: l'un, càlid, alimentat per una surgència termal i l'altre, fred, alimentat per aigua subterrània poc profunda. L'aigua mesclada surt a la superfície, constituint el corrent que alimenta la surgència. La totalitat del curs d'aigua ve caracteritzada per un desprendiment de CO_2 i una progressiva precipitació de travertins. L'atmosfera de la cova posseix un elevat índex de CO_2 (superior al 9,1 % del volum) i la precipitació de calcita més baixa es dóna a les «cave formes rimestones dams». A la superfície de l'aigua el desprendiment ràpid del gas comporta l'abundant formació de travertins. Els coeficients d'aquests procesos són quantificats utlitzant la composició química de les mostres d'aigua i els càlculs de transferència de volum. Els coeficients de diposició de travertins són més elevats en les zones amb corrent turbulent i quan el cabal d'aigua minva, a l'estiu i a la tardor.

RESUMEN

Se presentan observaciones físicas y químicas para explicar la evolución de la química del agua a lo largo del curso de agua de la cueva de Warm River y Falling Spring Creek. La corriente empieza en la cueva de Warm River y está formada por la mezcla de una corriente cálida, alimentada por una surgencia termal, y una corriente fría, alimentada por agua subterránea poco profunda. El agua mezclada sale a la superficie como corriente de alimentación de manantial. La totalidad del curso de gua se caracteriza por el desprendimiento de CO_2 y en precipitación de travertinos. La atmósfera de la cueva posee un elevado contenido de CO_2 (superior al 9,1 de volumen en %) y una precipitación de calcita más baja en las «cave formes rimestones dams». En la superficie de la corriente el desprendimiento de gas más rápido conduce a una formación extensiva de travertino. Los coeficientes de estos procesos se cuantifican utilizando la composición química de las muestras de agua y los cálculos de transferencia de volumen. Los coeficientes de deposición de travertino son mayores en las zonas turbulentas de la corriente y durante las condiciones de bajo caudal del verano y otoño.

SUMMARY

Chemical and physical observations are presented to explain the evolution of water chemistry along the flow path in Warm River Cave and Falling Spring Creek. The stream begins in Warm River Cave and is formed by the mixing of a warm stream, fed by a thermal spring, and a cold stream, fed by shallow groundwater. The mixed water emerges at the surface as a spring-fed stream. The entire flow path is characterized by outgassing of CO_2 and travertine precipitation. The cave atmosphere is very high in CO_2 (up to 9.1 volume %) and minor calcite precipitation in the cave forms rimstone dams. In the surface stream, more rapid outgassing leads to extensive formation of travertine. Rates of these processes are quantified using the chemical composition of water samples and mass transfer calculations. Rates of travertine deposition are greatest in turbulent sections of the stream and during the low-flow conditions of summer and fall.

Introduction

Mixing of carbonate waters, carbon dioxide ingassing or outgassing, and calcite precipitation or dissolution are the most important geochemical processes occurring in carbonate aquifer systems. Warm River Cave and Falling Spring Creek in Alleghany County, Virginia, offer an ideal field site for observation of the mixing of two carbonate waters in the subsurface and of calcite precipitation resulting from CO_2 outgassing in the subsurface and at the surface of the earth. This paper presents chemical and physical observations to explain and quantify the evolution of stream water chemistry inside the cave and along the surface stream.

Location

The field site for the present study is located in the thermal springs area of the folded and faulted western anticlines in the Valley and Ridge province. The local geologic section consists of a thick sequence of Lower Ordovician dolomites and Middle and Upper Ordovician limestones. Like other thermal springs in this area of Virginia and West Virginia, the spring issuing in Warm River Cave appears to be fed by deeply-circulated meteoric water that was heated under a normal geothermal gradient (Hobba et al., 1979).

The thermal spring inside Warm River Cave exceeds 38°C. The spring water flows through the cave as a warm stream and converges with a cold stream derived from shallow groundwater. The mixed stream continues flowing through 305 m of cave passage, approximately 37 m below the surface, before entering a breakdown pile and then resurging as Falling Spring on the surface (Holsinger, 1975). Falling Spring forms the stream called Falling Spring Creek. Approximately 0.8 km downstream from Falling Spring, where the stream breaches a small sandstone ridge, the stream flows over a 18-21 m waterfall. The cliff is covered in travertine and more travertine deposits are evident in the stream bed immediately above and below the waterfall.

Methods

Three field trips for the collection of samples along the surface stream and the accessible parts of the warm stream, cold stream, and mixed stream inside Warm River Cave (Fig. 1) were completed. The warm stream can be followed all the way upstream from the junction of the two streams to where the hot spring issues, but the cold stream can only be followed upstream for about 40 m before breakdown blocks the passage. Breakdown has also made it impossilbe to traverse the entire length of the mixed stream to the point where Falling Spring emerges. Seven aditional trips for collection of surface water samples were made.

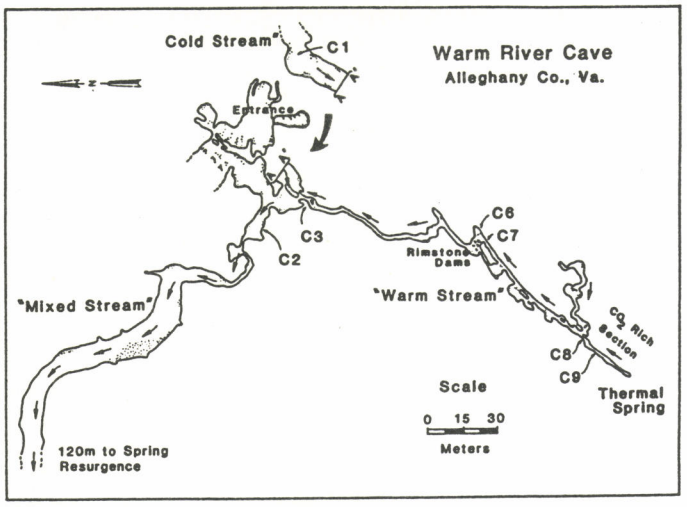

Figure 1. Map of Warm River Cave (after Lucas, 1971) showing locations of sample collection points.

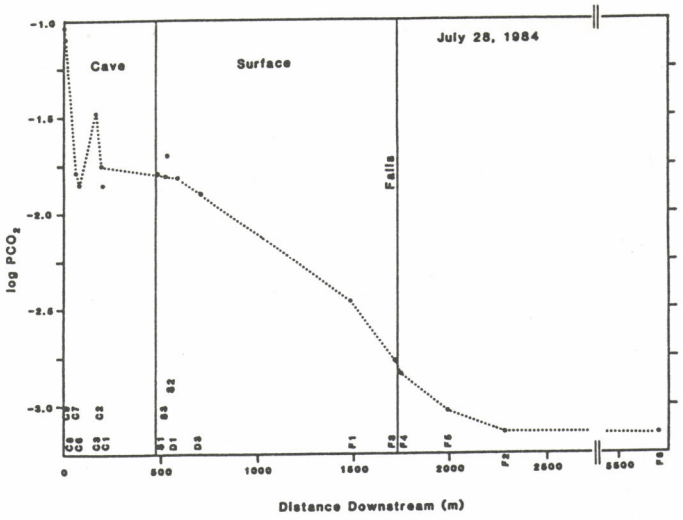

Figure 2. Log P_{CO2} for water samples versus distance along the flow path. The thermal spring inside Warm River Cave is taken as the start of the flow path (0 m).

Surface water sampling sites ranged from three distinct springs just outside the breakdown pile closing off Warm River Cave to stream sites above and below the falls. Temperature, pH, conductivity, and alkalinity were measured in the field. Additionally, discharge was obtained by measuring flow velocity with a current meter and determining the cross-sectional area of the stream with a measuring rod and tape.

Water samples were collected in polyethylene bottles, stored in a cooler, and returned to the laboratory. Immediately upon delivery to the laboratory, all samples were filtered, split, and refrigerated. Alkalinity titrations were performed within 24 hours of collection. Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} were determined on acidified samples by standard atomic absorption procedures. SO_4^{2-}, Cl^{-}, NO_3^{-}, and PO_4^{3-} were determined by Ion Chromatography.

The chemical concentration data, pH, and temperature for each sample were input (Moses and Herman, 1986) to a geochemical speciation model, WATEQF (Plummer et al., 1976). This computer code, based on thermochemical data, calculates the temperature-corrected saturation state of a water sample with respect to mineral phases and the CO_2 partial pressure (PCO_2) with which the water sample is in equilibrium.

The chemical compositions at consecutive sampling points along the flow path were used to quantify the masses of calcite and CO_2 that must be transferred into or out of solution in order to satisfy the observed evolution of water chemistry. An estimate of reaction time was calculated from stream velocity and distance between sampling points. Reaction times combined with the results of the mass transfer calculations were used to calculate rates of CO_2 outgassing and calcite precipitation.

Results

Analyses show that Ca^{2+} and HCO_3^{-} dominate the chemical character of the water at every point in Warm River Cave and Falling Spring Creek. The other important ions are SO_4^{2-} and Mg^{2+} whose sources are most likely the gypsum and dolomite units lower in the Ordovician section. Na^{+} is present in low concentrations, and K^{+} is elevated relative to Na^{+} as has been observed in other geothermal waters of the area (Helz and Sinex, 1974; Hobba et al., 1979). Cl^{-} and F^{-} are present in low concentrations. NO_3^{-} and PO_4^{3-}, concentrations are all below 5 and 1 mg/L respectively.

Evolution of water chemistry

The evolution of water chemistry along the flow path in Warm River Cave and Falling Spring Creek is characterized by outgassing of CO_2 (Fig. 2). A highly charged solution issues at the thermal spring where CO_2 may first escape the hot carbonate groundwater. The partial pressures of CO_2 are extremely high near the thermal spring $-10^{-1.04}$ atm (9.1 vol %). The first two samplig locations are above the partial sump at the upstream end of the cave. As the warm stream leaves that restricted environment to flow through the more open passages of the cave, PCO_2 drops to approximately $10^{-1.80}$ atm (1.5 vol %) for the rest of the samples, including the cold stream.

The mixed stream of the cave emerges through a breakdown pile to the surface as springs that display chemical compositions similar to the cave stream. The stream from Falling Spring flows along a relatively smooth and straight stream bed for approximately 0.8 km until the falls and the smaller riffles near the top of the falls are encountered. Water turbulence forces more rapid outgassing of CO_2. The samples collected above and at the crest of the falls show significant loss of CO_2 compared to the upstream samples. The rate of CO_2 outgassing in the surface stream, after the initial surge of outgassing at the surface spring, reaches a distinct maximum at the waterfalls. Although the loss of CO_2 continues as the water flows on downstream, the creek is still slightly supersaturated with CO_2 at the farthest downstream sampling point. Approximately 8 hours elapse while a volume of water flows from Falling Spring to the last sampling point.

The loss of CO_2 from the stream leads to changes in the saturation state of the water. As CO_2 is lost, pH increases and the water becomes more supersaturated with respect to calcite. Along most of the flow path the calcium concentration decreases (Fig. 3) indicating that calcite is precipitating. The bicarbonate

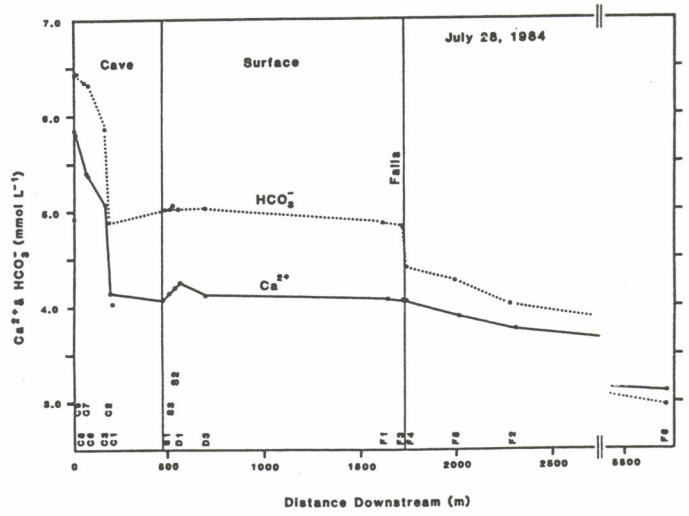

Figure 3. Millimolar Ca^{2+} and HCO_3^{-} concentrations versus distance along the flow path.

concentration decreases even more dramatically (fig. 3). Both calcite precipitatin and CO_2 outgassing are removal mechanisms for aqueous bicarbonate.

Decreases in calcium and bicarbonate concentrations also occur inside the cave (Fig. 3), indicating that some calcite is precipitating along the warm stream. Rimstone dams are observed inside the cave. However, the largest decrease in concentrations in the cave results from dilution of the warm stream by the shallow carbonate groundwater.

Physical evidence for extensive calcite precipitation exists in the travertine deposits observed in the streambed in the last 100 m above the cliff and for at least 1.0 km below the falls. However, it was only at the base of the falls that fresh white crusts were observed on everything including undecomposed leaves and twigs. Calcite precipitation occurs mainly where increased water turbulence causes more rapid outgassing of CO_2 and, thus, a great increase in the calcite supersaturation. At the crest of the falls in July, the stream is more than 15 times supersaturated. With this high degreee of supersaturation kinetic inhibitions on calcite precipitation are overcome. Calculated calcite precipitation rates show a distinct maximum at the falls at all times of the year, although the magnitude of the precipitation rate is greatest in summer.

There is a marked seasonal variation in the amounts of calcite deposited along the surface stream. The greatest amounts of travertine are deposited during the low-flow conditions of summer and early fall. In those seasons, shallow groundwater causes the least dilution of deep warm groundwater at the beginning of the flow path. Net calcite precipitation was observed for all months, but in winter and early spring there were short stretches of stream where calcite was dissolving.

Conclusions

The processes of mixing of two carbonate waters, CO_2 outgassing, and calcite precipitation all play a role in the evolution of stream water chemistry in the present study. In Warm River Cave, loss of CO_2 from a supersaturated solution, minor calcite precipitation as rimstone dams, and, most importantly, mixing of shallow groundwater with more concentrated thermal groundwater explain the observed trends in water chemistry. In Falling Spring Creek, CO_2 outgassing, especially localized in the more turbulent reaches of the stream near the waterfalls, drives the solution to high degrees of supersaturation with respect to calcite. Travertine precipitation consumes dissolved Ca^{2+} and HCO_3^- at a greater rate in the late summer and fall than in the winter and early spring, but it is rerely adequate to bring the supersaturated stream water to equilibrium with respect to CO_2 or calcite.

Acknowledgements

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Chemical composition of fracture–karst water of sulphate karsted massifs

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RESUM

La composició hidroquímica de l'aigua sub–superficial canvia en direcció vertical i horitzontal. La precipitació, amb mineralització, de 0, 18–0,51 g/l de SO_4 –HCO_3 o de SO_4 –Cl es filtra a través de la capa sòl-vegetació. L'aigua amb la mateixa composició penetra als dipòsits de les cavitats càrstiques. Trobant–se saturats de materials solubles, l'aigua canvia la seva composició i grau de mineralització. Incorpora HCO_3 –Ca i incrementa la seva mineralització. Quan es filtra en direcció vertical, l'aigua pot atravessar les roques càrstiques o circular pels dipósits de cavitats cárstiques. En el primer cas, la fàcies hidroquímica es decanta per una composició de SO_4 – Ca i la mineralització de l'aigua augmenta. En el segon cas, l'aigua circulant dels dipòsits de cavitats cárstiques conserva la seva composició de HCO_3 – Ca. Quan mesclada amb aigua de composició SO_4 –Ca, la mineralització és igual a 1-2 g./l. A la zona de trànsit horitzontal, l'aigua es filtra en la direcció del riu i es dilueix en l'aigua que penetra en el massís durant el període alt de les aigües.

RESUMEN

La composición hidroquímica de agua subsuperficial cambia en dirección vertical y horizontal. La precipitación con mineralización de 0.18-0.51 gr/l. y SO_4 –HCO_3 o SO_4 – CL se filtra a través del estrato suelo-vegetación. El agua con la misma composición pentra

en los depósitos de cavidades kársticas. Estando saturados con materia soluble el agua cambia su composición y mineralización toma HCO_3 –Ca e incrementa su mineralización. Cuando se filtra en dirección vertical el agua puede penetrar las rocas kársticas o circular en los depósitos de cavidades kársticas. En el primer caso la facies hidroquímica se decanta hacia una composición SO_4 -Ca y la mineralización del agua aumenta. En el segundo caso el agua circulante en los depósitos de cavidades kársticas conserva la composición HCO_3 -Ca. Cuando mezclada con el agua de composición SO_4 -Ca en la zona de tránsito horizontal el agua se filtra en la dirección del río y se diluye con agua que penetra en el macizo durante el período de altas aguas.

SUMMARY

Hidrochemical composition of subsurface water changes in vertical and horizontal directions. Precipitation with mineralization 0.18–0.51 gr/l and SO_4 -HCO_3 or SO_4 -Cl composition filtrates through soil-vegetation layer. Water with the same composition penetrates into karst-caving deposits. Being saturated with soluble matter water changes its composition and mineralization: it aquires HCO_3 -Ca facies and its mineralization increases. When filtrating in vertical direction water can enter karstic rocks or circulate in karst-caving deposits. In the first case hydrochemical facies turns to be of SO_4-Ca composition and water mineralizatiopn grows. In the second case water circulating in karst-caving deposits retains HCO_3 -Ca composition. When mixing with water of SO_4 -Ca composition, mineralization equals to 1-2 gr/l. In horizontal tranzit zone water filtrates in the river direction and is diluted with water entering the massif during high water periods.

Chemical composition of facture–karst waters influences greatly on karst process dynamics and depends on conditions of subsurface water circulation. Our investigations carried out on a number of gypsum-anhydrite massif (Preduralje) showed weak alkaline medium of water there. In most cases waters are of SO_4 –Ca facies with general mineralization equals to 2-3 gr/l and SO_4, Cl and HCO_3 ions content varies from 1.2-1.6 gr/l, 0.17-0.2 gr/l and 0.054-0.2 gr/l, respectively. At the same time there are the zones with general mineralization to be 3 gr/l and abnormal content of SO_4 and Cl ions. Water samples collected from individual bore-holes in Polazna village area had general mineralization more than 5-6 gr/l and SO_4 and Cl content 2.02-2.9 gr/l, and 1.2-3.6 gr/l, respectively. Abnormal mineralization zones are usually associated with outliers formed by gypsum-anhydrite rocks. This fact is vividly illustrated by the isoline scheme of Ca-SO_4 and Cl ions concentrations in fracture-karst water of Polazna massif (Fig. 1)(Pechorkina, Rekina, 1985). Gypsum-anhydrite outliers are accurately outlined by $CaSO_4$ concentration isoline at value of 1 gr/l. Towards the tops of outliers Ca+SO_4 concentration increases up to 2.2-2.4 gr/l. Depressions filled with karst-caving deposits are contoured by Ca-SO^4 concentration isoline at value of 0.06 gr/l. The same situation is observed for Cl-ions concentration. In depressions its concentration decreases up to 0.07 gr/l and sometimes even up to 0.006 gr/l; while at the tops of outliers which contours are outlined by Cl concentration isoline at values of 0.01 gr/l it increases from 0.19 up to 1.4 gr/l and sometimes it achieves 3.6 gr/l. The indices of fracture-karst water saturation with $CaSO_4$ (G) are changed in the same way and are calculated by (Plummer, Jones, Trusdell, 1975):

$$SiG = lg = \frac{a^{2+}_{Ca} \cdot a^{2-}_{SO4}}{L_G},$$

where: L_G– gypsum solubility product; $a^{2+}_{Ca} \cdot 2^{2-}_{SO4}$ activity of Ca and SO_4.

The plot (Fig. 1) shows that fracture-karst water saturation with gypsum increases from depressions to outliers. In depressions areas it varies from -2.5 up to -0.7 and is regularly increased with the increase of absolute elevation of gypsum-anhydrite rock roof. On the slopes of outliers it averages about O, varying from -O.4 up to +1. However with the increase of elevation mark of the roof, i.e. with the increase of depth of gypsum-anhydrite rock accurrence, the tendency in increasing saturation index is observed. It is believed that partial discharge of highly mineralized supersaturated with $CaSO_4$ waters from gypsum-anhydrite outliers and their mixing up with waters from karst-caving deposits take place at the elevation mark of 115-125 m. In most cases waters circulating in contour of outliers are supersaturated with $CaSO_4$: G varies between -0.05 and +0.8. The above said gives grounds to conclude that at the given stage of karst process development outliers are considered to be the areas of the most intensive karst process development.

In karst-caving deposits filling depressions developed between the outliers formed by Irensky gypsum rocks, conditions of subsurface water circulation change to the worse. Fracture-karst waters are mixed here with fracture-stratal and fracture-ground waters of HCO_3 -Ca composition. This fact is confirmed by water samples collected in karst-caving deposits (Polazna village) 30-40 m below the surface. General mineralization of the samples does

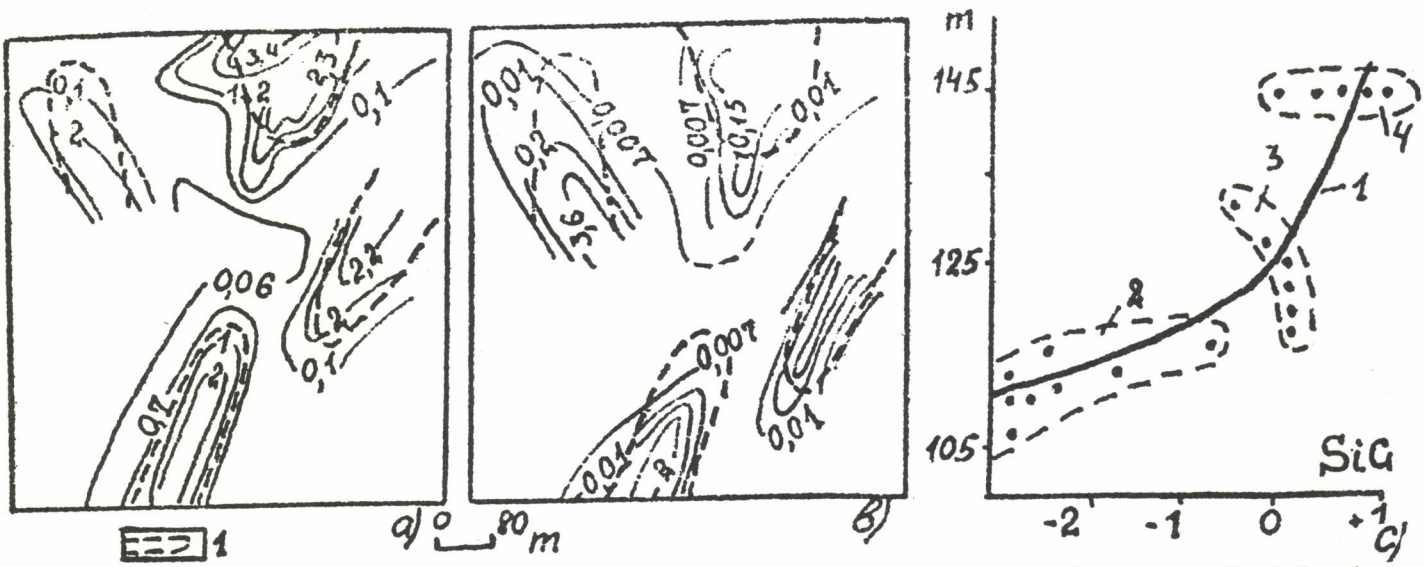

Fig. 1. Concentration isolines: a-for Ca+SO_4 content in Polazna area (mg/l); b-change of fracture-karst water index of saturation with gypsum (G_1)depending on the depth of ocurrence of gypsum-anhydrite bed roof; 1-the general tendency; 2-bottoms of depressions; 3-slopes of outliers; 4-tops of outliers (indices of water saturation are calculated by A. V. Leknov)

not exceed 1 gr/l and varies in the range of 0.32-0.77 gr/l; SO_4 and Cl content decreases up to 0.019-0.38 gr/l and 0-0.19 gr/l, respectively. Hydrochemical facies is found to be same or changed by HCO_3–Ca. All in all, mineralization increases with depth. In the shoreline zone of the water bodies it is decreased because of mixing with waters entering from the water body.

In Kungur city area formed by gypsum-anhydrite beds 25-35 m thick interbedded with dolomite bands main components content variations of fracture-karst waters chemical composition have been studied both in vertical an horizontal cross- sections. Thickness of dolomite overlying gypsum-anhydrite rocks varies from 20 up to 5 m. In some places dolomites are completely ruined and from karst-caving deposits. Soluble rocks are covered by sandy-clayley deposits 20-30 m thick (Fig. 2).

When comparing the plots of Ca, SO_4, Ca+SO_4 variations along the strike of gypsum-anhydrite bed with geological cross-

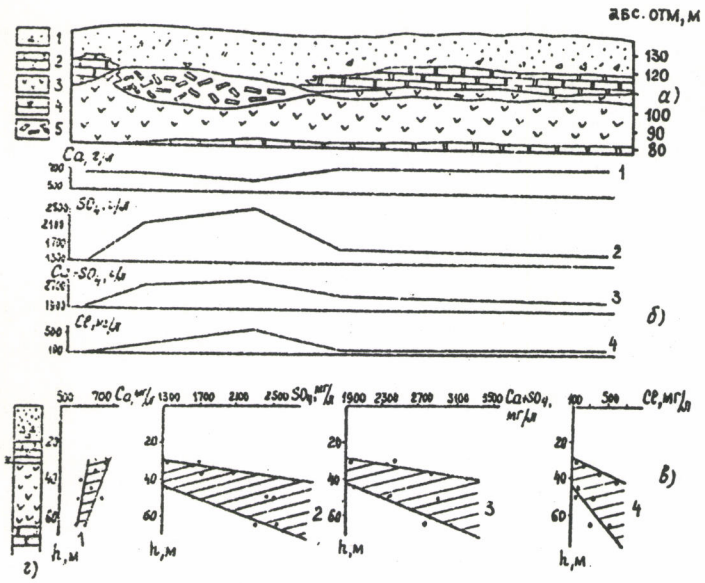

Fig. 2. Change of main components of fracture-karst water chemical composition for Kungur area: a-geological cross-section; 1-sandy-clayley deposits with gruss and debris of dolomites; 2- dolomite; 3- gypsum-anhydrite rocks; 4-subsurface water level; 5-karst-caving deposits; change of concentrations: 1-Ca; 2-SO_4; 3-Ca+SO_4; 4-Cl along the strike of gypsum-anhydrite rock at the elevation mark of 98 m; 5-Cl with depth (h, m); c - generalized geological cross-section of the area.

section of the area, the following law-governed regularities can be easily distinguished (Fig. 2). Ca content of subsurface water is in the range of 620-800 mg/l, minimum content is found in places where gypsum-anhydrite rocks are overlain by karst-caving deposits and karst water level is at the minimum elevation mark. The content of all the rest components of subsurface water chemical composition is maximum. The composition is maximum. For instance, if overlying deposits of dolomite are 20-15 m thick, SO_4, Ca+SO_4 and Cl content in subsurface waters is 1.32-1.68 gr/l, 2.1-2.5 gr/l and 0.15-0.2 gr/l, respectively; if dolomites overlying gypsum-anhydrite rock are 5 m thick, so SO_4, Ca+SO_4 and Cl content is 2.5, 3.1 and 0.65 gr/l, respectively.

It is possible that increase of karst-water mineralization beneath karst-caving deposits is due to retard circulation resulted from joints colmatage in the upper part of gypsum-anhydrite rocks by the products of distruction of the overlying rocks.

When analysing plots of variations of subsurface water chemical components with depth (Fig. 3) a certain decrease of Ca concentration in the foot direction of gypsum-anhydrite bed is observed. It being know that Ca concentration at the cap of bed changes from 0.66 up to 0.76 gr/l, while at the foot –from 0.58 up to 0.64 gr/l, i.e. the domain of Ca concentration variations decreases with depth. Quite different situation is observed for SO_4 and Ca+SO_4 ions which concentration increases significantly with depth. Depth intervals for which concentration of these ions constant are also increased. For instance, SO_4 content to be 1.300 gr/l, depth interval makes about 15 m (30-45 m below the surface) while for SO_4 content to be 2.6 gr/l, depth interval increases up to 25 m (40-65 m below the surface). The same depth intervals form which minimum and maximum concentrations are constant have been obtained for Ca+SO_4 and Cl ions.

Thus there are two levels where mineralization of subsurface water circulating in gypsum-anhydrite bed is changed. The first level is in depth interval 30-40 m below the surface and coincides with the upper part of gypsum-anhydrite bed 10-12 m thick. The second is in the depth interval 40-65 m below the surface and it is associated with the lower part of gypsum-anhydrite bed 25 m thick. It worth mentioning in this connection that the change of SO_4, Ca+SO_4 and Cl content is more intensive in the upper level than that in the lower one. This phenomenon can be explained by penetration of slightly mineralized waters from aeration zone into the upper level.

Significant changes in fracture-karst water mineralization have been observed in Kungur Ledjanaja (Ice) Cave area. During high water periods water from the Sylva River enters the massif and decreases intensive solution of rock at the level of aquifer. The process is the most active in the entrance part of the cave (Fig. 3). Fig. 3 shows that when moving down into the massif $CaSO_4$ content in water increases and in 150 m distance away from the river it makes 1.67 gr/l i.e. 0.01 gr of $CaSO_4$ is dissolved at 1 m of route. 250 m away from the river $CaSO_4$ content is 1.9 gr/l. In this interval 0.009 gr of $CaSO_4$ is dissolved in 1 l of water. It shows that the intensity of karst process development is 10 times decreased.

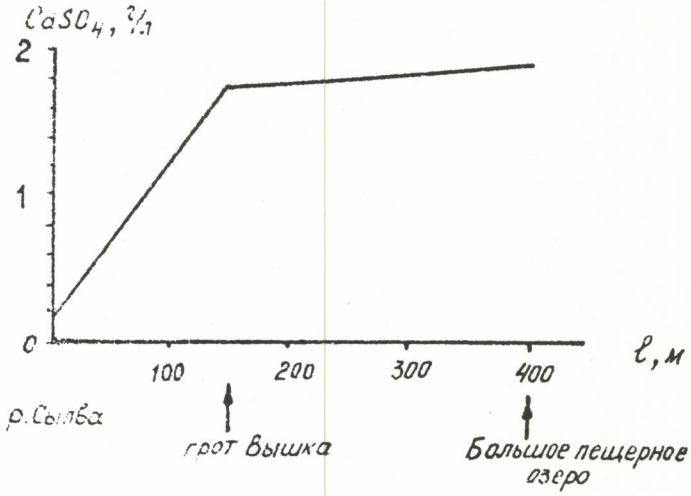

Fig. 3. Change of $CaSO_4$ content depending on the distance from the water edge of the Sylva River during high water period in 1974 (data by V. S. Lukhin and E. P. Dorofeev

Thus hydrochemical composition of surface water is changed both in vertical and horizontal directions. Atmospheric precipitation with mineralization varying from 0.18 up to 0.51 gr/l and SO_4-HCO_3 or SO_4-Ca composition filtratres through soil-vegetation layer. In most cases water passed through this layer retains its SO_4 -HCO_3 or SO_4-Ca facies. Then water retaining the same composition penetrates into karst-caving or overlying deposits: beig saturated with soluble matter water changes its composition and mineralization. Water acquires HCO_3-Ca facies and its mineralization increases up to 0.23-0.35 gr/l. When filtrating in vertical direction, water can enter into karstic rock (in the areas of outliers) or circulate in karst-caving deposits (in the low areas between the outliers). In the first case hydrodynamic facies turns to be of SO_4-Ca composition and water mineralization gradually grows up to 2-3 gr/l. In the second case water circulating in karst-caving deposits retains its HCO_3-Ca composition. Mineralization increases very slowly and at first it equals to 0.7 gr/l, then at a point of mixing with water of SO_4-Ca composition mineralization increases up to 1-2 gr/l. Hydrochemical facies is changed to be of SO_4-Ca composition. When getting into horizontal tranzit zone, karst water of SO_4-Ca composition filtrates in the river valley direction. In the areas adjoining to the river

valley this water can be diluted with water entering the massif during high water periods. The above mentioned shows how complex and multiform is the hydrochemical situation of karst gypsum-anhydrite massifs.

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Les Karst du Burnot

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RESUM

Quan les aigües de la vall de Burnot van excavar el seu llit sobre les calcàries Givecianes, un carst abandonat va començar a reactivar-se en nombrosos punts. L'any 1978 es va dur a terme un estudi geològic complet, mentre equips espeleològics identificaven un sistema molt ric i dens que recobria una superfície de més de 20 km². Durant aquest reconeixement es varen comptabilitzar 21 engolidors que comunicaven amb la capa d'aigua. A Bois-de-Villers, després d'haver-se emplenat un engolidor amb immundícies, es va detectar la conseqüent pol-lució. L'estudi afectuat pretén evitar, en el futur, noves formes de contaminació.

RESUMEN

Desde que el valle de Burnot excavó su lecho en las calizas Givecienses, un antiguo Karst se reactivó en numerosos lugares. En 1978 se realizó un estudio geológico completo, mientras que equipos espeleológicos reconocían un sistema muy rico y denso que cubría una superficie de más de 20 km². En este reconocimiento, se contaron 21 sumideros que comunican con la capa de agua. En Bois-de-Villers, después del terraplenado de un sumidero por inmundicias, se detectaron las poluciones características. El estudio debe impedir esas poluciones en el futuro.

SUMMARY

Since the Burnot valley has digged out its bed into the Givetian limestone, an old karst has been regenerating on numerous places. A complete geological study has been conducted in 1978 while speleological teams were exploring a very valuable and dense tracery covering more than 20 km². In this exploration 21 collector wells connecting to groundwater have been counted. At Bois-de-Villers characteristic pollutions due to collector wells filled in with dirt have been recorded. This establishement must prevent these pollutions in future.

Nous voudrions vous dire combien les relations entre la surface et la nappe karstique du BURNOT rendent sensibles les problèmes de cette nappe.

L'historique de ce karst, en partie réactivé au quartenaire, doit être fait si l'on veut y comprende le fragile équilibre qui régit ses circulations d'eau aujourd'hui.

Etage du Dévonien Supérieur, Givétien et Burnatien il fait partie d'un ensemble de calcaires récifaux qui alternent avec des grès marins assez grossiers et très métamorphosés.

Lors des diverses orogénèses qui façonnèrent le Condroz, les Ardennes et tout le Sud de la Belgique, ces masses calcaires furent plusieurs fois érodées par des eaux de surface, et grâce à une fracturation avancée, une première série de dissolutions encore visibles à flanc de coteaux ouvrit des cavités d'une importance moyenne.

Plusieurs de ces cavités furent utilisées par des populations du néolithique, comme des vestiges osseux ont permis de la constater à Profondville.

Depuis la fin de la dernière glaciation, et surtout depuis le surcreusement de la vallée de la Meuse et de ses affluents dont le BURNOT une intensification notable de la karstification s'observe dans tout le bassin.

La vilaine source en est un élément inconstestable.

Parmi les éléments sensibles du système décrit ci-dessus et dont toute observation de la carte géologique donne une confirmation rapide, nous fournirons surtout les exemples des chantoirs du plateau de Bois de Villers qui commencèrent à s'enffondrer lors de l'intensification de l'agriculture. La forte fumure azotée, les chlorures potasiques et autres produits chimiques contribuèrent fortement á l'accélération de la dissolution dans le sous-sol.

Si l'on ajoute à cela que le déboisement à augmenté le ruissellement et amené au fond des dollines d'importantes quantités d'eau acide, on comprendra que le processus de karstification ne pouvait que s'accentuer rapidament et aller jusqu'à l'effondrement des voûtes calcaries..

Pour pallier aux désagréments de ces effondrements, les cultivateurs eurent recours à des remblais divers: briques, gravats, béton... et jusqu'aux dépouilles de leurs animaux domestiques.

Ces dernières ne pouvaient certes plus apporter une garantie de solubrité à l'eau souterraine s'écoulant du massif; mais les autorités locales et régionales ont encore agravé la situation jusqu'à y conduire les égouts des villages et les déchets domestiques dont on ne savait se défaire dans la région. De nombreuses équipes spéléologiques ont découvert des détritus jusqu'a 3.000 en aval des points de rejets.

Aussi, nous voulons profiter de cette tribune pour montrer jusqu'où peut aller la sottise de techniciens qui ne connaissent pas le mécanisme des eaux dans les massifs karstiques. Il faut qu'un plan d'ensemble puisse garantir la protection des eaux dans le futur.

Conservation problems in underwater cave environments

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RESUM

Arran de la creixent exploració (i explotació) dels sistemes hidrogeològics càrstics del medi ambient d'aigua dolça i del medi mari, s'ha plantejat la necessitat d'endegar una estratègia per a la conservació d'aquests medis, de manera que sigui possible de preservar-los per al seu estudi científic abans no es vegin irreversiblement alterats per l'impacte humà.

En alguns casos concrets (p. ex, la Lucayan Caverns de Gran Bahama) ja s'ha considerat la necessitat d'arbitrar mesures per a la seva utilització, però són moltes les coves potencialment amenaçades. Aquest treball intenta definir els aspectes d'aquestes cavitats que poden merèixer un estudi més minuciós, els problemes que afecten aquests ambients i els problemes inherents a la conservació i manipulació d'aquests hàbitats naturals.

RESUMEN

Con la creciente exploración (y explotación) de los sistemas hidrogeológicos kársticos en el medio ambiente del agua dulce y marina, se ha desarrollado la necesidad de estrategia de conservación general para conservar este medio ambiente, en tal sentido que se puedan estudiar sus variados aspectos científicos de primera mano y antes de que sean demasiado alterados por el impacto humano.

En algunos casos individuales (ej. Lucayán Caverns de Gran Bahama) ya se han considerado necesarios los métodos de utilización. Aparecen otros casos potenciales. Este trabajo trata de definir los aspectos de tales cavidades que pueden merecer un estudio más detallado, los problemas que afectan estos medios ambientes, y los problemas que podrían afectar la conservación y manipulación de estos hábitats naturales.

SUMMARY

With the growing exploration (and exploitation) of underwater cave systems in both fleshwater and marine environments, there has developed a need for a general conservation strategy to preserve such environments, in such a way that their various scientific aspects can be studied at first hand before they become too greatly altered by human impact.

In certain individual cases (eg. Lucayan Caverns of Grand Bahama), management policies have already been deemed necessary. Other potential cases are emerging. This paper attempts to define the aspects of such caves which might deserve more detailed study, the problems that affect such environments, and the problems that might affect conservation and management of such natural habitats.

Introduction

Major underwater cave systems have been found in only two rock types, lavas and limestones. Lava tubes are generally long single passages that may extend for several kilometres, but which offer a limited scope for faunal diversity. There are exceptions to this rule, which suggest they deserve consideration within this study (Wilkins and Parzefall 1974). Limestone caves can form in a variety of complex three-dimensional structures, and are more common by far than lava tunnels. Both types can contain freshwater and/or saltwater and can, according to various physical and biological parameters, offer a variety of transient or established underwater habitats.

Exploration of underwater caves began seriously with the development of SCUBA (Self-Contained Underwater Breathing Apparatus) in the 1930's and 40's. Comprehensive and serious scientific exploration of the environments presented by purely underwater cave systems began much later, after several decades of predominantly physical exploration of underwater cave passages, usually with the intent of discovering dry, air filled passages beyond a flooded section of river cave (Farr 1980).

In the past two decades, there has been a developing interest in the environment of completely submerged cave systems in all parts of the world. Classic examples of those under current study include anchialine caves from Bermuda and the Bahamas (Iliffe 1981, Palmer et al 1984 Cunliffe 1985), Yugoslavia and the Yucatan Peninsula of Mexico (Back, Hanshaw and Van Driel 1984). These caves offer a cryptic environment of great biological importance to both freshwater and marine biologists, and can be regarded as unopened scientific warehouses of undiscovered knowledge. It is becoming obvious, however, that continuing human impact by both divers and diverse commercial interest is having a negative effect on the stability of such underwater ecosystems.

Underwater cave systems are of scientific interest in several ways, and can offer much to the scientific community. In biological terms, they can provide a great deal of information on the behaviour of known organisms in a tightly-defined underwater environment, as well as offering a new and cryptic environment, containing a little-studied and exciting fauna for original research purposes.

Underwater cave systems, in some instances, provide a direct access to the underground freshwater lens of islands. This offers an unusual opportunity to study the internal workings of such a resource, and to directly monitor the effects of groundwater pollution. Geologically, they offer a first-hand opportunity to observe the mechanics of karst development within the phreatic zone of a limestone mass.

Finally, there is a limited but definate recreational potential for such underwater caverns, because of the sheer beauty and drama of their environment. To ensure that such useage is both safely managed, and offers little or no detramantal influence to major sites, is of primary importance. A conservation and management policy is no light undertaking.

Major factors presently influencing underwater caves:

a) Groundwater pollution from commercial and social sources: This can affect both cave biota and local groundwater potability. An inteconnecting cave system with tidal or drainage currents can disperse pollution for considerable distances from the point of entry into the water table, with a resulting detramental effect on both cave environment and the long-term quality of freshwater resources.

b) Groundwater removal. Removal of artesian water without a full understanding of water movement and replacement within

the aquifer can harm not only the local cave environment, but the future resource potential for freshwater from that area. Where a cave acts as a major drainage/tidal conduit, local removal of water can affect resources many kilometres distant. Life within an anchialine cave can be adversly affected by even slight changes in water chemistry so discrete are the parameters involved in its survival.

c) Quarrying/Surface Development: careless planning of quarrying operations, allowing them to interfere with underground drainage routes, can seriously affect cave life and water movement within a freshwater lens or phreas. The removal of established surface flora can seriously disrupt the flow (or curtail it) of organic material into the caves below. This has a correspondingly negative affect on the cave fauna, whose primary energey input this is.

d) Human Impact: Divers entering a cave system can impact the environment theirin in many ways. Direct removal of speleothems or sediments has a deliterious effect both on the visual quality and local passage environment of the cave. Continual disturbance of sediments on a regular basis may lead to a disruption of established biotic habitats. Disturbed sediments might be transferred for a considerable distance from their original site by current flow. Such physical damage is accentuated tremendously when cave passages are used for training sites for divers not yet experienced in the extreme diving techniques necessary for underwater cave exploration. Training should not take place in a significantly important cave site.

The factors affecting the quality of the underwater cave environment can be summarised as follows:

a) Biological problems:
- Direct physical damage to fauna/sediments (eg. diver clumsiness).
- Damage to established sediments.
- Defoliation or damage of surface environment.
- Groundwater pollution.
- Salinity changes due to freshwater extraction.
- Scientific over-collection of limited faunal populations by divers.

b) Hydrological problems:
- Alteration to groundwater movement patterns by quarrying/ land development.
- Salinity changes due to freshwater extraction.
- Groundwater pollution.
- Intermixing of stable water layers by divers.

c) Geological problems:
- Speleothem removal.
- Sediment disturbance.
- Removal of overburden (eg. quarrying / deafforestation / building) causing an effect on sedimentation/future development.
- Direct quarrying of caves.

Other local pressures in each category may exist on specific cave systems or in particular ethnic or social areas. Any cave management policy must leave room for improvisation in particular cases.

Conservation policies

Cave conservation might involve either a specific reaction to a particular event or problem regarding a specific cave site, or it might more ideally be an anticipatory reaction to protect particularly significant systems before problems arise.

The formation of well-qualified consultancy groups (eg. the existing IUCN Red Data Book groups) to establish an outline conservation policy for underwater cave habitats is a primary essential. It is important that such groups in each case should be representative of all the facets of management and conservation involved, and that such groups should have the power to co-opt members in response to particular problems to allow unbiased strategies to be worked out in each individual case. Ideally such groups should be in a position to report directly to a national or international body which has the authority to implement the decision. No management policy, however well-designed, is of any real worth unless the designating body has a real power to implement it. Penalties to deter offenders might range from a ban on individual persons, to heavy fines or imprisonment for individual or corporate offending bodies. They MUST be of sufficient force to deter offenders, and MUST be implemented.

Within any country, control can vary in both quality and efficiency. With complex cave sites, especially inland, it is vitally important to preserve both the cave and its related surface environment intact, as the biology of the cave is related to, and dependant upon, its biotic overburden. The same may well be true of marine underwater cave sites –their internal biology is a reflection of the conditions generated by the seafloor environment in their immediate vicinity (Warner and Moore, 1984). Conservation of such underground environments must take into account the relationship of the cave to its surface environment.

It is recommended that an international catalogue of underwater cave sites be established, together with some form of grading system by which sites of significant biological or geological importance can be identified. Governmental and international policies should be sought to allow sites to be protected as they are discovered. Suggested qualifications for inclusion in such a list might include:

a) Biological content: does the cave contain a diverse or particularly significant population of cave-adapted fauna? Is there a rare or significant biological aspect to the cave? Is the biotic overburden of the cave unmodified by man?

b) Hydrology: does the cave contain features of distinct hydrological significance (eg. currents, haloclines)?

c) Geology: does the cave contain significant geological features? Does it exhibit classic developmental features which might offer potential for geological study? Is it still actively forming? Does it contain important speleothem deposits?

d) Is it in immediate danger of human/commercial impact?

The listing of designated Protected Sites should be open to constant revision, and sites re-classified accordingly as exploration of underwater caves continues. Serious scientific exploration and study by qualified cave divers should be encouraged. It is further suggested that a site be chosen for a research centre to be established to further promote and co-ordinate the study of underwater caves. Such a centre would have internacional significance, and could be run on a self-funding basis as a cave and marine research centre.

Conclusion

Underwater caves are an important and little studied geological phenomena of international significance. An effective and sustainable conservation and management strategy is essential for future scientific, economic and commercial development and exploration. Such a conservation strategy should have official international recognition, and should be implemented by an authority or authorities with sufficient power to ensure its success.

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Hazardous Fumes Rising from Contaminated Cave Streams

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RESUM

El març de 1985, l'United States Centers for Disease Control va publicar un advertiment adreçat a la zona de Bowling Green (Kentucky), contra els gasos potencialment tòxics i explosius procedents dels corrents càrstics contaminats, que afectaven a cases i edificacions. Com a conseqüència d'aquesta crida la U.S. Enviromental Protection Agency Emergency Response Team (Superfund) va reunir diversos instituts estatals i locals, amb el propòsit de resoldre el problema. El Dr. Nicholas Crawford i el Center for Cave at Karst Studies at Western Kentucky University foren emplaçats per la EPA i la ciutat de Bowling Green per a col·laborar en la investigació.

Les activitats de la investigació i correcció que s'han dut a terme fins ara han suposat: a) l'aireig de les coves per mitjà de ventiladors comunicats per tubs instal·lats dins de canalons excavats a la roca. b) La inspecció exhaustiva dels abocadors de productes químics, llençats deliberadament a fonts i avencs, abocaments accidentals i filtracions de tancs subterranis d'emmagatzament i c) una investigació dels recorreguts dels corrents superficials i de les cavitats mitjantçant colorimetria, microgravetat, perforacions d'exploració i topografia de coves.

RESUMEN

En Marzo de 1985 el United States Centers for Disease Control publicó una advertencia para la zona de Bowling Green, Kentucky, contra los gases potencialmente tóxicos y explosivos procedentes de corrientes kársticas contaminadas, que alcanzaban casas y edificaciones. La acción de advertencia iniciada por la U.S. Environmental Protection Agency Emergency Response Team (Superfund), reunió agencias estatales y locales con intención de resolver el problema. El Dr. Nicholas Crawford y el Center for Cave and Karst Studies at Western Kentucky University, fueron empleados por EPA y la Ciudad de Bowling Green para colaborar en la investigación.

Las actividades de investigación y corrección hasta ahora excluyen lo siguiente: a)aireación por medio de ventiladores comunicados por tubos instalados dentro de grietas de los estratos, que aparecieron por excavación: b) una inspección extensiva de las fuentes de los productos químicos que fueron arrojados deliberadamente a manantiales y sumideros, derrames accidentales y falta de estanqueidad en tanques subterráneos de almacenaje, y c) una investigación de los recorridos de las corrientes superficiales y cavidades mediante coloración, micro-gravedad, perforaciones de exploracion y topografía de cuevas.

SUMMARY

In March, 1985 the United States Centers for Disease Control inued a health advisory for the Bowilng Green, Kentucky area due to potentially toxic and explosive fumes rising into homes and biuldings from contaminated cave steams. The adivisory initiated action by the U.S. Enviromental Protection Agency Emergency Response Team (Superfund), who joined state and local agencies in an attempt to solve the problem. Dr. Nicholas Crawford and the Center for Cave and Karst Studies at Western Kentucky University were employed by EPA and the City of Bowilng Green to assist with the investigation.

Research and corrective activities to date include the following: a) ventilation by fans attached to pipes extended into bedrock crevices which were exposed by excavation; b) an extensive search for the sources of the chemicals which have included deliberate dumping into wells and sinkholes, accidental spills, and leaking underground storage tanks; and c) an investigation of subsurface flow routes and caves by dye tracing, micro-gravity, exploratory drilling and cave surveying.

The Pollution of the karstic Ground Water; the Example of Krupa

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RESUM

En l'última dècada s'han dut a terme una sèrie d'investigacions exhaustives a la zona de la surgència de Krupa, situada al sud d'Eslovènia, que creiem interessant de referir ja que tracten una metodologia d'interès en els treballs d'investigació càrstica.

A més d'un estudi hidrològic efectuat l'any 1981 i d'una sèrie de mesures de la descàrrega de la surgència, es va dissenyar un mapa geològic d'escala 1: 25.000, amb foto geològica. Alhora, es va confeccionar un mapa hidrològic, inventariant tots els fenòmens hídrics permanents o periòdics, amb freqüències de descàrrega i dades altimètriques.

Es varen investigar també els engolidors de la zona tributària més propera, així com els punts de pol·lució i abocadors que van poder ésser localitzats.

Alguns dels fenòmens hídrics es van estudiar amb més detall; entre ells l'embassament de la font de Krupa, que fou revisat mitjançant un taquímetre. També va ésser estudiat sistemàticament i hidrològica durant dos anys i explorat per escafandristes.

El test de coloració de la depressió del torrent de Vrčica no va oferir dades molt segures sobre el recorregut subterrani. Es poderen observar indicis de coloració, no molt fiables, a les surgències pròximes a Črmošnjica. Es varen efectuar anàlisis químiques, bacteriològiques i biològiques de les aigües. Sobre aquesta base, la idea era que el tributari principal de la surgència de Krupa calia buscar-lo molt més cap el nord i que el poble de Semič no rebia influències directes sobre la qualitat de l'aigua en els nivells inferior i mitjà.

Una extensa zona fracturada va de Vrtača fins a Krupa, alguns kms. al N.E. de Semič.

La pol·lució del PCB (bijenils policlorinats) va resultar que era produïda a la planta de condensadors elèctrics de «Iskra» a Vrtača, prop de Semič.

La pol·lució de l'aigua càrstica subterrània: el cas de Krupa (N. de Iugoslàvia).

Las investigaciones extensivas en la zona de la surgencia de Krupa, situada en el Sur de Eslovenia, han sido realizadas en la última década. Habría que citarlas como una metodología significativa para el trabajo de investigación kárstica.

Además de un estudio hidrológico efectuado en 1981 y medidas periódicas de descarga de la surgencia se levantó un mapa geológico de escala 1:25.000 con foto geológica. Al mismo tiempo se confeccionó un mapa hidrológico inventariando todos los fenómenos hídricos permanentes o periódicos con frecuencia de descarga y datos de altitud.

Se investigaron todos los sumideros de la zona tributaria cercana, así como tantos puntos de polución y vertederos como pudieron ser localizados.

Algunos de los fenómenos hídricos se estudiaron con mayor detalle y entre ellos el embalse de la fuente de Krupa, que fue revisado mediante taquímetro, así como también se observó sistemática e hidrológicamente durante los dos años. El embalse de Krupa fue recorrido por escafandristas.

El test de coloración de la depressión del arroyo de Vrčica no ofreció datos seguros acerca del recorrido subterráneo. Se observaron indicios de coloración que no eran de fiar en las surgencias cercanas a Črmošnjica. Se efectuaron tres análisis de aguas, químicos, bacteriológicos y biológicos. Sobre esta base la idea era que el tributario principal de la surgencia de Krupa debería buscarse muy hacia el Norte y que el pueblo de Semič no recibía influencias directas sobre la calidad del agua en el nivel inferior y medio.

Una vasta zona fracturada conduce desde Vrtača hacia Krupa, algunos kms. al N-E de Semič.

La polución de PCB (bifenilos policlorinados) resultó producida por la planta de condensadores eléctricos de «Iskra» en Vratča, cerca de Semič.

SUMMARY

Extensive researches within the range of the spring Krupa situated in the south of Slovenia were conducted in the last decade. They should be mentitioned as a significant methodology for the karstic research work.

Beside a hydrological study made in 1981 and periodical discharge measurements of the spring a geological map on the scale of 1:25 000 with photogeologucak ubteroretatuib was made. Simultaneously a hydrogeological map was made and all permanent or periodic water phenomena with the renewed discharge and altitude measurements were inventoried.

In the near tributary all the sink-holes were investigated and as many poluters and dump hills as possible were tried to be discovered.

Some of the water phenomena were researched more in detail among them the pool of the spring Krupa which was noted tachymetrically as well as observed sistematically and hydrogeologicaly during the two years. The pool of Krupa was researched by cave divers.

The colouring test of sinking brooklet Vrčica gave no sure data about the underground runoff. Unreliable colour traces were observed in the springs near Črmošnjica. There were numerous chemical, bacteriological, biological analyses of waters made. On that basis the idea was that the main tributary of the spring Krupa should be searched for towards the north, and that the village Semič has no direct influence on the quality of water at the low and middle water stage.

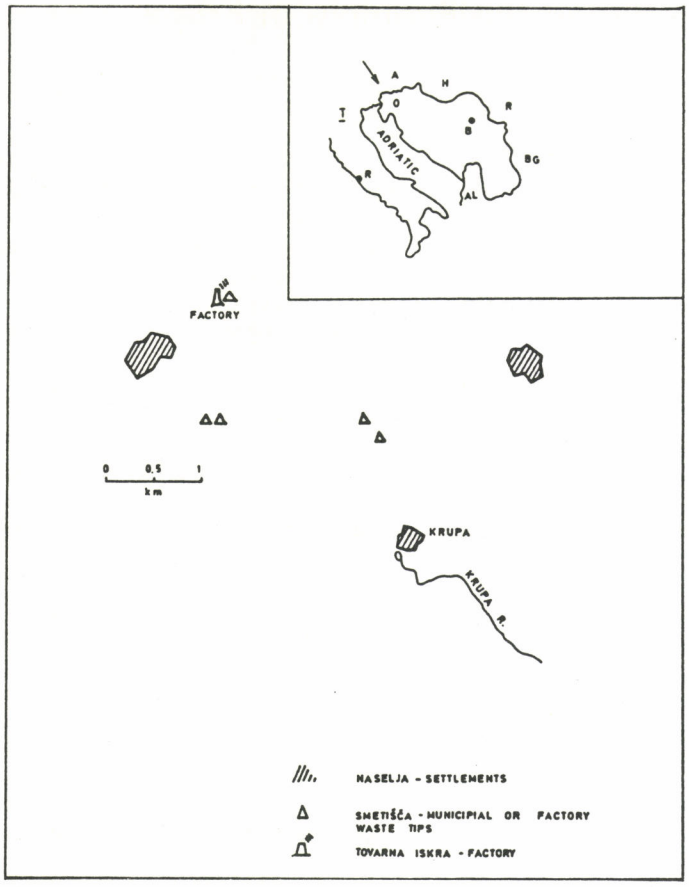
A very large fractured zone leads from Vrtača towards the Krupa some kilometers to the northeast from Semič

The pollution with PCB (polychlorinated biphenyls) caused by «Iskra» electrical condensators plant at Vrtača near Semič was found.

In the southern part of Slovenia (N Yugoslavia), Krupa is one of the largest springs on Karst.

The geological structure and various conceptions in its interpretation were dictated by yearlong researches and the application of other methods. Namelly the spring was becomming more and more important because of the provision of karst area with water. From the economic point of view this area was owing to the lack of water more and more behind.

Bacteriological analyses which have been done from time to time at the location of the spring were not in accordance with



normatives what is no exception in the case of karstic springs. They showed faecal pollution and too many germs in water. In the close hinterland of the spring there are villages, fields, vineyards. Water was being troubling from time to time and so at the middle water table we selected in December 1982, 1.8 mg/l of suspended material, at higher water table in October, 226 mg/l (of suspended material).

Two decades ago in the years 1964-65 we were systematically observing some components of physical-chemical regime of the spring. The temperatures were stabilized at about 10°C, carbonate resp. total hardnesses are high and are distinctly changing regarding the external circumstances:

Hardnesses

carbonate	total
10.2-13.2° dH	10.2-16.8° dH

In october, November, and April we noticed the climaxes in hardnesses, whereas in February, March and during the summer months i.e. July and August, the hardnesses were the lowest. The quantity of Cl-ion is increasing especially in February in accordance with precipitations wich are bringing moisture from the seaside, and the winter salting of roads may reflect here as well. The karstic ground water appears at the depth of about 30 m below the surface.

After some later chemical analyses it was not possible to estimate greater chemical or organic pollution. All values were within the permissible normatives, yet at that time we did not search for less common substances in water.

The periodical increase of Fe and Mn quantity in water occured due to the washing these elements out of soil after precipitations. The increased periodic ocurrence of nitrates is conditionned mostly by the incorrect manuring (too much organic manure or the usage of liquid manures at the unsuitable time).

Certain analyses have presented certain rise in quantities of Zn, Pb, and Cd what does probably not originate from the agricultural activities.

The direct hinterland of the spring is composed of the limestone with the intercalations of dolomite. More distant surrounding has in its structure as the basic elemet the triassic dolomite which is probably thrusted over the younger limestone. In the hinterland there are some agricultural settlements and one major place, Semič, and vinicultural region of Semič Breg. Only about 20 % of the surface is such where we could expect more intense agrotechnical measures and owing to that the pollution of the ground water. The soil is very heterogenous and so is the agricultural production. The washing out of substances is possible from the brown post-carboniferous soil, whereas the sink-holes with legal or illegal municipal or factory waste hills are dangerous. The soil is heavier and the absorbtivity with great capacity is possible, however the pH is low and the permeability is high. We also established that in the present condition the usage of agricultural chemicals, fertilizers, biocides etc. did not reach such quantity that some elements in water would surpass the allowed quantity.

Numerous data are confirming the supposition about the special separated ground water current which is draining the water off the Semič area towards the South so that the Krupa spring is not directly affected. Nevertheless the analyses of water and sediments indicated that Krupa spring was affected by the pollution with polychlorated bifeniles (PCB) as a result of the industry producing condensors which is located few km away in the settlement Vrtača, directly in the area of the fault, connecting the factory with the spring.

The factory has been rather inconsistently taking care of the protection of its enviroment. Few years ago the wastes were heaping up in the nearby sink-holes, whereas the residual waters are now also flowing into nearby sink-hole what means polluted underground for many years.

Iskra started its production in the year 1962 and it reached the climax in the consumption of material (200 tons) in the year 1970.

Nor municipal nor agricultural pollution but in this case the difficulty and the problem is right in industrial pollution and in (illegal) waste pits for which we do not know vhere they are now because they have been overgrown by vegetation. The polluted sediments in the underground cannot be mechanically cleaned in the forseable future.

One can draw a conclusion that on karst area special attention should be payed at industrial plants and at pollution which is specific for smaller plants. The pollution of water on karst is spread over great distances and rather quickly; there are no self-cleaning processes. The substances heavier than water are deposited in the underground also in sediments.

Further explorations are directed towards the limitation of the polluted area and towards the searching for the best location outside this area where we could by means of borehole capture the necessary quantity of unpolluted water. For that reason the detailed geological mapping and the appropriate geophysical explorations should be applied.

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Teneur en CO_2 de l'air de quatre grottes de hongrie

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RESUM

A principis d'estiu de l'any 1985 es va mesurar el contingut de diòxid de carboni de l'atmosfera de quatre coves d'Hongria. Es van efectuar al voltant de 70 anàlisis.

Dues de les coves es trobaven situades als Carpats meridionals, on aquests presideixen la depressió panoniana; les altres dues a Budapest mateix.

A la muntanya de Bückk, al N.E. de Budapest, la cova de Létrási-Vizes donà un contingut mig de CO_2 de l'ordre de 600 ppm. prop de l'entrada i entorn de 1.100 ppm. un xic més lluny (total mesures: 36).

Dues coves hidrotermals foren també estudiades a Budapest: la cova de Pal-Völgyi, de recorregut laberíntic, presenta un contingut mig de CO_2 de l'ordre de 700 ppm. (13 mesures) i la de Jòzsef-Negyri, geoda meravellosa, de 1.200 ppm. a les galeries i pous, i de 1.700 a les fissures. (10 mesures).

Finalment, al S.O. de Budapest, a les muntanyes Bakony, dominant el llac Balaton, la cova d'Alba-Regia presentava, en el petit sector on vàrem efectuar 10 anàlisis, un contingut mig molt elevat: 3,2 %.

Paroxalment no és a cap de les dues coves que presenten una morfologia o be dipòsits d'origen hidrotermal on es troben actualment els majors índexs de CO_2.

RESUMEN

A principios del verano 1985 se han efectuado medidas del contenido de diòxido de carbono de la atmósfera en cuatro cuevas de Hungria. Se han realizado alrededor de 70 análisis.

Dos de las cuevas estaban localizadas en los Cárpatos meridionales, allá donde éstos dominan la depresión panonina y otras dos en el mismo Budapest.

En la montaña de Bückk, al NE de Budapest, la cueva de Létrási- Vizes mostró un contenido medio de CO_2, del orden de 600 ppm. cerca de la entrada y de alrededor de 1.100 ppm. más lejos (en total, 36 medidas).

Dos cuevas hidrotermales fueron estudiadas en Budapest: la cueva de Pal-Völgyi, de plano laberíntico, presenta un contenido medio del orden de 700 ppm. (13 medidas) y la de József-Negyri, geoda maravillosa, con un contenido medio de alrededor de 1.200 ppm. en las galerías y pozos y 1.700 en las fisuras (10 medidas).

Finalmente, al SO de Budapest en los montes Bakony, dominando el lago Balaton, la cueva de Alba-Regia presentaba en el pequeño sector en el cual hicimos 10 análisis, un contenido medio muy elevado: 3,2 %.

Paradójicamente no es en las dos cuevas que presentan una morfología o bien depósitos de origen hidrotermal, donde se observan actualmente los mayores contenidos de CO_2.

SUMMARY

The carbon dioxide content of the atmosphere of four Hungarian caves was measured during the summer of 1985. Some 70 analyses were carried out. All the caves studied are located in the Hungarian Ridge («Hungarische Mittelgebirge»).

In the Bükk Mountains, NE of Budapest, the Létrási-Vizes Caves displayed an average CO_2-content aorund 600 ppm near the entrance and around 1100 ppm farther on (36 measurements). Two hydrothermal caves were investigated in Budapest: the Pál-völgyi maze cave revealed an average content around 700 ppm (13 measurements), whereas in the beautifully decorated József-hegyi Cave the average content was about 1200 ppm in the galleries and pits, and about 1700 ppm in two fissures (10 measurements). Finally, SW from Budapest, in the Bakony Mountains, near Lake Balaton, the Alba Regia Cave displayed, in the area where we caried out 10 analyses a very high value, averaging 3, 2 %.

Paradoxically, it is thus not the caves which display a hidrothermal morphology or hydrothermal formations which show the highest CO_2-contents.

1. Introduction. Le problème

On conaît l'importance du dioxyde de carbone dans l'acidification des eaux qui dissolvent le calcaire et créent ainsi les phenomènes karstiques (voir, p. ex., L. JAKUCS, 1977, pp. 232 et 237 à 239).

Il est important, pour pouvoir expliquer les variations de teneur du CO_2 dans l'eau, de connaître sa répartition dans l'air du sol et l'air des grottes. La problématique de l'étude du CO_2 a été très bien exposée par L. JAKUCS (1977, PP. 28-48). On trouvera un historique des mesures de CO_2 dans Ph. RENAULT (1985) et une liste de mesures récentes dans C. EK et M. GEWELT (1985).

Pour les analyses faites en Hongrie, on trouvera des données dans L. JAKUCS (1977) et, pour ce qui est plus récent, dans les publications spéléologiques, par exemple dans P. TIHANYI (1982), L. LÉNÁRT (1980, 1982), I. ESZTERHÁS (1983), etc.

2. La méthode

Le dosage CO_2 de l'air a été effectué à l'aide d'un détecteur de gaz GASTEC. L'appareil est constitué d'une pompe dont le piston aspire 100 cm^3 d'air à travers un tube contenant un réactif et un indicateur coloré. On trouvera une description détaillée de la méthode et de la technique en français dans C. EK *et al* (1981) et dans M. GEWELT et C. EK (1983) et en anglais dans M. GEWELT et C. EK (1985).

La technique utilisée ici a une précision garantie de ± 25 % seulement, mais la reproductibilité observée par les chercheurs qui l'utilisent (p. ex. C. EK *et al.*, 1981) est beaucoup meilleure: ± 10 % dès qu'on est au-dessus de 500 ppm.

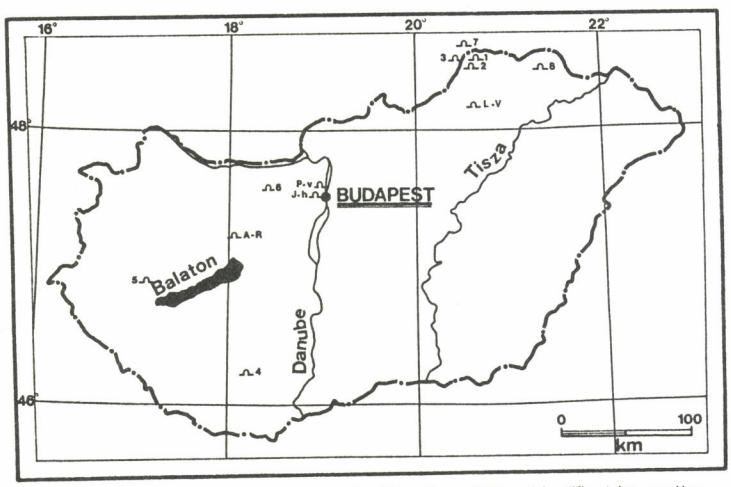

Fig. 1. Localisation des quatre grottes étudiées. Les chiffres identifient les grottes du tableau V, où des mesures de CO_2 antérieures avaient été faites par des chercheurs hongrois.

3. Grottes étudiées et résultats des mesures

Les quatre grottes étudiées sont toutes localisées sur le versant méridional de la Dorsale hongraise, à la retombée des montagnes sur la dépression pannonienne. La première grotte est dans la motagne de Bükk, deux autres sont à Budapest, la quatrième est dans les monts Bakony. La figure 1 localise les cavités étudiées.

a. *Létrási-Vizes-barlang*

La grotte est située à Létrás, et s'ouvre dans un ponor sur le grand plateau de la montagne de Bükk (LÉNÁRT L., 1980). Elle a été creusée dans les calcaires du Trias supérieur et du Jurassique inférieur. Son développement dépasse 2200 m et sa profondeur 90 m.

Le tableau I montre que les teneurs sont généralement inférieures à 1000 ppm dans la zone d'entrés, jusqu'à une trentaine de mètres de celle-ci, aux environs de Hágcsós-terem; dès qu'on dépasse ce point, les teneurs sont un peu plus fortes. Dans les parties intérieures de la grotte, la teneur est généralement plus élevée près du plafond que près du sol. Nous pensons que ceci est en relation avec la fourniture de CO_2 d'origine biologique par les fissures.

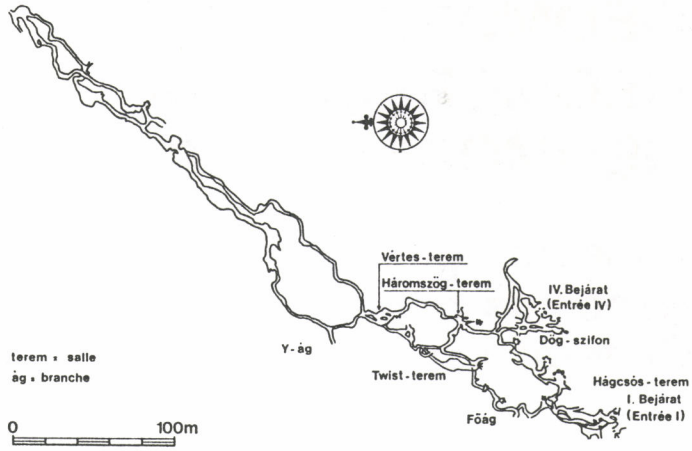

Fig. 2. Létrási-Vizes-barlang. Plan (d'aprés MEAFC, 1977).

LÉTRÁSI - VIZES - BARLANG 28 Juin 1985.

N°		H cm	CO2 ppm
1	Air libre, à 6m. de l'entrée principale	10	500
2	Idem	160	400
3	Salle melegedő, près entrée n° III	10	500
4	Idem	160	600
5	Porte de fer, coin inférieur gauche	5	800
6	Idem, coin supérieur droit	85	1000
7	Salle Hágcsós au-dessus du puits	10	900
8	Idem	160	1000
9	Bord de la rivière, sous l'échelle de fer	10	900
10	Idem	160	1100
11	Fond de la salle de l'échelle de bois	10	1000
12	Idem	160	900
13	Branche principale, source	10	900
14	Idem	160	1000
15	Branche principale, entrée du labyrinthe inférieur	20	1200
16	Idem	160	1200
17	Branche principale, 5m avant le 1er siphon	10	1200
18	Idem	160	1200
19	Premier siphon (h galerie = 0,3m)	10	1400
20	Salle de l'échelle, sur l'échelle	300	1100
21	Idem	500	1000
22	Idem	700	1300
23	Branche Patyolat, Pont des soupirs	10	900
24	Idem	180	1000
25	Idem	300	1000
26	Idem	500	1100
27	Fenêtre	100	1800
28	Idem	-100	1000
29	Idem	-400	1100
30	Idem	-700	1100
31	Fenêtre, dans une étroite fissure (20 cm)	-700	1300
32	Au pied du Mur du Zèbre	10	1000
33	Idem	300	1600
34	Salle de la tête d'argile,au pied du puits infér.	0	900
35	Idem, 3m plus haut	10	900
36	Idem, encore 3m plus haut	10	1000

EK Camille, GÁBRIS Gyula, LÉNÁRT László.

TABLEAU I. Teneurs en CO_2 de l'air de la grotte Létrási-Vizes.

b. *Pál-völgyi-barlang*

Située à Budapest même, dans les calcaires éocènes, la grotte de Pál-völgyi est une grotte thermale, au plan labyrinthique, d'un développement de plus de 4 km et de 98 m de dénivelée.

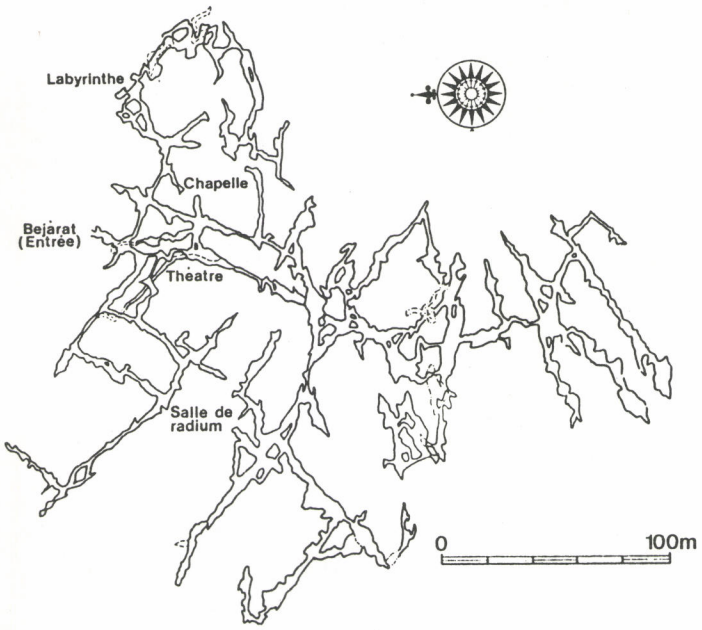

Fig. 3. Pál-völgyi-barlang. Plan (d'après KÁRPÁT J., in KESSLER H., s.d.).

La grotte est touristique et, le jour des mesurs, près de 100 touristes étaient passés avant nous. Dans le secteur –touristique– où nous avons fait des mesures, cette présence n'a pas provoqué de perturabtion apparante dans la teneur en CO_2: nulle part celle-ci ne dépasse 800 ppm; en moyenne, la teneur est de moins de 700 ppm, ce qui est nettement modeste, d'autant plus que la teneur observée à l'entrée de la grotte (500 ppm) est assez élevée, ce qui nous semble ici plus en relation avec la circulation routière importante qu'avec la végétation de forêt claire des abords de la grotte. La comparaison des mesures que nous avons faites systématiquement à chaque endroit à 10 et à 160 cm de hauteur au-dessus du sol montra qu'il n'y a pas de différence significative entre le bas et le haut des galeries, ce que est un signe de bonne ventilation de la cavité. Le minimum observé à la dernière mesure est en relation avec une sortie impracticable à l'homme, mais connue, et source d'aération.

PÁL - VÖLGYI - BARLANG - 3 Juillet 1985.

N°		H cm	CO2 ppm
1	Dehors, à 5 m de l'entrée	160	500
2	Au delà de la 1ère salle (l'escalier tourne)	10	700
3	Idem	160	700
4	Petite salle, carrefour de 5 passages	10	700
5	Idem	160	600
6	Petite salle près du puits, hors parcours touristique, beaucoup plus bas	10	700
7	Idem	160	700
8	Petite salle dans parcours touristique, plus haut que n° 6-7	10	700
9	Idem	160	700
10	Petite salle, plus bas que la précédente, hors parcours touristique	10	600
11	Idem	160	800
12	Salle terminus des touristes, près du puits du radium.	10	700
13	A 5 m du terminus, & 25 m du précédent, net courant d'air.	10	500

EK Camille, FLECK Nóra

TABLEAU II. Teneurs en CO_2 de l'air de la grotte de päl-völgyi.

c. *József-hegyi-barlang*

Située dans la ville même de Budapest, comme la précédente, la grotte József-hegyi a été récemment découverte dans les calcaires éocènes (et triasiques dans la partie inférieure de la grotte) de la rive gauche du Danube. Elle est toujours en voie d'exploration (LEÉL- ÖSSY S., 1985). C'est une merveilleuse géode: au bas des puits d'entrée, on débouche dans des salles toutes tapissées de merveilleuses concrétions blanches considérées comme hydrothermales. On n'est du reste pas loin des thermes romains de Buda. Le plan de la grotte n'était pas encore terminé (elle était toujours en voie d'exploration) quand nous l'avons parcourue en juillet 1985; la partie explorée atteignait déjà alors un développement de plus de 3000 m et une profondeur de 70 m.

JÓZSEF - HEGYI - BARLANG - 3 Juillet 1985.

N°		H cm	CO2 ppm
1	Air libre, à 6 m de l'entrée	160	400
2	A 15 m sous le niveau de l'entrée, dans une fissure du puits,à 60cm dans la fissure	10	1.700
3	Même puits, à 20m sous le niveau de l'entrée à 80cm dans la fissure	10	1.700
4	Fond du puits d'entrée	10	1.000
5	Petite salle, à -40m.	10	1.200
6	Grande salle: Kinizhsi Station,à -64m, au pied du puits d'entrée	10	1.300
7	Idem	160	1.000
8	Salle de la crême glacée	10	1.200
9	Idem	160	1.300
10	Même salle, plus loin	500	1.400

EK Camille, TAKÁCSNÉ BOLNER Katalin, LEÉL-ÖSSY Géza.

TABLEAU III. Teneurs en CO_2 de l'air de la grotte József-hegyi.

On voit sur le tableau III que la teneur est de 1000 ppm au pied du puits d'entrée, à 20 m de profondeur; au-deà de ce point, la moyenne des teneurs des salles et galeries est un peu supérieure à 1200 ppm, tandis que le chiffre de 1700 est atteint dans les fissures de la zone d'entrée. Dans l'ensemble, la grotte apparait, comme la précédente, assez bien aérée et pourvue d'une atmosphère relativemente homogénéisée. Les teneurs sont un peu plus fortes ici qu'à Pál-Völgyi- barlang, mais sans être très élevées.

d. *Alba-Regia-barlang*

Dans les Monts Bakony, au nord du lac Balaton, s'ouvre dans un ancien ponor dans les calcaires du Jurassique et du Crétacé la grotte dÁlba-Regia (ESZTERHÁS I., 1983). Son développement connu est de 2200 m, sa dénivelée de 200 m. Cette grotte a été l'objet d'un grand nombre d'études très poussées. En ce qui concerne les mesures de CO_2, on se référera entre autres à la publication de TIHANYI P. (1982).

Dans cette vaste cavité, nous avons concentré nos mesures dans un seul secteur de la grotte: celui de l'aven Hu (voir fig. 4). La moyenne des mesures y atteint 3,2 % de CO_2. C'est une valeur plus élevée qu'aucun des maximums enregistrés durant notre campagne dans les autres grottes étudiées. On approche là la teneur limite admissible pour un séjour de longue durée ou pour l'exécution d'un travail fatigant. La teneur en CO_2 élevée de l'atmosphère de la grotte était bien connue des chercheurs spécialistes de la grotte. Nos mesures confirment les leurs.

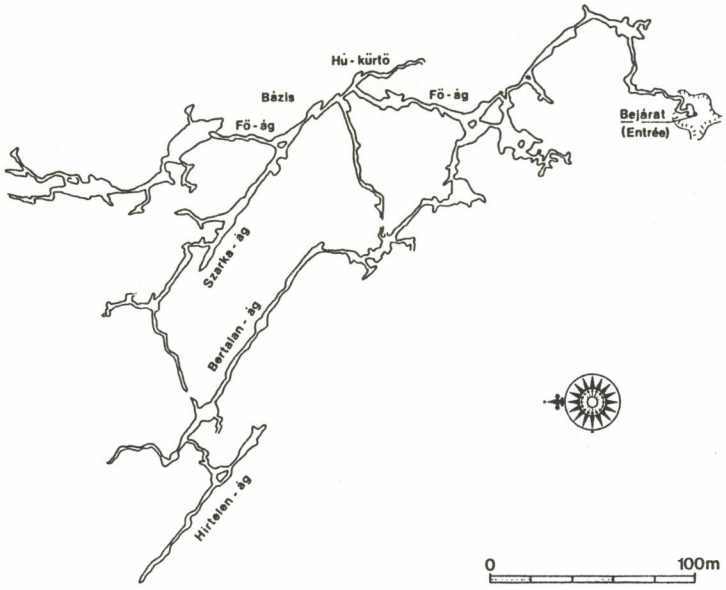

Fig. 4. Alba-Regia-barlang. Plan (d'après KÁRPÁT J., 1980, simplifié).

ALBA - REGIA - BARLANG - 4 Juillet 1985.

N°		H cm	CO2 ppm
1	Air libre, entrée n°2, sous futaie de hêtres, pas de taillis	160	400
2	Idem, près de la litière, pas de végétation herbacée	0	400
			%
3	Aven Hu	20	1,7
4	" "	160	3,1
5	" " (mesure annulée)	300	
6	" "	300	3,3
7	" "	20	3,2
8	" "	160	3,2
9	" "	300	3,2
10	Panneau Hu	20	3,3

EK Camille, ESZTERHÁS István, GÁBRIS Gyula, GÖNCZÖL Imre, TERÉK Tibor, ZENTAI Ferenc.

TABLEAU IV. Teneurs en CO_2 de l'air dans la grotte de Alba-Regia.

4. Discussion

a. *Comparaison des quatre séries d'analyses*

Une septantaine de mesures constitue un nombre très restreint de données et nos conclusions seront donc très prudentes.

Toutes les mesures ont été faites au début de l'été, du 28 juin au 4 juillet 1985, durant une période très pluvieuse.

Pál-völgyi-barlang apparaît comme la cavité la mieux aérée, la puls pauvre en CO_2, des quatre grottes concernées. Ceci est certainement à mettre en relation avec l'existence de plusieurs orifices à cette grotte. L'autre cavité connue comme étant d'origine hydrothermale, József-hegyi-barlang, montre des valeurs de près du double de la précédente. Nous y sommes descendus plus profondément sous le niveau d'entrée que dans Pál-völgyi-barlang. Dans la montagne Bükk, Létrási-Vizes-barlang a des teneurs du même ordre de grandeur. Alba-Regia-barlang, par contre, montre des teneurs beaucoup plus fortes.

b. *Comparaison avec d'autres analyses en Hongrie*

Les mesures dans l'atmosphère des grottes hongroises portent surtout sur la température et l'humidité.

On trouvera cependant dans le tableau V une liste de mesures de CO_2. Les mesures les plus nombreuses ont été effectuées dans les grottes dÁlba-Regia et de Cserszegtomaj. Dans ces grottes sont connues des variations sainsonnières.

Le tableau V montre que nos mesures sont situées dans la gamme des teneurs déjà observées en Hongrie, que des teneurs plus fortes ont déjà été observées, à Alba-Regia en particulier, et que les grottes glacées présentent par contre des teneurs pouvant être beaucoup plus faibles.

N°	Nom de la grotte	Teneur en CO_2	Source
1	Baradla (Aggtelek)	0,2-0,7 %	Fodor I., 1981
2	Béke (Aggtelek)	0,2-0,7 %	id.
3	Domica (id.; CZ)	0,3-0,4 %	id.
4	Abaliget (Mts Mecsek)	0,2-0,6 %	id.
5	Cserszegtomaj(Bakony)	0,7-0,9	Kárpát J. (1)
6	Veres-hegyi (Mts Gerecse)	0,2-1,6 %	Juhász M. (1)
	Alba Regia (Bakony) 1981	0,2-5,2 %	Szolga F. (1)
	id. 1982	0,3-4,1	Kárpát J. (1)
	id. 1983	88-150 mg/l	Németh I. (1)
	Grottes glacées		
7	Silické l'adnica (CZ)	0,01-0,2 %	Fodor I., 1981
	Demänovska l'adova (CZ)	0,01-0,5 %	id.
8	Telkibánya (Mts Tokaj) artif., roches volcaniques	0,4 %	id.
	CZ: Tchécoslovaquie		(1): inédit

TABLEAU V. Mesures de CO_2 dans d'autres grottes de Hongrie. Les numéros des grottes permettent de les localiser sur la figure 1. Les mesures inédites sont extraites des rapports annuels des groupes spéléologiques de l'Achéron (1983), d'Alba Regia (1981, 1982, 1983) et de Vértes László (1981) conservés à la Société hongroise de Spéléologie et de Karstologie (M.K.B.T.), a Budapest.

On pourra comparer ces mesures à des analyses dans d'autres pays du monde dans EK et GEWELT, 1985.

Remerciements

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Deforestation on Limestone Slopes, northern Vancouver Island, Canada

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RESUM

Els paisatges de l'illa de Vancouver està dominat pels boscos i la seva economia per la indústria forestal.

Durant els mesos de maig i de juny del 1986 s'estudiaren els efectes de la deforestació en els pendents calcaris de la part nord de l'illa de Vancouver. Es van seleccionar, com a zones de control, dues àrees de selva verge, una de pendent suau i una altra de pendent abrupte. Els dos graus de pendent estan representats en els tres terrenys que varen ésser deforestats en diferents períodes (això és, fa 5, 10 i 20 anys). L'erosió del sòl, l'aflorament de la roca mare, el tipus de vegetació i la seva abundància (a petita i gran escala) així com la fotografia aèria són algunes de les mesures d'anàlisi adoptades per a comparar les diferències i examinar el conjunt dels efectes de la deforestació.

RESUMEN

El paisaje de la Isla de Vancouver está dominado por los bosques y su economía por la industria forestal.

Durante los meses de Mayo y Junio de 1986 se estudiaron los efectos de la deforestación en las pendientes calizas de las partes Norte de la Isla de Vancouver. Se han seleccionado como lugares de control dos áreas de selva virgen, una de pendiente suave y la otra de pendiente abrupta. Los dos grados de pendiente están representados en los tres terrenos que fueron deforestados en diferentes períodos (es decir 5-10 y 20 años) la erosión del suelo, la exposición de la roca madre, el tipo de vegetación y su abundancia (a pequeña y gran escala) así como la fotografía aérea son algunas de las medidas adoptadas para comparar las diferencias y determinar el conjunto de efectos de la deforestación.

RÉSUMÉ

Le paysage de l'île de Vancouver est dominé par les forêts et son économie par l'industrie forestière. Les effets du déboisement sur les pentes calcaires de la partie nord de l'île de Vancouver seront étudiés durant les mois de Mai et Juin de l'année 1986. Deux aires de forêt vierge ont été sélectionnées comme sites de contrôle, un avec une pente douce et l'autre avec une pente abrupte. Les deux degrés de pente sont représentes dans les trois terrains, qui ont été déboisés à différentes périodes (c'est à dire 5-10 et 20 ans) l'érosion du sol, l'exposition de la roche mère, le type de végétation et son abondance (a petite et grande échelle) ainsi que la photo aérienne sont quelques-unes des mesures adoptées pour comparer les différences et déterminer l'ensemble des effets de déboisement.

The landscapes of Vancouver Island are dominated by forests and the economy by the forest industry. The effects of deforestation on limestone slopes on the northern portion of Vancouver Island will be investigated during May and June of 1986.

Two areas of virgin timber have been selected to act as control sites, one with a gentle and one with a steep-sloping gradient. Both degrees of slope gradient are represented by field sites which have been deforested at different times (i.e. 5, 10, and 20 years ago). Soil erosion, exposed bedrock, vegetation type and abundance (at the micro and macro scale) and aerial photography are some of the measures adopted to compare the different sites and to determine the overall effects of deforestation.

Speleological phenomena and seismic activity in Dinaric karst area in Yugoslavia

Dr. Mladen Garašić Dr. Dragutin Cvijanović

RESUM

En la línia de contacte entre la cubeta adriàtica i la zona càrstica Dinàrica, al llarg de la costa de la mar Adriàtica, hi ha una zona amb una importat activitat sísmica. Aquesta zona, a més, és la més important des del punt de vista càrstic de lugoslàvia. Els procesos sismo-tectònics que originen els terratrèmols, són també la causa de moltes formes i fenòmens càrstics. Alguns del procésos sísmics més típics de la zona (seqüències de petits terratrèmols) poden relacionar-se amb l'origen dels sistemes subterranis. L'aigua és l'element més important en aquest procés (de pluja, superficial o subterrània) i els seus efectes dinàmics o químics són els que, directament o indirecta, desencadenen els procesos tectònics i originen l'activitat sísmica local.

RESUMEN

En la línea de contacto entre la cubeta adriática y la zona kárstica Dinárica, a lo largo de la Costa del Mar Adriàtico, existe una zona de importante actividad sísmica. Dicha zona es, además, la más importante desde el punto de vista kàrstico de Yugoslavia. Los procesos sismotectónicos que originan terremotos, dan también lugar a las formas y fenómenos kàrsticos. Algunos de los procesos sísmicos más típicos de la zona (series de pequeños terremotos) pueden relacionarse con el origen de los sistemas subterráneos. El agua es el elemento más importante en este proceso (de lluvia, superficial o subterránea) y son sus efectos dinámicos o químicos los que directa o indirectamente causan la aparición de los procesos tectónicos y originan la actividad sísmica local.

SUMMARY

Along the line where the Adriatic basin meets the Dinaric karst area, all over the coastal parts of the Adriatic, the zone of reinforced seismic activities was founded. At the same time, that area is the region of the most explicit karst in Yugoslavia. Seismotectonic processes, which cause the earthquakes, undoubtedly cause the speleological forms and phenomena in the that area, as well. Some of the typical local seismic activities (series of weak earthquakes and thunders) can be driven in the causal connection with the system of caves. The basin factor in that process is water (rainwater, current water or underground water) which with dinamical or chemical effects indirectly or directly, cause the appearance of the tectonic processes, and the o occurence of the local seismic activities.

Introduction

Effect on rock masses is multiple. It goes so far that it can initiate earthquakes. A. Imamura, (1937) concluded, for the territory of Japan, about the relationship between rainfall and earthquakes, that after long rainless period when begin sudden and big rains, seismic activity grows. Some examples that showed similar relationship were exposed in works of Cvijanović, D. and Garašić, M. (1984., 1985). Dinaric karst area (Dinaric system) is known because of great number of speleological phenomena (caves and pits) and relatively great amount of rainfall.

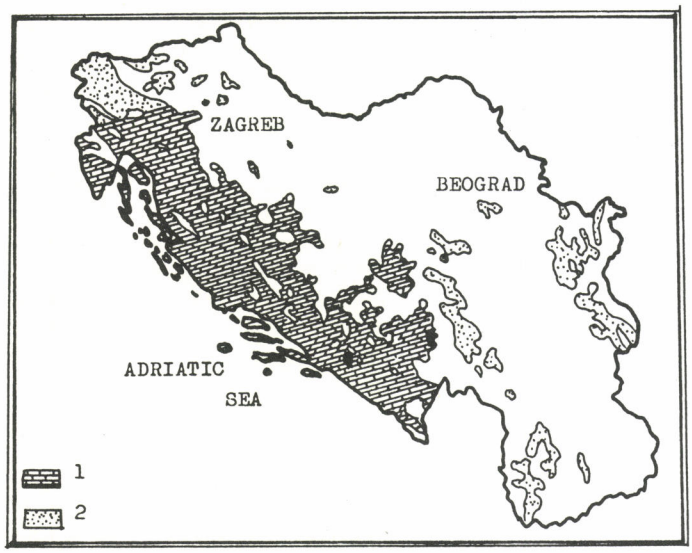

Fig. 1. Dinaric karst system in Yugoslavia (1= Dinaric karst belt, 2= others karst regions in Yugoslavia)

Speleological phenomena (caves and pits)

Dinaric karst system in Yugoslavia streches through four republics (Slovenia, Croatia, Bosnia and Herzegovina and Montenegro) (Fig. 1.). Up to now near 11000 caves and pits are registrated in Dinarids (in Yugoslavia over 15000 rest of them in Alps and in other karst regions).

There are about 19 % horizontal (caves) which shows the considerable vertical penetration of water. The deepest vertical object (shaft) is explored up to 897,5 metres. The longest speleological object (caves) is over 15 kilometres long. If we analyse genesis of the caves, the asymuths of the main channels of speleological objects have approximately direction northwest-southeast (Dinaric stretching direction) –nearly 66 %, while the rest of the objects are differently oriented. However, it is just one more accumulation of data– 13 % of objects strethes almost vertically on Dinaric stretching direction (northwest-southeast). Crucial in that are fault tectonity, fissured zones, reversal faults etc, (figure 2.).

Altitudes above sea level of the entres in the Dinaric karst speleological objects vary from zero metres to 2500 metres of altitude. There also caves under the sea (vrulje-underwater springs in sea, and flooded horizontal rooms –chambers). The deepest of them is about 53 metres under the sea level.

Geological observed, dinaric karst system is composed and made from mesozoic sediments –carbonates (limestones, dolomitic limestones, calcious dolomites, dolomites), clastical rocks, conglomerates, breccias. Among karst rocks in some parts we find impenetrable strata of flished materials, like marl and clay, claystone, siltstone, mudstone etc. Exactly in such places we can see many springs and sinking holes in karst Dinaric area. Nearly 15 % of all registrated speleological objects in Dinaric karts (in Croatia) are with permanent waters, and in 30 % of them waters are periodically present during the year.

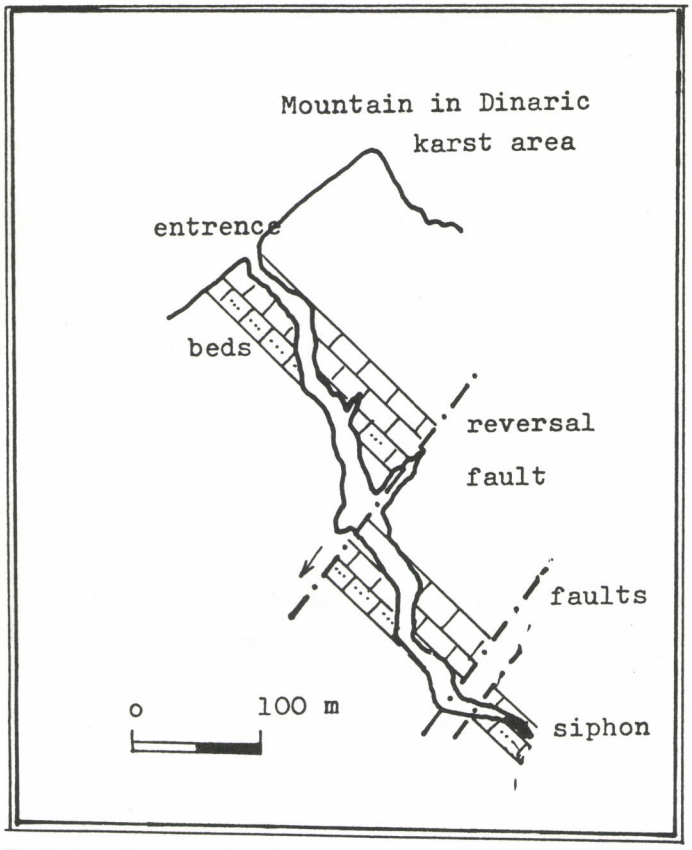

Fig. 2. Shematic presentation of speleological objects in Dinaric karst area that originated by reversal faults..

Analysing the disposition of speleological objects (phenomena) and the seismic activity in Dinaric karst of Yugoslavija, we can see certain relationship among them. Namely, more caves and pits were found in tectonic and neotectonic active regions and in the places with great amount of rainfall. Those places are mostly high mountains (Velebit, Dinara, Biokovo, Orjen, Lovćen, Durmitor etc.).

Along the karst fields (polje) in Dinaric karst, the rhythmical disposition of former and today spring and sink holes (ponors) zones is shown (Garašić, M, 1985) in relationship with altitudes above sea level. From all the analysis we conclude that the all Dinaric karst belt (system) is tectonicaly very active (neotectonic –Garašić, M. 1980, 1981) and that speleological phenomena are in close connection with it. Dinaric karst seismic activity, besides registrating instrumentally on the surface, is also registrated in great cave systems (fig. 3), in big underground chambers, where the changes between two or more destructable earthquakes are noticed. The biggest halls are 160 × 140 × 100 metres of size.

The drilling researches results in the coastal part of Dinaric belt (by the Adriatic sea) show that even on depths of 4000 metres we can find cavernous spaces with stalactites and stalagmites, and that the thickness of carbonate mesozoical complex here is over 7000 metres. That means that karst processing goes very deep in Dinaric karst and that the possible causes of some local earthquakes can be explained by the great number of cavities caused by some longer rainy periods. But there is no confident evidence about that.

Speleological phenomena (caves and shafts) are one of the basic characteristics of Dinaric karst belt, which counts among the regions in Europe with more explicite seismic activity. Number of objects, their disposition, their size, lenght, depth and orientation tell us about certain similarity and relationship with epicentral seismic activated regions. The cause of that is not resolved yet.

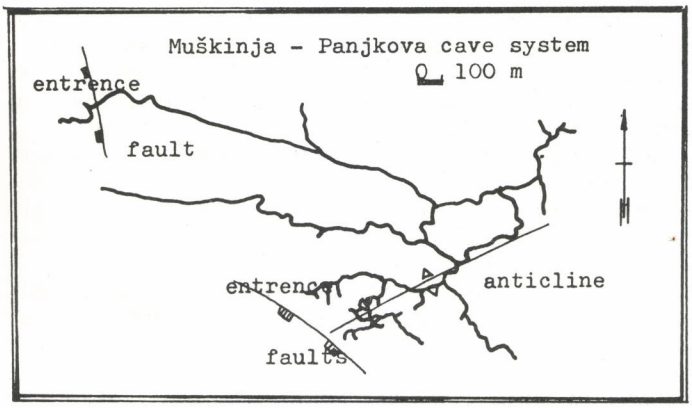

Fig. 3. Cave system neotectonic map where the activity is observed

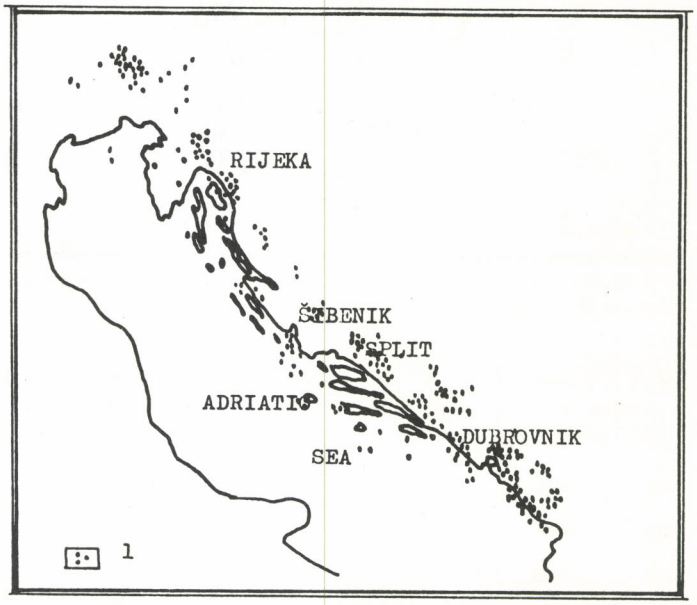

Fig. 4. Strenghtened seismic activity belt along coastal part of the Adriatic in Yugoslavia (1 = epycenters of earthquakes)

Seismic activity

Results of the researches seismologists, existing up to now, show that along whole coastal part of Adriatic sea stretches the belt of reinforced seismic activity (fig. 4). Inside that belt there are several accentuated epycentral regions, like for example, region of Rijeka, region of Zadar and Šibenik, Biokovo coastal area, Dubrovnik coastal area, and Montenegro coastal area. Generally, going from northwest to southeast seismic activity grows, and possible maximal magnitudes of earthquakes are from M = 6,0° in region of Rijeka to M = 7° in Dubrovnik-Montenegro coastal epycentral region. Besides strong earthquakes, on some terrains there are occurences of great number of weaker earthquakes and thunders. Such terrains, are Vinodol and island Krk (fig. 5), the edges of almost all karst fields-polje (Polje of Lika, Livno, Imotski, Kupres, Popovo etc.), island Hvar (Starigrad) and island Mljet (Babino Polje), Ston, Dubrovnik, and the bay of Boka Kotorska. If we observe the seismic activity –weather– time variations, we can see that the strong earthquakes as well as the weaker ones happen more often in some periods of the year (fig. 6. and 7). Searching for the reasons of that phenomena, we started from the assumption that the rainfalls directly or indirectly, penetrating in underground through speleological objects (caves and vertical shafts) and through secondary porosity (fissures, faults) that are disposed in the big fault zones, acted like the additional factor in speeding up the liberation of seismic energy, or rather in the origin of earthquake (Garašić, M. Cvijanović, D. 1984., 1985).

There are two presumed ways in acting of water in the beginning of earthquake: direct and indirect way.

–To illustrate the direct acting of water, the data of daily amounts of rainfall (in milimetres) and the moment of the occurence of earthquake (arrow) in region of Rijeka are given in table:

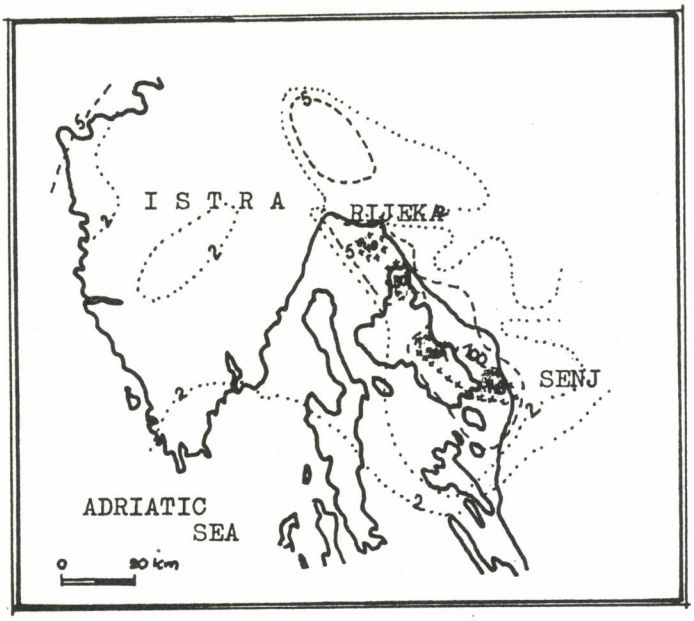

Fig. 5. Spacious variations of the epicentral region of Rijeka (isolines of the same frequences of earthquakes)

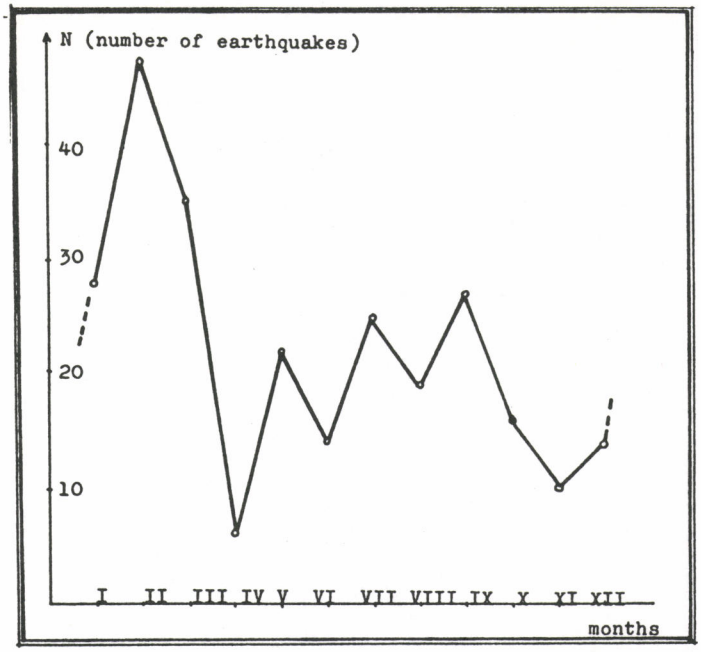

Fig. 6. Annual going earthquake frequency in epycentral region of Rijeka (1870-1970).

days in month / number of earthquake		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Feb	1980										1	25	↓ 22																			
May	1889	4					27	7						7													9	↓ 43	4	35			
July	1896	55	1									3						↓ 51	↓ 50	4					1	1					1	1
Aug	1898									13										↓ 1										30	↓	
Nov	1898	5		4	13	4				2	1	16											68	24	20	19	17	15	12	47	2	
Oct	1899	10					22	↓ 113					12	88		13	2															4
Jan	1904	2					6	1	8				1	1	24	↓ 24	1															24
Jan	1906					1	32	14							1				1	↓ 54											
Feb	1908	6														4	47	42						1	23					↓ 9		
Apr	1909												5	4														1	51			
May	Q1909		3	2	↓ 5			2	34		1																15	7	5			
July	1913			1	↓ 48		1	9	2	17	18						6			2	6	3	1	16	5			8				

↓ occurence of earthquake
54 rainfall in milimetres

From the data it can be seen that such earthquakes, mostly weaker ones, appear just after the heavy rainfalls (several hours or at the most day or two after the beginning of the rain period).

–To illustrate the indirect acting of water on the origin of earthquake, diagram of the time variations– deviations of the amount of rainfall ΔR (in milimetres) from the lasting several years average is given, as well as the moment of the origin of strong earthquakes in Biokovo epycentral region (fig. 8). Extremelly rainy period was in October and November 1961., and the strengthened seismic ctivity started at the beginning of January 1962, consequently several months later (1-3 months). In this case we speak of the strongest earthquakes. It is immportant than in Biokovo mountain region about 400 vertical shafts is explored, mostly more than 300 metres of depth (the deepest 576 metres).

Conclusions

Since the earthquakes as well as the speleological phenomena are connected with the fault zones, respectively with tectonic processes which happened in them, we can expect certain causable relationship among them. Dinaric karst belt (area) is typical example for that. Orientation and size of the speleological objects (caves and shafts) speaks in contribution to that.

It would be usefull to continue such researches, because in that way we can explain and, maybe, prognosticate the occurence of weaker earthquakes and thunders, that cause fear and anxiety among local population, and can cause the changes in system of underground waters, the changes in quality and quantity of waters etc. Direct measurements of tectonic movements (Garašić, M. 1981) and seismic activity in speleological objects should be led through methodically and on more terrains in the whole Dinaric karst belt (area). Only after that we will be in position to make conclusions about connection between karst proccesing and seismic activity in the karst regions.

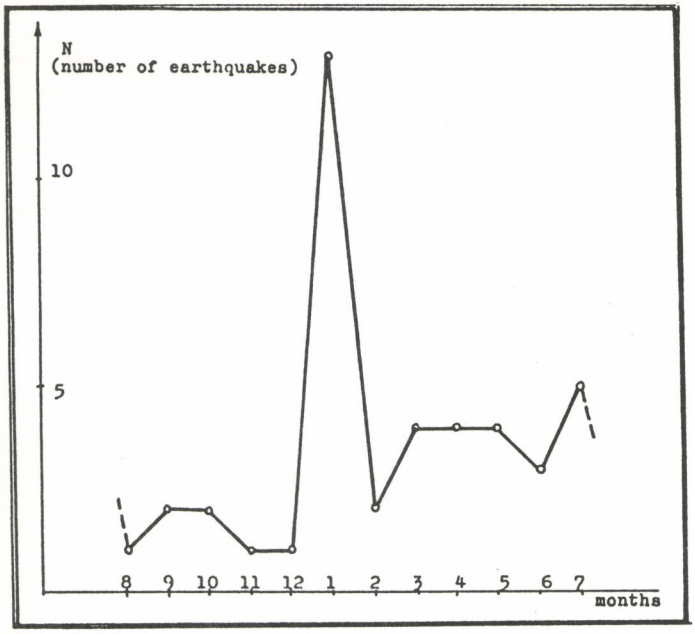

Fig. 7. Heavier earthquakes frequences diagram in epycentral region of Biokovo from 1901 to 1970.

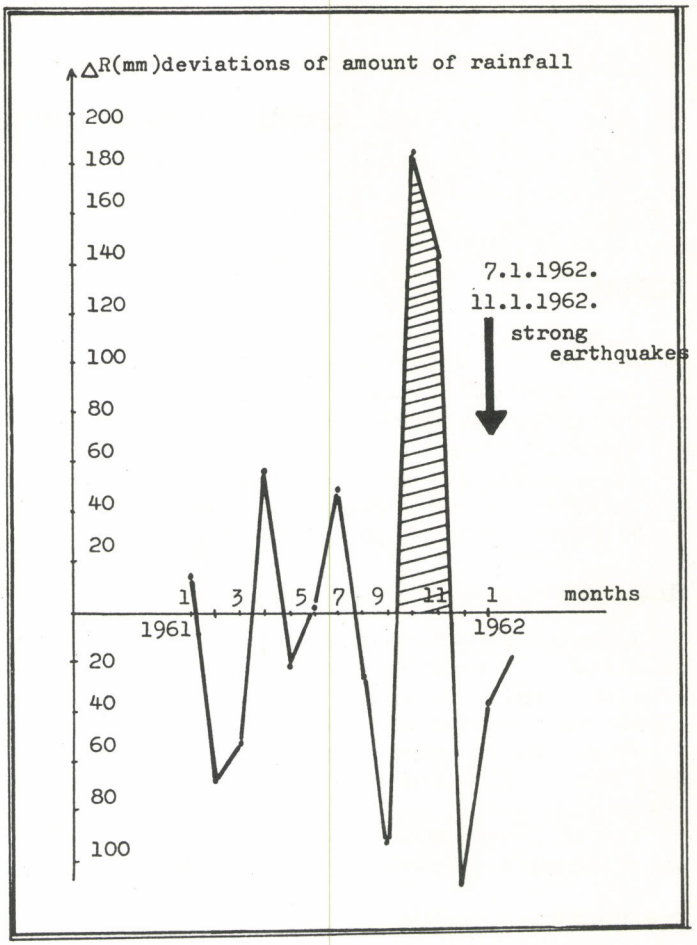

Fig. 8. Time variations deviations of amount of rainfalls (in milimetres) from lasting several years average (Makarska) and the moment of occurance of the heaviest earthquakes at the beginning of period of the strenghtened seismic activity, 1962., in epycentral region of Biokovo

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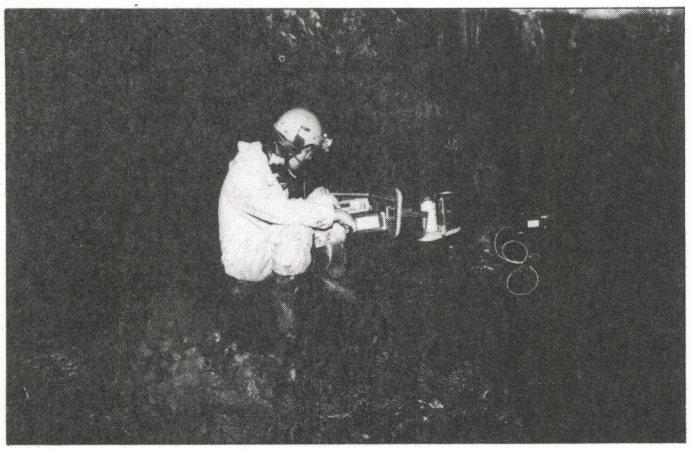

Photo. 1. Measuring in Muškinja. –Panjkova– Crno vrelo cave system

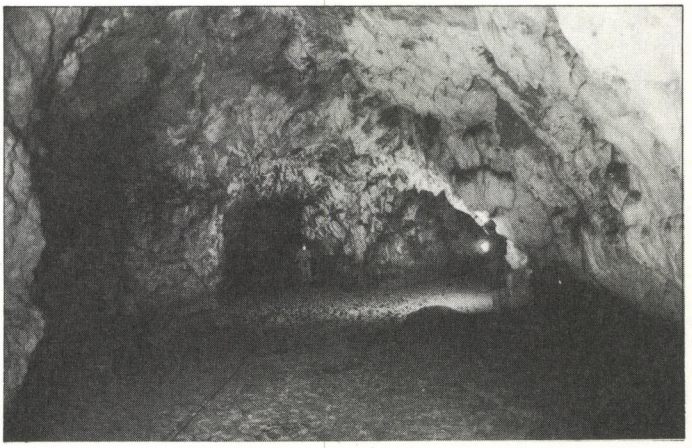

Photo. 2. Big chambers in Dinaric karst caves where the earthquakes is registrated.

Sinkhole development near an iron mine

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RESUM

Prop d'Auerbach (Frankenalb septentrional, Alemanya Occidental) a mitjan dels anys 70, es va començar l'explotació d'un dipòsit de mineral de ferro. Aquest es troba en una formació cretàcica d'una vall càrstica fòssil del període Precenomanià. Aquest episodi de carstificación va afectar quasi tot l'espessor (superior als 200 m. en l'actualitat) del Malm, la qual cosa es va posar de manifest a través de diferents observacions. Mitjançant vàries perforacions van ésser localitzades diversas cavitats d'aquest període.

Durant els anys posteriors a l'exploració de la nova mina, van aparèixer nombrosos engolidors a una distància de 0,5 i 2 km. de la mina. Alguns d'ells es van obrir al llit d'un petit rierol, escorrent- se cap el seu interior tota l'aigua.

Aquest procés es pot atribuir a la reactivació d'antics cursos d'aigua formats en fluir l'aigua subterrània d'acord am el nou nivel freàtic en forma d'embut creat al voltant de la mina.

RESUMEN

Cerca de Auerbach (Frankenalb septentrional, Alemania Oc.) a mediados de los años 70, se inició la explotación de un depósito de mineral de hierro. Este se halla en una formación cretácica en un valle kárstico fósil de un período Precenomaniense. Dicho episodio de karstificación afectó a caso todo el espesor, superior a los 200 m. en la actualidad, del Malm lo que se puso de manifiesto por diferentes observaciones. Cavidades de dicho período fueron encontradas mediante varias perforaciones.

Durante los años siguientes a la exploración de la nueva mina aparecieron numerosos nuevos sumideros a una distancia entre 0,5 y 2 km. de dicha mina; ocurrió que algunos de ellos se abrieron en el lecho de un pequeño arroyo, sumiéndose en su interior toda el agua.

Este proceso puede explicarse como debido a la reactivación de antiguos cursos de agua a causa del fluir del agua subterránea según el nuevo nivel freático en forma de embudo que se ha creado alrededor de la mina.

SUMMARY

Near Auerbach (northern Frankenalb, W-Germany) the explotaition of an iron ore deposit was started in the middle of the 70's. This iron ore is a cretaceous formation in a fossile karstic valley of a precenomanian period. In this karstic period nearly the whole Malmian layer of limestone and dolomite, more than 200 m today, was affected, this was evidenced by numerous observations. Caves of that period were also found at several drillings.

In the years after the beginning of the exploitation of the new mine numerous new sinkholes developed at a distance of about 0,5 ... 2 km. from the mine; it also happened that these sinkholes opened in the bed of a little river so that the water disappeared.

These affects can be explained by reactivation of fossile waterways caused by the flow of underground water in the region of the funnelshaped water table around the mine.

For centuries people have exploited iron ore in the northern Frankenalb which was deposited in karstic valleys during the upper cretacions period. These valleys are situated on a dislocation from NW to SE at the NE end of the Frankenalb of today. There is a lot of special literature on the formation of these ore deposits /1/. It has been proved that it has been deposited during a period of ocean transgression in the upper cretacious age after an intensive karstification period under tropical or subtropical conditions in the lower cretacious age. Some relicts of this karstification period will be mentioned later on. It has to be pointed out that NE of the dislocation zone there was elevation and increased erosion afterwards so that today there are no more malmian layers of limestone.

At the moment the last of these iron ore deposits is being exploited. The mine was sunk during the seventies and goes down to the base of the malmian layers of limestone at a depth of about 180 m below ground.

Since the end of the seventies, in an area west of the iron mine numerous sinkholes appeared. Some of them rapidly enlarged, others did not change later on. In one case a –up to then completely filled– cave opened; this sinkhole meanwhile has reached a depth of 12 m, the cave is also 12 m long. A few times, small rivers completely disappeared in newly developed sinkholes.

The iron ore deposits belong to the lowest layers of the sediments which covered the whole Frankenalb in the upper cretacious period. The one which is now being exploited was formed in a karstic valley of about 3 km length and 0,5 km width; the declivity in part is vertical an up to 200 m high and the bottom occasionally has already reached the lower limit of the limestone layer. This valley developed during the lower cretacious age. The formation of the iron ore deposit can be explained by precipitation from waters which came from the area NE of the pit where the ironbearing Dogger ß had been elevated by tectonic procedures /1/. A fossile surface draining of the mine area as well as of a number of similar fossile karstic valleys cannot be found, the draining obviously went subterranealy, probably to S or SW. In an other fossile karstic valley nearby, whose iron ore deposit has been exploited before, large caves were proved to have existed at the base of the former declivity of the valley. Also on other places of the iron ore pits deep karstification of the malmian limestone was observed.

Some kilometers north of Auerbach there is the remarkable valley of Königstein, a fossile polje of the lower cretacious age, 5 km in length and 0,3 to 1 km in width which, according to drillings, in places has malmian layers of only 7 m below it. At the brink of this polje there was an ochre pit until 1955. The ochre exploited there was the content of a cave of a length of several 100 m filled with cenomanian sediments. /2/

In the years till 1943, during the building of an extension of the water supply for the city of Nürnberg, numerous drillings in the area of the Veldensteiner Forst (some kilometers SW of Auerbach) were affected. At almost all drillings fossile karstic caves, partly with fragments of sinter, were found. Most of these

caves were filled with sand or clay, but some were open. The deepest one –2 m high, and partly filled with manganese ore, was registrated at– 118 m below today's river level /3/

These fossile karstic waterways can be active today. A spring near Ranna, used for the watersupply of Nürnberg since 1912, carries water which comes from such deep fossile karstic horizons. The sediments in these waterways lead to a great reduction in the speed of the flowing water and to thorough filtering.

It is sure by all that, that down to the base of the karstic malmian layers there are large caves, generally filled with cretacious sediments. Steep karstic valleys on the surface were proved to have reached down onto this level.

The beforementioned iron ore mine near Auerbach has to pump out up to 55 m^3 of water every minute. Most of this water comes from the karst, and the karstic water, which before was almost motionless in that region, has started to move. Near the pit, the draining direction was turned around, with drastically increased speed. Effects can be realised over a distance of several kilometers, for example the spring of Ranna produces less water. The clay contained in the water from the pit shows that the speed of the water is great enough to transport cretacious sediments from the fossile caves into the pit.

In the areas where this karstic water flow induced by the sinking of the water level near the mine runs in fossile caves with stable roofs of limestone respectively dolomite, this means only that a cave filled with sediments turns into one filled with water.

However, it is to be expected that, as these caves once were formed under tropical conditions, they had connections to the surface through steep sinkholes and shafts. These also proved karstic forms on the surface are, too, filled with cretacious sediments and in general cannot be recognized today.

If sediment is carried away at the base of these shafts and sinkholes, it has to be expected that their relatively loose sediment filling –sand and clay– begins to move and that on the surface sinkholes turn up in a small area. Obviously this is the case with the sinkholes which opened in that area in the last few years.

Furtheron it is evident that fossile caves filled with sediments, which reach down from near today's surface to the present –lowered– karstic water table can become water conductive and can swallow whole rivers. All cases of river disappearing occured at places where an artificial riverbed was installed near the karstic malmian dolomite, without thick pleistozene layers in between as with natural riverbeds.

The great number of sinkhole occurences in a relatively small area within the region of the funnel-shaped water table near the mine is a hint at an influence of the changed hydrologic conditions. Observations on sinkhole activity in the Frankenalb date back as far as to the middle of the 19th century. As such occurences are rather rare it can be deducted that the frequency of the mentioned sinkhole development near Auerbach is by several orders of magnitude higher than elsewhere in the Frankenalb, with respect to the area. This fact alone means that it is extremely improbable that the development of these sinkholes does not depend on artificial action in this region.

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On the role of climatic and lithologial control in high mountain glaciokarst

Jurij Kunaver

RESUM

Els Alps italians i de Kamnik, al nord-oest de lugoslàvia, són dues de les zones de carst glacial més extenses i interessants del país. La distància entre aquestes zones és d'uns 60 km. i aquesta és una de les causes responsables del descens de les precipitacions en la direcció oest-est. Els Alps de Kamnik només reben la meitat de les precipitacions (2.000 mm.) si ho comparem amb els gairebé 4.000 mm. per any de Kanin, a la part occidental del Alps Julians.

Aquest treball versa sobre els efectes d'aquestes variables sobre les formes de superfície mesocàrstiques i microcàrstiques. També presentarem els efectes de la litologia, la diferent intensitat de les glaciacions i altres factors, així com les peculiaritats i/o universalitat de la tipologia de les diferents formes i relleus càrstics.

RESUMEN

Los Alpes Italianos i Kamnik, en el Noroeste de Yugoslavia, son dos de la zonas de karst glacial más extensas e interesantes del país. La distancia entre ellas es de unos 60 km. y ésta es una de las razones que origina un descenso de las precipitaciones en la dirección de Oeste a Este. Los Alpes de Kamnik sólo reciben la mitad de la precipitación (2.000 mm.) en comparación con los casi 4.000 mm. por año de Kanin, en la parte Oeste de los Alpes Julianos.

Este trabajo versa sobre los efectos de estas variables sobre las formas de superficie mesokársticas y microkársticas. También se presentarán los efectos de la litología, diferente intensidad de las glaciaciones y otros factores, así como la particularidad y/o universalidad y la tipología de las diferentes formas y relieves kársticos.

SUMMARY

The Julian and the Kamnik Alps in northwestern Yugoslavia are the two of the most interesting larger regions of alpine glaciokarst in the country. They are about 60 kilometers apart from each other and this is one of the reasons for the decrease of the precipitations in the direction from west to east. Kamnik Alps get only half of the precipitations (2000 mm) in comparison to nearly 4000 mm/ year in Kanin Mts. in the western Julian Alps.

In the article the effects of this relations to the mezo- and microkarstic landforms will be discussed. Also the effects of the litology, different intensity of the glaciation and other influences will be presented together with the discussion on the individuality and universality as well the typology of the karstic landforms and landscapes.

A Comparison of Longitudinal Stream Profiles in Some Karst Basins of the Eastern United States

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RESUM

S'ha investigat molt del que fa referència als perfils longitudinals dels cursos d'aigua en conques no càrstiques. El present treball investiga el comportament dels perfils dels cursos d'aigua a les regions càrstiques de l'Est dels EE.UU., i en particular a les conques associades al cinturó orogènic dels Apalaches. Es presenten dades i perfils, els quals són comparats, tant els d'una mateixa conca com els de vàries conques entre sí. Els diversos paràmetres que poden afectar els perfils dels cursos són debatuts, posant especial èmfasi en les formes observades a les àrees objecte d'estudi. Finalment, es fan alguns comentaris relacionats amb la naturalesa global dels perfils dels cursos d'aigua de les regions càrstiques, enfront dels perfils que es donen a les conques clàssiques de drenatge.

RESUMEN

Se ha investigado mucho acerca de los perfiles longitudinales de los cursos de agua en cuencas no kársticas. El presente trabajo investiga el comportamiento de los perfiles de cursos de agua en regiones kársticas del Este de los Estados Unidos, particularmente en cuencas asociadas con el cinturón orogénico de los Apalaches. Se presentan datos y perfiles que se comparan dentro y entre las cuencas. Los diversos parámetros que pueden afectar los perfiles de los cursos, se discuten con especial énfasis en las formas observadas en las áreas de estudio. Finalmente se ofrecen algunos comentarios respecto a la naturaleza general de los perfiles de cursos en regiones kársticas frente a los que se dan en las cuencas clásicas de drenaje.

SUMMARY

Much research has been done pertaining to longitudinal stream profiles in non-karstic basins. The present paper investigates the behavior of stream profiles in karst regions of the Eastern United States, specifically basins associated with the Appalachian orogenic belt. Data are presented and profiles are compared within and between basins. The various parameters which may affect stream profiles are discussed with emphasis on the forms observed in the study areas. Finally, some comments are made regarding the general nature of stream profiles in karst regions as opposed to those in clastic drainage basins.

There has been much interest over the years in the morphometry of streams. The concept of the graded river, with its accompanying idealized longitudinal profile, has been embraced in many forms by many researchers, (Davis, 1902; Hack, 1957; Langbein and Leopold, 1964; Carlston, 1969; and numerous others). Most field and theoretical studies, however, have been concerned with streams in clastic terranes.

The current paper is concerned with the longitudinal profiles of streams in soluble rock (karst) terranes, using examples from drainage basins in the Appalachian Highlands. Previous studies of karst stream profiles in the Appalachians include the Obey River Basin, Tennessee (White and White, 1983) and Burnsville Cove, Virginia (White and Hess, 1983).

The drainage basin of the Dry Fork of the Elk River is located in Pocohantas County in the central-eastern portion of the state of West Virginia, U.S.A. Rocks of Mississippian age are exposed in the area, with the stream network incising through the clastic Mauch Chunk Formation into the Greenbrier Limestone. Physiographically The basin is on the Allegheny Plateau, about 8 Kilometers west of the Allegheny Front. The surface drainage area of the basin is approximately 26 square kilometers. Most of the surface channels are dry except during flood stage. Baseflow drainage is subsurface in a system of caverns whose extent is only partially known at this time. A significant portion of the subsurface drainage routes have been delineated by other workers, (Medville, 1977).

The Lost Cove/Crow Creek drainage basin is located at the extreme southern border of the central portion of the state of Tennessee, U.S.A., in Franklin County. It is on the escarpment of the Cumberland Plateau where stream networks with dendritic patterns are exposing the Bangor Limestone on the valley floors after cutting through the Walden and Lookout Sandstones. The rocks are all of Carboniferous age. Valley floor to plateau relief is on the order of 300 meters. Total drainage area of the basin is 60 square kilometers, with about 39 square kilometers of that area being contributed via a closed depression at the head of the valley which drains through cave systems. The karst hydrology of the system has been investigated extensively by Crawford, (1980, 1978). This area is approximately 800 kilometers south-west of the Dry Fork Elk River area.

The Hills Creek and Bruffey Creek drainage basins lie on the flanks of the Yew Mountains in southern Pocohantas County, West Virginia. The upper portion of the catchment lies on Upper Mississippian and Pennsylvanian age clastic rocks; the lower portion is underlain by the cavernous Mississippian Greenbrier Limestone. Both creeks flow into a karstic valley separated from the main portion of the Greenbrier River Basin by Droop Mountain, 200 meters high, capped with sandstone, but underlain by gently westward dipping Greenbrier Limestone. Some of the overflow from the two drainage basins travels underground along the karst valley to the Friars Hole Cave System. Much of the flow, however, passes directly beneath Droop Mountain to resurge at Locust spring.

The longitudinal profiles of the longest drainage routes in the three basins are shown in figures 1 and 2. One obvious feature is the subsurface drainage route of Crow Creek. It is interesting to note that the underground drainage route serves on the average to smooth the lontigudinal profile. The stream sinks at Big Sink swallet and resurges at Buggytop Cave. The convexity of the upper reach is a result of the incomplete dissection of the

Cumberland Plateau. Although the stream flows on limestone for most of its length, the upper reach is on the Lookout Sandstone.

The Dry Fork Elk River, on the other hand, exhibits a normal stream profile. The valley is underdrained by a shallow conduit system, but the surface channel is maintained and carries water during periods of high runoff. It is considered to be an intermittent stream on the topographic map. The profile of this stream is generally the same as Crow Creek if one disregards the upper convex portion of Crow Creek and its karst saddle above the Big Sink.

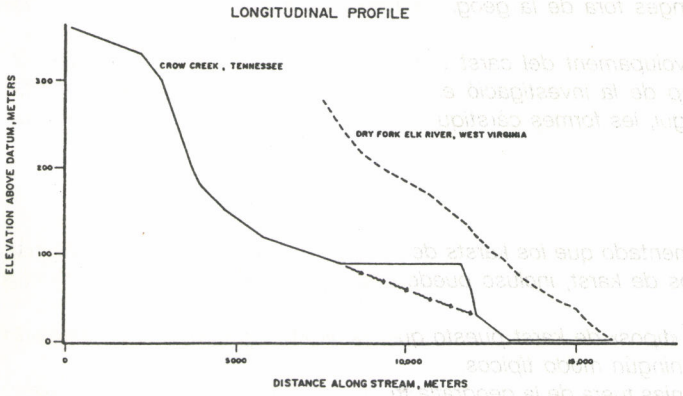

Figure 1. Longitudinal stream profiles of Crow Creek, Tennessee and Dry Fork Elk River, West Virginia. Elevations taken from U.S.G.S. topographic maps. Elevations normalized to zero at mouth of stream networks. Arrows indicate idealized subsurface drainage route from Big Sind swallet to Buggytop Cave. Vertical exaggeration is about 25 times.

The valleys of Hills and Bruffey Creeks are now perched, supported in Pleistocene valley in-filling. The gradients of their lower reaches can be extended across the barrier wall of Droop Mountain and found to be accordant with the doline karst surface in which the Locust Creek channel is incised. In this way blind and underdrained valleys can record older erosion surfaces. The records are preserved in the profiles of the channels, not on terraces or receding knickpoints. Even in this more extreme example of a blind valley, the upper active reaches of the stream can be extrapolated beneath the underdrained and perched karst valley to maintain grade with the resurgence point of the active stream.

In Summary: Allogenic streams that make up much of the drainage system of the fluviokarst of the Appalachian Mountains maintain their profiles through the underground drainage system. Underdrained valleys support normal stream profiles. Those valleys with thalwegs blocked by saddles of barrier ridges maintain a subsurface flow that is close to grade with active allogenic infeeders and with surface streams that head in the resurgences. Dry valley profiles retain an important geomorphic record and are a useful tool for interpretation of valley development.

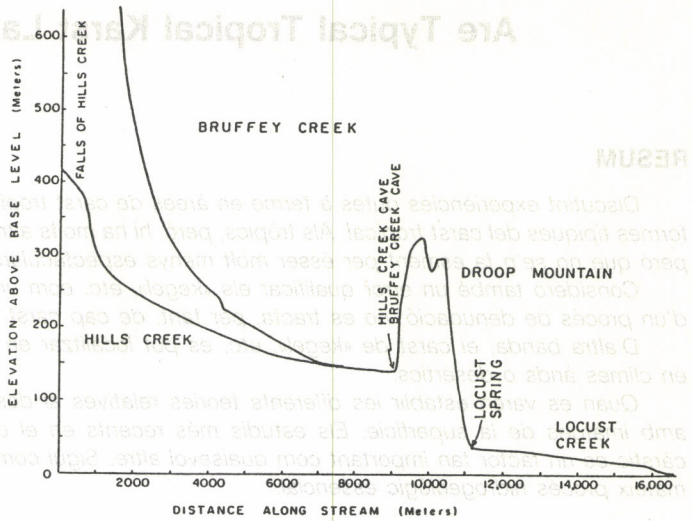

Figure 2. Longitudinal stream profiles of Hills and Bruffey Creeks, West Virginia. Elevations taken from U.S.G.S. topographic maps. Elevations normalized to zero at mouth of stream networks. Vertical exaggeration about 20 times

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Are Typical Tropical Karst Landforms Typical and Tropical?

Dr. Attila Kósa

RESUM

Discutint experiències dutes a terme en àrees de carst tropical s'ha argumentat que els carsts de «kegel», «cons» i «torres» són formes típiques del carst tropical. Als tròpics, però, hi ha molts altres tipus de carst que, possiblement, es trobin amb més abundància, però que no se'n fa esment per ésser molt menys espectaculars.

Considero també un error qualificar els «kegel», etc. com uns tipus de carst, ja que aquests no són altra cosa que el resultat d'un procés de denudació; no es tracta, per tant, de cap carst típic.

D'altra banda, el carst de «kegel», etc. es pot localitzar en franges fora de la geografia tropical i, inclús, en casos especials, en climes àrids o desèrtics.

Quan es varen establir les diferents teories relatives al desenvolupament del carst tropical es van estudiar, fonamentalment, amb imatges de la superfície. Els estudis més recents en el camp de la investigació espeleològica demostren que el drenatge càrstic és un factor tan important com qualsevol altre. Sigui com sigui, les formes càrstiques no són altra cosa que el resultat d'un mateix procés hidrogeològic essencial.

RESUMEN

Discutiendo experiencias en áreas de karst tropical se ha argumentado que los karsts de «kegel», «conos» y «torres» son formas típicas del karst tropical. En los trópicos existen muchos otros tipos de karst, incluso puede que éstas sean mayoría pero mucho menos mencionadas por no ser espectaculares.

Se considera también un error clasificar los «kegel», etc. como «tipos» de karst puesto que éstos no son más que el resultado de un proceso de denudación en condiciones especiales, pero de ningún modo típicos.

Por otro lado, el karst de «kegel», etc. se puede encontrar en franjas fuera de la geografía tropical e incluso, en casos especiales, en climas áridos o desérticos.

Cuando se establecieron las teorías sobre el desarrollo del karst tropical, se estudiaron poco más que con imágenes de la superficie; lo último en el campo de la investigación espeleológica muestra que el drenaje kárstico en los trópicos es un factor tan importante como en cualquier otro lugar. Sea lo que fuere, las formas kársticas no son más que producto del mismo proceso hidrogeológico esencial.

SUMMARY

Discussing experiences in tropical karst areas it is argued that «kegel», «cone» and «tower» karsts were typical landforms of tropical karst. Many other types of karst exist in the tropics, these may even be the majority but much less publicized being not spectacular.

It is considered also a mistake to classify «kegel» and etc. as «types» of karst since these are but phases of a denudation process at special but by no means typical conditions.

On the other hand «kegel», etc. karsts can be found outside of the geographical tropical belt and also in arid or even desertic climates in special cases.

When theories on tropical karst development were conceived little else had been studied than views of the surface. Letter day speleological research proves that karstic drainage is as important a factor in the tropics as anywhere else, whatever karst landforms are but products of the essecially same hydrogeological process.

Leafing through the literature on karsts in the tropics /«tropical karst»/ one gets the idea that the typical result of karstic denudation is always and only a very spectacular multitude of steep, beehive-like hills and/or marching towers over green rice fields. Names were given by the lots, such as kegel-, cone-, tower-, pinnacle-, mogote-, polygonal-, cockpit-, rain forest-, etc. karsts. Many of these names mean the same thing some of them nothing, like rain forest karst /Jakucs, 1977/ Identical phenomena wearing the same names may confuse the reader e.g. kegel-cone or tower-pinnacle etc. while the Cuban mogote means both and more. Needless to say, that there exists a type of karst in the tropics that is usually described as «the typical tropical karst». On the other hand more than this one type of karsts exist in the tropics. Jimenez /1964/ classifies Cuban karsts into the listed types:

1. Mogote karst
2. Hill and mountain karst
3. Plain karst
4. Partially submerged swamp karst
5. Partially undersea karst
6. Coastal karst
7. Terrace karst

It is not very certain, that the specification were complete or flawless, but it certainly shows that out of seven types of karsts ONLY the mogote wears the «typical marks of tropical karst».

There are karst areas at many tropical locations of the World and most of them are known of their chaotic, cockpitty, conehilly, towery nature. There have not been much news about other types of karst in the tropics. Looking at the Cuban example other types must coexist elsewhere whith the «typical» karst but they are largely unknown. No wonder. The majority of tropical lands belong to developing countries, thus local interest and expertship is usually in shortage. Foreign experts visiting these countries have to endure climate, insecurity, retarded communication. What will the expedition discover and explore? Obviously the outstanding, unmistakable «cone/tower» karst. Other types of karst will wait recognition and exploration for next generations.

Typical or not there is a karst type widely considered that, and discussing other types, it offers a lot of difficulties in itself. Does it really have a name? In Cuba they call it the «MOGOTE» karst and whatever it is the Viñales/Sierra de los Órganos/ is a very typical example of it. Let's sit on the terrace of the Los Jasmines Hotel as many intrepid explorers did and look around. We see mountains, the Sierra de Viñales /413 m above sea level/ the Sierra de Guasasa /447 m/ the Mogote de Valle /413 m/ These mountains are separated by a plain on which meandering streams flow. From this flat valley floor conical hills of various height emerge none of them higher than 200 m of elevation. Let us try to classify what we see.

The karstic mountains are topped by a *polygonal plateau* that

is composed of *cone-hills* and *polygonal shaped depressions* or *cockpits*. The karstic mountains which are of practically uniform elevation are parts of a once cotinuous plateau. They are now separated by *border plains* from which karstic *towers* protrude, which are the last remnants of the once continuous limestone on this level. A karstic «tower» may appear in many shapes, it may not be «towery» at all, its emergence of something else than limestone makes it a tower. On the border plain streams or rivers flow that enter and cross the mountains through large caves. Summarised:

Cone hilly, polygonal plateau – streem caves
Karst towers – border plain with rivers

That is, vertical movement of the water – rainfall and infiltration develop the polygonal karst plateau, horizontal water flow develop caves mostly by erosion and finally this leads to the destruction of the thick limestone beds to the degree of oblivion except for the remaining limestone towers. This role of the underground drainage is usually not recognized in classical models of tropical karst still in circulation.

In the described respects «cone», «tower-», etc. karsts can not be identified as types of karst, they are but phases of denudation of a single type. Cones, towers etc. occur in many different *styles* /Williams, 1972/ rather than types.

What would be a good and unmistakable name for the discussed type of tropical karst. «Cone» and «tower» fall out as they do not represent types, only phases of denudation. Also they are the sources of wild mistakes /Jakucs, 1977/ As cave development does not differ much or at all from temperate climate karsts but the surface of limestone that is exposed in plateaus is substantially different –the polygonal depressions must be emphasized as many authors realized. It may be cockpit/cone karst/Jennings, 1985/ As polygonal depressions are not always exactly cockpits *conical-polygonal* karst is suggested as these two features are considered widely as very typical karstic phenomena.

It has been pointed out, that conical-polygonal karst is not exactly «the» typical karst as many others exist in the tropics. If it is not typical, is it tropical? Only tropical? Or do they exist beyond the geographical Tropics? Yes, of course. Two thirds of the most spectacular «tropical» karst in South China is located North of the Tropic of Cancer thus this karst is SUBtropical, not tropical.

Putting the question in a more proper from, do conepolygonal karsts exist in substantially different climates than tropics? The answer is still yes. There is a karst area in North Africa, Libya, Tripolitania /Kósa, 1981/ complete with cone hills, cockpits, border plain, towers. /fig. 1/ Estimated annual rainfall doesn't exceed 130 mm. This amount is about only 10 % of a not very wet tropical area. The climate is desertic. The karstified rock is gypsum. Since the solubility of gypsum is a high multiple of that of limestone, no wonder that with so much less rain still tropical landforms develop.

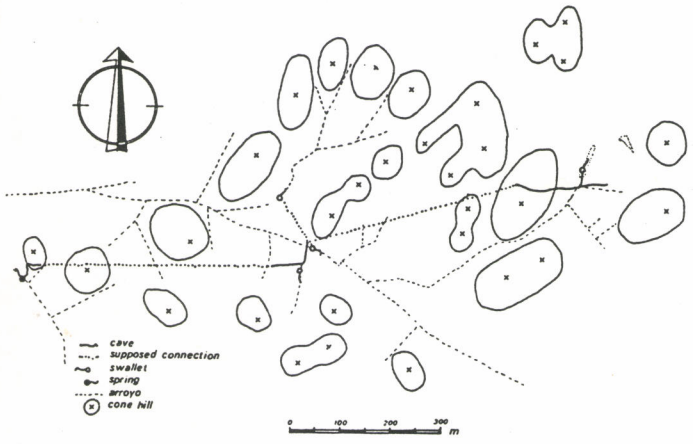

Figure 1. Part of the 300 kmsq desertic conical –polygonal Bir al Ghanam Gypsum Karst. Tripolitania

Are there then conical-polygonal *limestone* karsts in substantially non tropical climates? The answer is still yes. A conical-polygonal karst was recognized in Cyrenaica, Lybia /Kósa-Csernavölgyi, 1983/ in Myocenic limestone. Annual rainfall is an estd. 300 mm and it falls from October to March. Mean temperature of the rainy season is about 15° C, thus the climate is far from tropical. The relief of the karst is rather flat, the diameter/height ratio of the cone hills is 6 to 8 /fig. 2/

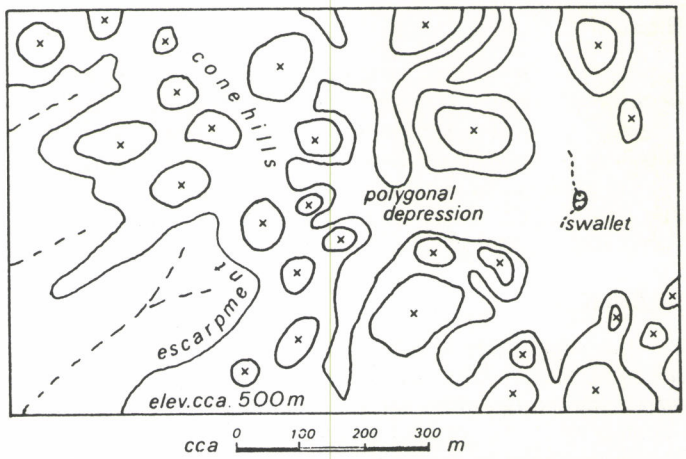

Figure 2. Part of the arid conical-polygonal limestone karst in Cyrenaica, near al Marj. /Sketch from aerial photograph

We have seen conical-polygonal karsts in limestone, marble /Kósa-Szentes, 1984/, gypsum. We have seen c-p karsts in different climates 24° C/2000 mm in Colombia, 23° C/1100 mm in Cuba, 16° C/1150 mm in Kweichow, China, 15° C/300 mm/rainy season/ in Cyrenaica, 15° C/130 mm in Tripolitania, Bir al Ghanam. The differences are substantial and still there must be something that results in the same or very similar type of karst in many different styles. It has been recognized /Sweeting 1973/ that possibly rainfall intensity is responsible for tropical karst landforms, rather than the rest of the factors. This applies to other than tropical climates like our Cyrenaican and Tripolitanian examples, where the intensity of precipitation is usually very high. /No precise data are available here, or almost anywhere else in the tropical karst areas./

Can the rhetorical question in the title of this paper be answered? The exploration of karst in tropical areas is not sufficiently advanced even in the case of the most scenic cone-polygonal karsts. It is hard to tell what percent of all known/unknown karst do they represent, but they are *not exclusively typical* in the tropics. On the other hand they are not *exclusively tropical* either as examples of conical karsts occur in other then tropical climates.

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Estudio preliminar de los cenotes y cavidades del área de Homun-Cuzama, Estado de Yucatán, México

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RESUM

Les característiques climàtiques, geològiques i tectòniques de la península del Yucatán, al sud-est de Mèxic, han fet possible el desenvolupament d'un carst tropical molt característic on hi predominen les formes anomenades «cenotes» (dolines d'enfonsament i cavitats de desenvolupament horitzontal). A la zona de Homún-Cuzama és possible dintingir cinc tipus de formes subterrànies sobre les que exerceixen una influència genètica els sistemes de fractures dominants de la península (N 30° O - N 50° E) i, d'una manera especial, les variacions litològliques de les dues formacions calcàries del Terciari que configuren la zona. També s'ha observat que les variacions del nivell del mar durant el Plistocè han tingut una gran influència en el desenvolupament de les cavitats i dels «cenotes», originant variacions considerables del nivell freàtic.

RESUMEN

Las características climáticas, geológicas y tectónicas de la península de Yucatán, al Sur-Este de Méjico, han permitido el desarrollo de un Karst tropical muy característico donde predominan las formas llamadas «cenotes» (dolinas de hundimiento y cavidades con desarrollo horizontal). En la zona de Homún-Cuzama, se han diferenciado 5 (cinco) tipos de formas subterráneas que tienen la influencia genética de los sistemas de fracturas dominantes en la península (N 30° O - N 50° E) pero sobre todo variaciones litológicas de las 2 (dos) formaciones calcáreas del Terciario, que configuran la zona. También se ha observado que las variaciones del nivel del mar durante el Pleistoceno, han tenido una gran influencia en el desarrollo de las cavidades y cenotes permitiendo variaciones del nivel freático y variaciones considerables.

RESUME

Les caractéristiques climatiques, géologiques et tectoniques de la péninsule de Yucatán, au Sud-Est du Méxique, ont permis un développement d'un karst tropical très caractéristique où prédomine les formes appelées «cenotes» (dolines d'effondrement et cavités à développement horizontal). Dans la zone de Homún-Cuzamá, on a différencié 5 (cinq) types de formes souterraines qui ont eu une influence génétique des systèmes de fractures dominantes dans la péninsule (N 30° W - N 50° E) mais surtout des variations lithologiques des 2 (deux) formations calcaires du Tertiaire, qui conforment la zone. On a aussi observé que les variations du niveau de la mer pendant le Pleistocène, ont eu une grande influence dans le développement des cavités et cenotes permettant des variations du niveau phréatique, et des variations considérables.

Generalidades

El área Homún-Cuzamá se encuentra en la parte Centro NW del estado de Yucatán, dentro de los municipios de Homún y Cuzamá, delimitada por los paralelos 20° 38' y 20° 45' de latitud norte, y los meridianos 89° 15' y 89° 22' de longitud este.

Fisiograficamente se encuentra en la provincia de la Península de Yucatán, dentro de la subprovidencia Planicie Interior, en la porción denominada por Velázquez (1985) «NOROCCIDENTAL» cuyas principales características son: su escaso relieve, suelo delgado y discontinuo y una amplia karstificación cuyas más importantes formas son los Cenotes y cavidades. Las principales características de la Planicie Interior, son la ausencia total de corrientes superficiales como ríos y arroyos y la presencia de un acuífero instalado en calizas terciarias, las cuales tienen una permeabilidad muy alta, de tipo primario y secundario (Lesser y Anaya, 1960) cuyo nivel freático se encuentra entre los 0 y los 20 m de profundidad en la porción noroccidental.

En el área Homún-Cuzamá se estudiaron 135 km^2. Se trata de una región prácticamente plana, con 17 MSNM en promedio, en donde afloran calizas del terciario. Su clima es cálido subhúmedo, del tipo AWO (D.G.G.T.N., 1981), con lluvias en verano y una precipitación media anual de 1.100 mm, la temperatura media anual es de 27° C (D.G.G.T.N., 1981), lo que ha permitido el desarrollo de un bosque tropical caducifolio, muy característico de Yucatán (RZEDOWSKY, 1978).

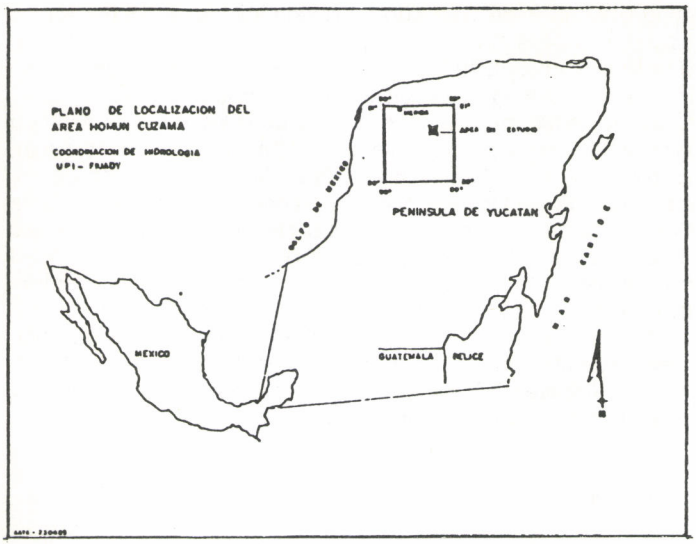
Su paisaje kárstico presenta un lapiaz muy extendido, en forma de pequeñas depresiones circulares del orden de los milímetros, hasta unos pocos centímetros de diámetro y profundidad, muy rara vez llegan a rebasar estas dimensiones. También presenta surcos de disolución poco desarrollados, y las «SARTENEJAS» nombre local dado a formas circulares de pocos centímetros de profundidad y generalmente 1 m de diámetro, en las cuales se acumula agua durante la época de lluvias. Otra característica de la karstificación, es la existencia de campos de lomas circulares, que llegan a alcanzar hasta 5 m de altura. Existen pocas dolinas de disolución, abundando las del tipo «CENOTE» (definidas por Stringfield y Legrand, 1974), originadas por el colapsamiento de los planos de estratificación en el techo de las cavidades.

La karstificación subterránea se manifiesta por la presencia de varios tipos de cavidades, siendo característico, «EL CENOTE», nombre dado localmente a cavernas total o parcialmente inundadas, el cual es una deformación en lengua española de la palabra maya «TS'ONOT» que significa «CAVERNA CON AGUA DEPOSITADA» (Barrera, Vázquez, ET. AL., 1980).

Geología y tectónica

En el área Homún-Cuzamá sólo afloran las formaciones Carrillo Puerto (Mioceno Superior-Plióceno) y Chichen Itzá (Eoceno), ambas compuestas por secuencias calcáreas, cuyas características más importantes se dan a continuación:

FORMACIÓN CARRILLO PUERTO.– Se compone de una secuencia de coquinas, calizas impuras y arcillosas y calizas puras y blancas y duras. La estratificación es muy variable, desde unos 20 cm hasta masiva. Sin embargo, en todas las cavidades estudiadas en esta formación, se observó que los estratos tenían espesores entre 30 y 60 cm, con capas horizontales.––I *FORMACIÓN CHICHÉN ITZÁ.*– Aflora en la Península en tres miembros calcáreos. En nuestra área en estudio únicamente aflora el miembro Pisté (Eoceno Medio) el cual presenta generalmente calizas masivas, finas y amarillentas, aunque en varias cavidades y cenotes



se observaron estratos horizontales entre 0.60 y 1.2 m de espesor.

El contacto entre ambas formaciones es discordante, ya que falta parte del Eoceno Superior, todo el Oligóceno y la mayor parte del Mioceno. Esto parece deberse a una falta de depósito de sedimentos, debido a levantamientos que sufrió el sur de la Península en el Eoceno Superior.

La Península de Yucatán presenta un tectonismo muy somero, especialmente en la Planicie Interior, en donde se manifiesta por 2 sistemas de fracturas cuyas direcciones preferenciales son, entre los 35° y los 65° en uno, y en el otro en los 315° y los 335°. La parte sur de la Península, a partir de la Sierra de Ticul, tiene un tectorismo más acentuado, manifiesto por sistemas de fallas normales, fracturas y pliegues suaves.

Descripción de las cavidades

En la región Homún-Cuzamá se localizaron 18 cavidades, las cuales se clasificaron en 4 tipos, de acuerdo a su morfología:

Las cavidades del tipo I tienen principalmente un desarrollo horizontal, su morfología está influenciada por los sistemas de fracturas y los planos de estratificación. Presentan cuerpos de agua freática, cuyas dimensiones son reducidas. Las entradas de las cuevas o grutas se han originado por colapsamientos a lo largo de los planos de estratificación. Se observó un mayor desarrollo de concreciones en las cuevas de la formación Carrillo Puerto.

En las cavidades del tipo II, la boca casi siempre da inicio a una rampa por medio de la cual se penetra. La morfología de este tipo es variada, pero con una orientación bien definida. Presentan cuerpos de agua relativamente amplios y profundos (hasta 15 m). Estas cavidades llegan a presentar grandes concrecionamientos, y en casi todos los casos grandes columnas y estaláctitas cubiertas por las aguas freáticas. Al igual que en las cavidades del tipo I, colapsamientos sucesivos de los estratos del techo, han abierto sus bocas. Es de notar que estas cavidades sólo se encontraron en la formación Carrillo Puerto.

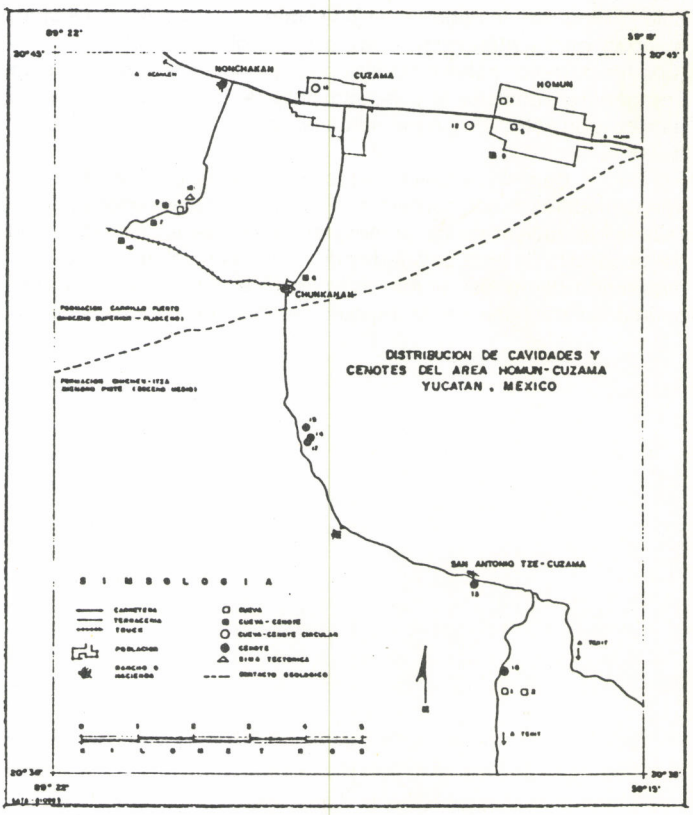
Las cavidades del tipo III, tienen una planta circular y cuerpos de agua amplios y profundos. Su morfología está muy influenciada por colapsos desarrollados a lo largo de los planos de estratificación. Estas cavidades sólo se encontraron en la formación Carrillo Puerto.

Las cavidades del tipo IV, también presentan una planta circular. Sus bocas son muy amplias y circulares. Sus paredes son verticales en la mayor parte de su perímetro. Tienen cuerpos de agua bastante grandes, visibles desde la superficie, que en muchos casos ocupan la mayor parte del fondo de la cavidad. Su interior contiene exuberante vegetación, lo cual ha ocasionado que sus cuerpos de agua tengan poca visibilidad. Su morfología parece deberse a sistemas de fracturas verticales, a lo largo de los cuales han ocurrido colapsamientos, dando el carácter vertical a sus paredes. No se encontró influencia de los planos de estratificación, ya que todas estas cavidades se localizaron en la formación Chichen Itzá en donde predominan las calizas masivas. Tampoco presentan desarrollo de concreciones.

Génesis y desarrollo de las cavidades

En general se ha visto que los factores más importantes que han permitido el origen de las cavernas son:

1. *Presencia de rocas solubles.* Que son los casos de las calizas de las formaciones Carrillo Puerto y Chichen Itzá. Los cambios en el tipo de estratificación entre ambas (estratos delgados para la Carrillo Puerto, y masivos para la Chichen Itzá) han originado estilos diferentes de cavidades, muy específicos para cada formación.
2. *Estructuras Geológicas.* En general se observó como los sistemas de fracturas han influido en la génesis de las cavidades al permitir que las aguas subterráneas circulen más fácilmente a lo largo de éstas. Los planos de estratificación han tenido una influencia muy posterior a la génesis, al permitir colapsamientos y abrirse muchas bocas, dando origen en muchos casos, a la morfología actual. En las calizas que tienden a ser masivas, como las de la formación Chichen Itzá, los colapsamientos han sido preferentemente sobre sistemas de fracturas, estando su morfología más influenciada por este tipo de colapsos.
3. *Naturaleza de Circulación del Agua Subterránea.* El agua ha circulado preferentemente entre los sistemas de fracturas lo que dio origen a las cavidades, parece ser que esta circulación preferente se da principalmente abajo de los primeros metros del nivel freático, lo cual nos ha originado cavidades del tipo freático. La circulación parece que ha sido lenta desde el origen de las cavidades, pero su velocidad puede variar dependiendo de los cambios de dimensiones en los conductos subterráneos.
4. *Nivel Freático.* Durante el pleistóceno el nivel del mar estuvo variando con frecuencia, debido a los cambios climáticos que ocasionaron glaciaciones. Esto causó variacioes, más o menos grandes del nivel freático en la Península, lo cual influyó grandemente en el desarrollo de las cavidades, ya que permitió que éstas tuvieran varios niveles de desarrollo,



los cuales han quedado registrados en las cavernas. Esto se ha evidenciado por la presencia de huecos de disolución en el techo de cavidades secas, y concreciones dentro de los cuerpos de agua en cavidades inundadas.

5. *Climas.* El clima cálido subhúmedo (tropical) del área Homún-Cuzamá, proporciona buenas cantidades de agua a través de la lluvia (1.100 mm anuales), la cual se infiltra rápidamente al acuífero, el escurrimiento en la Planicie Interior no llega a los 10 mm anuales (D.G.G.T.N., 1983). Según Llopis Lladó (1970), las aguas frías son más agresivas que las aguas templadas y calientes (en la Planicie Interior el agua subterránea tiene un promedio de 27° en sus primeros 20 m). Sin embargo, N. Jiménez, V. Panos y O. Stecl (1968), en estudios efectuados en Cuba, señalan que la vegetación exuberante de las regiones tropicales produce cantidades muy grandes de CO_2, lo que elimina la influencia negativa de las altas temperaturas, así como el hecho de que el agua al pasar a través de una cubierta delgada de «TERRA ROSA» (suelo muy frecuente en Yucatán, en espesores delgados) se enriquece mucho de CO_2, lo cual la vuelve muy agresiva.

Conclusiones

En nuestra área en estudio, el agua subterránea circuló preferentemente sobre los sistemas de fracturas disolviendo la caliza a lo largo de sus trazas, dando origen a cavidades de tipo freático. La presencia de huecos de disolución en el techo de algunas cavernas, nos indica la posibilidad de que hubo corrientes de relativa magnitud. La morfología predominante actualmente, se debe al colapsamiento que hubo a lo largo de los planos de estratificación en algunas cavidades del tipo I y en todas las del tipo II y III, y al colapsamiento ocurrido a lo largo de fracturas verticales en las cavidades del tipo IV, y algunas del tipo I. Estos dos tipos de colapsamientos están influidos por el tipo de estratificación, diferentes en las formaciones Carrillo Puerto (delgado) y Chichen Intzá (masiva), lo cual ha diferenciado las cavidades de cada una de las formaciones. Esto mismo, la diferencia de estratificaciones, es lo que ha permitido un mayor concrecionamiento en las cavidades de la formación Carrillo Puerto.

Los colapsamientos han ocurrido gracias al descenso del nivel freático, permitiendo que las cavidades tuvieran acceso a la superficie. Stringfield y Legrand (1974), consdieran a las cavidades abiertas, de Yucatán, como una clase de dolina, la «dolina cenote». (Los tipos tradicionales de dolina son la disolución y las de colapso) caracterizada por el colapsamiento del techo de la cavidad, estrato por estrato, generalmente en calizas con estratificación delgada.

Dentro de las cavidades estudiadas, se ha podido identificar varias modificaciones del nivel freático, ocurridas en épocas geológicamente recientes. La primera corresponde a la etapa inicial del desarrollo de esta cavidades en la que el nivel freático estaba más arriba del actual, al menos unos 15 m. Esto probablemente ocurrió durante una de las etapas interglaciares del pleistóceno, en que el nivel del mar subió considerablemente. Stringfield y Legrand (1974) señalan que el período interglaciar Yarmouthiano, que se inició hace 240.000 años, durante unos 60.000 años (Harmon ET. AL., 1974), fue el último en el que el nivel del mar subió lo suficiente (30 m) para cubrir todo el norte de Yucatán, estando la línea de costa al pie de la Sierra de Ticul. Un segundo movimiento del nivel freático, que tuvo influencia en la génesis de las cavernas, probablemente ocurrió durante la última glaciación, la Wisconsiniana, en la cual el nivel del mar llegó a bajar hasta 110 m (Lorenzo, 1981) lo que permitió el desarrollo de gran cantidad de concrecionamientos, los cuales actualmente se encuentran bajo el nivel freático, al subir de nuevo el nivel del mar.

Algunos cenotes del oriente de Yucatán, en los cuales se han detectado cuerpos de agua con profundidades de hasta 125 m (Gaona Vizcayno, ET. AL., 1985), pudieran tener relación con este descenso del nivel del mar.

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Fluvial Origins of Cockpits

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RESUM

Els estudis del desenvolupament de la topografia dels «cockpit karst» han sigut generalment complexes per la manca de mapes topogràfics adequats i per la duresa del clima i de la topografia.

Algunes àrees de Belize i Guatemala posseeixen un carst cobert. Dels resultats de les anàlisis geomorfològiques d'aquestes regions es dedueix que aquests carsts de torres es van formar arran de la destrucció, per dissolució, de les xarxes fluvials preexistents que s'havien format en roques carbonatades. A Belize, un mostreig dels nivells rocosos i dels materials al·luvials en un d'aquests carsts constitueix una important hipòtesi en aquest sentit.

L'examen d'altres carsts semblants als tròpics ens indica que el model fluvial de desagregació pot tenir una aplicació molt més àmplia que el model del «desenvolupament d'equilibri» sorgit a Nova Guinea.

RESUMEN

Los estudios del desarrollo de la topografia de los «cockpit karst» han sido generalmente complicados por la falta de mapas topográficos adecuados y la dureza del clima y la topografia.

Algunas áreas en Belize i Guatemala están completamente cubiertas. Los resultados de análisis geomorfológicos en estas regiones implican que estos karst de torres se formaron consecuentemente a la destrucción por disolución de las redes fluviales preexistentes que se habían desarrollado en rocas carbonatadas. En Belize, un muestreo de los niveles rocosos y materiales aluviales en uno de estos karsts, constituye una hipótesis importante en este sentido. El examen de otros karsts similares en los trópicos indica que el modelo fluvial de desagregación puede ser de aplicación más amplia que el modelo «desarrollo de equilibrio» desarrollado en Nueva Guinea.

SUMMARY

Studies of the development of «cockpit karst» topography have been generally hampered by lack of adequate topographic maps and the rugged climate and topography.

Several areas in Belize and Guatemala do possess detailed coverage. The results of geomorphic analysis in these regions implies that these cockpiti karsts formed consequently to solutional destruction of pre-existing fluvial networks that had developed on carbonate rocks. In Belize, sampling of bedrock and alluvial materials in one of these karsts strongly supports this contention.

Examination of similar karsts in the tropics indicates that the fluvial disaggregation model may be of broader applicability than the «equilibrium development» model developed in New Guinea.

1039

Effect of Rainfall Intensity on Rill Formation – a Laboratory Experiment

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RESUM

La tècnica descrita per Glew i Ford (1980) per a induir la formació de petits solcs en condicions controlades de laboratori, s'utiliza per a examinar els efectes de la pluja en la gènesi i la morfologia del lapiaz. També s'examina l'efecte dels intervals entre dues pluges i la seva duració.

RESUMEN

La técnica descrita por Glew y Ford (1980) para inducir la formación de pequeños surcos bajo condiciones controladas de laboratorio,se usa para examinar los efectos de la lluvia en la producción y la morfología del lapiaz. También son examinados el efecto de los intérvalos entre dos lluvias y la duración de éstas.

SUMMARY

The technique described by Glew and Ford (1980) to induce rill formation under controlled laboratory conditions is used to examine the effect of intensity of rainfall on the production and the form of rillenkarren. The effect of intervals between, and duration of rainfall is also examined

10115

Polygonal Karst: Contrasts between temperate and tropical varieties

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RESUM

El concepte de carst poligonal va ésser introduït per Williams, per a substituir els conceptes, ambigus en certa manera, de carst de «cockpit» i carst de cons i torres, així com per a donar rellevància a les depressions tancades que representen els punts d'erosió activa. Definint les depressions tancades en termes de drenatge, va ser possible d'avaluar moltes de les seves propietats morfològiques. El concepte pot ésser aplicat al carst de dolines de climes temperats i, de la mateixa manera, pot subdividir-se en cel-les «runoff» internes. S'han fet comparacions entre el carst de dolines del Pennyroyal Plain del centre-sud de Kentuky, el carst de dolines de Highland Rim de Tenesse i el carst de dolines de relleu pobre del nord de Florida amb el carst tropical de Puerto Rico. El concepte de carst poligonal permet de precisar definicions de textura càrstica i pot ésser interpretat en termes de l'estratigrafia local i dins d'un marc estructural.

RESUMEN

El concepto de karst poligonal fue introducido por Williams para sustituir la distinción, en cierta manera ambigua, entre karst de cocpit y karst de conos y torres y para dar relevancia a las depresiones cerradas que representan los puntos de erosión activa. Definiendo las depresiones cerradas en términos de sus divisiones de drenaje, fue posible medir muchas de sus propiedades morfológicas. El concepto puede ser aplicado al karst de dolinas de climas templados y puede asimismo ser subdividido en celdas «runoff» internas. Se han hecho comparaciones entre el karst de dolinas del Pennyroyal Plain del Centro-sur de Kentuky, el karst de dolinas de Highland Rim de Tenesee y el karst de dolinas de bajo relieve del Norte de Florida con el karst tropical de Puerto Rico. El concepto de karst poligonal permite precisar definiciones de textura kártica que en su debido orden puede ser interpretado en términos de la estratigrafía local y marco estructural.

SUMMARY

The concept of polygonal karst was introduced by Williams to replace the somewhat ambiguous distinction between cockpit karst and cone-and –tower karst and to place the emphasis on the closed depressions which represent the sites of active weathering. By defining closed depressions in terms of their drainage divides, it was possible to measure many of their morphological properties. The concept can be applied to temperate climate doline karsts which also drain internally and can likewise be subdivided into internal runoff cells. Comparisons are made between the doline karsts of the Pennyroyal Plain of south-central Kentucky, the Highland Rim doline karst of Tenessee, and the low relief doline karst of north Florida with the tropical karst of Puerto Rico. The polygonal karst concept allows precise definitions of karst texture which in turn can be interpreted in terms of the local stratigraphic and structural setting.

10264

Interconnection Between Large Karst Forms and Tectonic Jointing Distribution

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RESUM

La cova de Novoafonskaja (U.R.S.S.) i les falles del carst de Palancares (Cañada del Hoyo, Espanya), segons (dades de A. Eraso et. al., 1979) són citats com a exemples per a mostrar una interconexió quantitativa entre la carstificació i la fracturació. Per primera vegada s'ha demostrat que les cavitats càrstiques desenvolupades en massissos de roques solubles, i les falles de superfície dels massissos adquireixen la seva màxima dimensió en les zones semi-dissecades per fracturació tectònica, ja que aquestes zones presenten una condició favorable de la seva situació hidrogeològica i de l'estabilitat dels arcs de cavitats. D'altra banda, on el nombre de falles a les cavitats càrstiques és més gran és a les altes zones de fracturació, si bé el tamany de les cavitats és de 2 a 4 vegades més petit que en zones de fracturació mitjana i baixa. Aquestes regularitats, regides per lleis, van acompanyades de seccions transversals, argumentacions i esquemes.

RESUMEN

La cueva Novoafonskaja (URSS) y las fallas de karst en Palancares, la Cañada del Hoyo (España) datos de A. Eraso et, al., 1979, son citados como ejemplos para señalar la interconexión cuantitativa entre la karstificación y la fracturación. Por primera vez se ha demostrado que las cavidades kársticas desarrolladas en los macizos de rocas solubles y las fallas en la superficie de los macizos adquieren su máxima dimensión en las zonas medio disecadas por fracturación tectónica, ya que dichas zonas tienen la

más favorable combinación de situación hidrogeológica y de estabilidad de los arcos de las cavidaddes. Por otra parte, el número de fallas en cavidades kársticas es el máximo en altas zonas de fracturación, mientras que el tamaño de las cavidades es 2-4 veces menor que éstos en zonas de media y ligera fracturación. Las citadas regularidades regidas por ley están ilustradas con secciones transversales, argumentos y esquemas.

SUMMARY

Novoafonskaja Cave (USSR) and karst failures in Palancares and Cañada del Hoyo (Spain) (data by A. Eraso et. al., 1979) are cited as examples to reveal quantitative interconnection between karstification and jointing. It is shown for the first time that karst cavities developed in the massifs of soluble rocks and failures on the massifs surface achieve maximum size in the zone medium dissected by tectonic jointing, for these zones have the most favourable combination of hydrogeological situation and stability conditions of the cavities arches. On the other hand, number of failures over karst cavities is the maximum in highly jointed zones, while size of the cavities is 2-4 times lesser than that in medium and slightly jointed zones. The above-mentioned law-governed regularities are illustrated by cross-sections, plots and schemes.

At present association of karst forms with jointed zones of the massifs formed by soluble rocks is no more in question. D.S.Sokholov yet (1962) showed that tectonic joints cutting the massif as a whole and providing water penetration into the massif play the most important role in formation of karstification.

The problem to be solved by the author is to reveal quantitative connection between karstification and jointing, Novo-Afonskaja Cave (USSR) and karst failures in Palancares and Cañada del Hoyo areas (Spain) given as an example.

Novo-Afonskaja Cave is developed in the north-western slope of the Caucasus, in Gumshikha-Penrtskha massif formed by 300 m Lower Cretaceous limestone thickness. The cave 3,285 long (the square is 49,565 m^2) described in details by L.K. Tentilozov (1976, 1983) consists of vertical and horizontal channels and chambers.

In cave area tectonic jointing has been carefully studied and mapped by the author. The methods of investigation are as follows: int he outcrops tectonic joints bedding elements and the distance between the joints have been measured. All in all, 1.500 joints have been mapped by the author. The data obtained make it possible to receive the scheme of tectonic jointing distribution (Sc 1:1.000) indicating all the joints being mapped by the author. Then the isoline scheme of the common length of tectonic joints calculated per 100 m^2 of the massif surface (L_j, m) has been compiled.

When analysing the scheme of L_j distribution (Fig.1), local zones differing in degree of dissection by tectonic jointing: highly (L_j = 400-600 m), medium (L_j = 200-400 m) and slightly dissected (L_j < 200 m) are distinguished.

Highly dissected zone is on the north of the area under consideration and intersects it in the west-eastern direction. The strike azimuth is 87°, the length and width of the zone are 360 and 50-120 m respectively.

In the area under study highly dissected zones are prevailing. In the northern part of the area these zones are of WE strike, their length and width are 110 and 20 m, L_j = 200 m. Moving to the south, orientation fo the zones changes to NE-SW and even N-S, in some places the W-E orientation is preserved. Slightly dissected zones are associated with the margins of the studied area. In the north part of the region these zones are of WE strike and insignificant size. On the south boundary of the area the strike of the zones changes into NE-SW and their size increases.

Having compared the scheme of tectonic jointing distribution with contour of the cave one can see that the largest and the broadest halls (Moscow, Iverija) are associated with highly dissected zones, while the majority of chambers and channels are developed in medium dissected zones.

Let have a view of a series of geological cross-sections (Fig.2) to reveal interconnection between subsurface cavities distribution and jointing. The cross-section (I-II) shows that large and high halis are associated with the zones highly dissected by tectonic jointing (Abhkazia, Gruzinskih Speleologov, Tbilisi), while minimum values of L_j coincide with the entrance and narrow parts of the cave. Due to high dissection by tectonic jointing in the vicinity of large halls intensive failures of roofs are observed. Cross-section III-IV intersects the Canyon Channel situated between Iverija and Tbilisi halls. The cavity is in the range of L_j values varying from 150 up to 500 m, the maximum depth of the cavity corresponds to the maximum degree of dissection by tectonic jointing (L_j = 500 m). Moscow Hall intersected by cross-section V-VI is in the limits of L_j values from 150 up to 400 m. The broadest and the highest part of the hall coincides with the maximum values of L_j; with the decrease of degree of tectonic jointing dissection, thickness

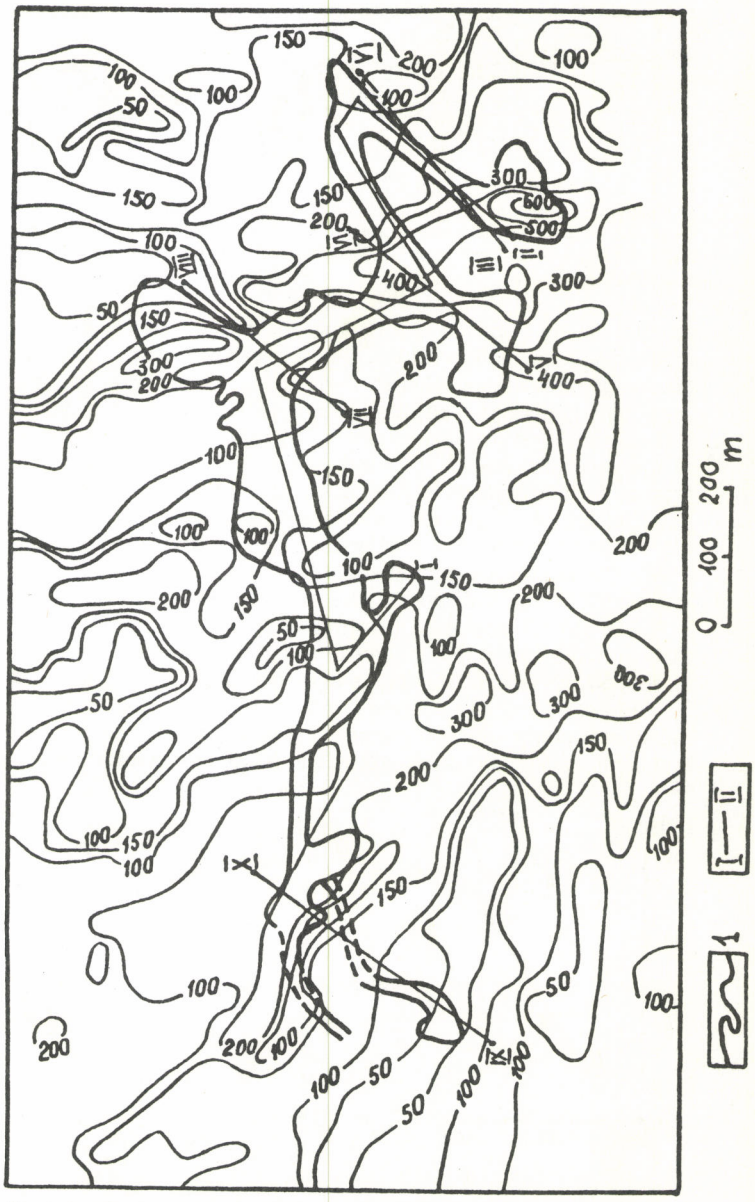

Fig. 1. Isoline scheme of the common length of tectonic joints per 1.000 m^2 of the massif surface (L_j, m) of Novo-Afonskaja Cave area. I – cave contours by L.K. Tentilizov.

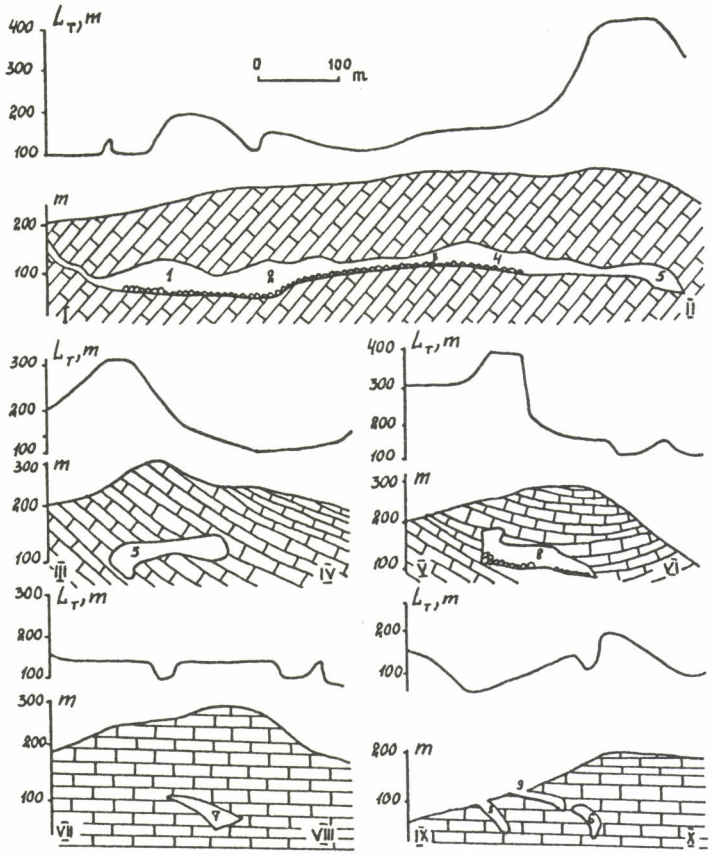

Fig. 2. Correlation of cross-section of Novo-Afonskaja Cave with plots of distribution of the common length of tectonic joints per 1.000 m^2 of the massif surface (L_j, m). Geological cross-sections and jointing are by L.K. Tentilizov, 1983. Zones: 1-Abhkazia; 2-Gruzinskih Speleologov; 3-Canyon; 4-Iverija; 5-Tbilisi; 6-Surprise; 7-Glinaniji; 8-Moscow; 9-Voshkodjaschiji.

of karst-caving deposits and dimensions of the hall are also decreased. Cross-section VII-VIII shows the zone with maximum degree of karstification. Glinjanyi Hall is developed there. The hall is not very large and associated with L_j values varying from about 100 up to 150 m, the maximum height of the hall corresponds to the minimum values of L_j and vice versa. Cross-section IX-X crosses both entrances of the cave and Surprise Hall. The maximum values of L_j coincide with those parts of the cave which are closer to the surface and entrance holes. The deeper is the cavity, the higher are the values of L_j, so dimensions of Surprise Hall developed in that part of the massif where L_j values equal to 200 m are considerable. It worth mentioning in this connection that with the approach to erosional cut the degree of massif dissection by tectonic jointing is also increased.

The analysis of the schemes and cross-sections cited shows the direct interconnection between tectonic jointing distribution and karstification and gives grounds to obtain the plots of dependence of degree of tectonic jointing on karst cavities dimensions.

The dependence of width and height of the main halls of Novo-Afonskaja Cave on the common length of tectonic joints per 1.000 m^2 of the massif surface (L_j) has been analysed by the author (Fig.3). Fig.3 shows the direct dependence of L_j on karst cavities dimensions.

Thus one would think, the higher is the degree of dissection by tectonic jointing, the greater are dimensions of cavities developed in the massif. But, please, do not jump to hasty conclusion.

Analysis and interpretation of the material concerning karstification and jointing of the areas Palancares and Cañada del Hoyo (Spain) published by A. Eraso (1979) showed that dimensions of karst failures on the surface are indirectly and their quantity is directly propotional to the degree of dissection by tectonic jointing.

In Spain Palancares and Cañada del Hoyo areas formed by Cretaceous limestone and dolomite rocks are considered to be the areas of the most intensive karst process development. In 1975-1976 under A. Eraso supervision detailed investigations of tectonic jointing have been carried out in the areas. Every joint (more than 1.000) has been shown on schematic map (Sc 1:5.000); tectonic jointing diagrams have been received and mathematical statistics methods have been used to correlate karst failures distribution with bedding elements of joints.

The author jointly with V.N. Kataev (Pechorkin, Kataev, 1985) compiled the isoline schemes of the common length of tectonic joints per 1.000 m^2 (L_j,m) for the areas of Palancares (Fig.4a) and Cañada del Hoyo (Fig.4b).

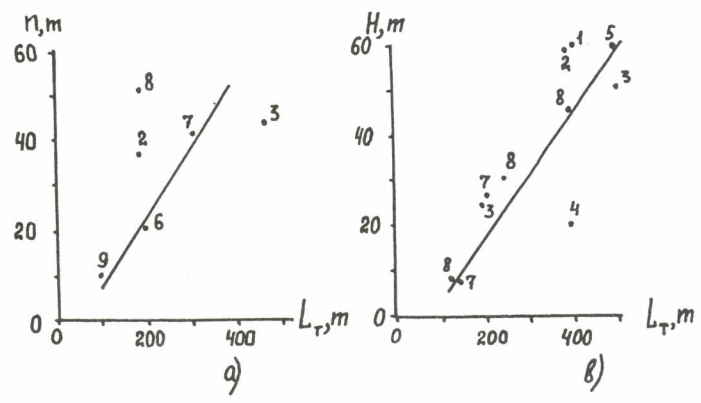

Fig. 3. Interconnection of degree of dessection by tectonic jointing (L_j, common length of joints per 1.000 m^2 of the massif surface) with a) width (N, m) and b) height (H, m) of Novo-Afonskaja Cave (indication see on Fig.2).

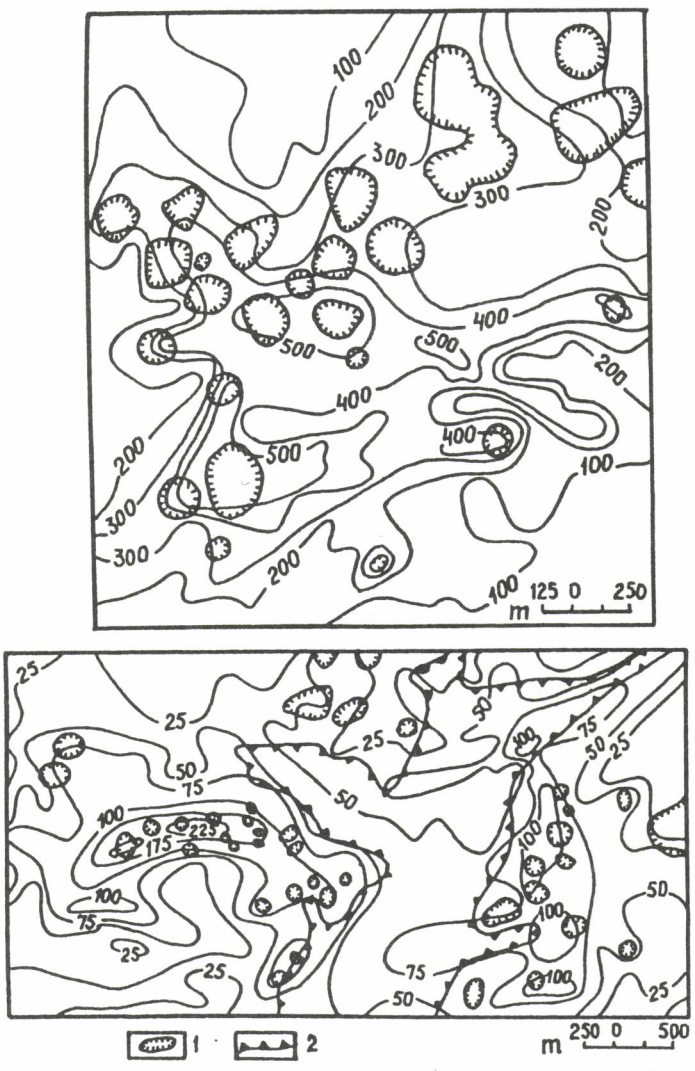

Fig. 4. Distribution of failures and L_j isolines in the areas of Palancares (a) and Cañada del Hoyo (b); 1-contours of failures; 2-boundary of Gudzon Polje (data by A.Eraso, 1979).

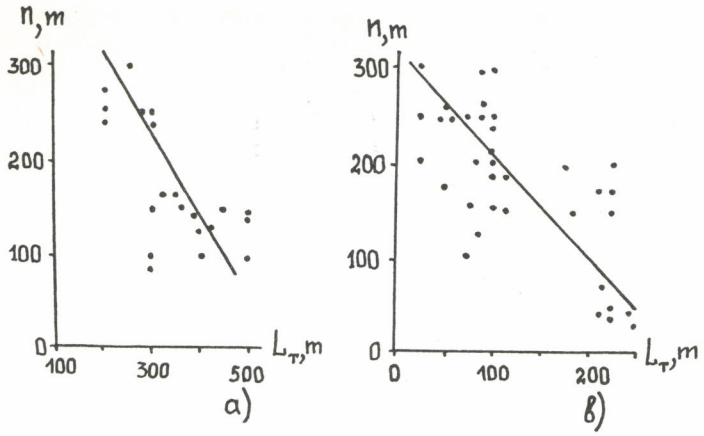

Fig. 5. Interconnection between the common length of joints per 1.000 m^2 of the massif surface (L_j, m) and average width of failures (N, m) for the areas of Palancares (a) and Cañada del Hoyo (b).

Let consider the scheme of jointing and karstification distribution in Palancares area. Three zones differing in dissection by tectonic jointing are distinguished in the area: highly (L_j-500m); medium (L_j-200-500m) and slightly dissected ($L_j < 200$ m). General strike of the zones coincides with the orientation of tectonic jointing revealed by A. Eraso. The scheme shows that the absolute majority of failures are associated with highly and medium dissected zones. Dimensions of failures developed in medium dissected zones are greater than that associated with highly dissected zones.

The same regularities in distribution of jointing and karstification are observed in Cañada del Hoyo area (Fig.4b). However this area is found to have lesser degree of dissection by tectonic jointing. Dimensions of failures are the same as in Palancares area; this fact can be explained by regional peculiarities of karst process development (stability of the cavities roofs through which the failures are occurred, hydrogeological conditions, etc) The values of L_j in highly, medium and slightly dissected zones are 175, 175-50 and 50 m, respectively. Gudzon Polje occupies medium dissected zone developed in the central part of the area. Configuration of L_j isolines coincides with the main direction of failures on the left and on the right sides of the polje. In our opinion A. Eraso was true to suppose that destruction of a great number of failures was due to lateral development of polje.

The plots of dependence of average width of failures (N, m) on the degree of dissection by tectonic jointing (L_j, m) for the both areas show that with the increase of values of L_j, dimensions of failures are decreased. When comparing the plots of dependence of diametrical parameters of karst cavities and failures on jointing one should mention that dimensions of chambers in Novo-Afonskaja Cave are several times greater than that in the areas of Palancares and Cañada del Hoyo: in slightly dissected zones ($L_j = 200$ m) it makes 15 times, while in highly dissected ($L_j = 500$ m) it is as much as 2 times lesser, this fact gives grounds to conclude that the process is more intensive in highly dissected zones. It takes long geological period of time to develop failures even over the largest cavities and even in the zone with the highest degree of L_j.

The above said makes it possible to conclude that in the zones highly dissected by tectonic joints the number and velocity of growth of karst cavities are several times greater than that in medium and slightly dissected zones and dimensions of the cavities and failures over these voids are greater in medium and sometimes slightly dissected zones since these are the zones where conditions for karst cavities development are found to be the most favourable. Joints provide aggressive water inflow into the massif, while insignificant jointing contributes to stability of the arches of large cavities.

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Session: Karstology-Geospeleology

1027

Deforestation on limestone Slopes, Vancouver Island, B.C.

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RESUM

Els efectes de la deforestació en les vessants calcàries seran investigats a la zona nord de les illes de Vancouver. S'utilitzaran zones de bosc verge com a emplaçaments de control de les vessants, las quals: (i) se'ls ha permès que la vegetació es regeneri espontàniament, i (ii) han rabut intervenció humana per a aquest procés de regeneració.

Les zones hipogees (p. e coves) si bé es poden esmentar, el principal objectiu de la conferència estarà relacionat amb els efectes superficials de la deforestació, tals com: l'erosió del sòl, aflorament de la roca mare i la naturtalesa de la vegetació.

RESUMEN

Los efectos de la deforestación en vertientes calizas serán investigados en la zona norte de las Islas de Vancouver. Se utilizarán zonas de bosque virgen como emplazamientos de control de las laderas, las cuales: (i) se les ha permitido que se regenere naturalmente la vegetación y (ii) han recibido ayuda humana para el proceso de regeneración.

Las zonas hipógeas (por ej. cuevas) pueden merecer atención, aunque el principal objetivo de la conferencia estará relacionado con los efectos superficiales de la deforestación, tales como: erosión del suelo, exposición del lecho de rocas y la naturaleza de la vegetación.

SUMMARY

The effects of deforestation on limestone slopes will be investigated in the Northern area of Vancouver Island. Areas of virgin timber will be used as control sites for slopes which have: (i) been left to revegetate naturally, and (ii) received human aid in the revegetation process.

Subsurface areas (eg. caves) may receive some attention, although the focus of the paper will be concerned with the surficial effects of deforestation, such as: soil erosion, bedrock exposure and the nature of the vegetation.

10200

Raised shorecaves on the norwegian west-coast as examples of preglacial morphology in Norway

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RESUM

En els darrers anys, l'autor ha explorat nombroses cavitats costaneres al llarg de la costa atlàntica septentrional de Noruega. Totes elles estan situades enfront del mar actual, però molt per sobre de la línea de la costa postglacial més allunyada de les zones estudiades.

La major part de les coves són de grans dimensions, abundant les de longituds superiors als 100 m. i altures de l'ordre dels 40 m. La més llarga que s'ha estudiat fins avui dia és la de Lispingdalskyrka, amb 325 m., essent la de major volum la d'Helvikshulen, amb una entrada de 250 m. d'amplada i 80 m. d'alçada.

El Dr. Larsen, del Servei Geològic de Noruega ha efectuat, recentment, una sèrie d'excavacions en una d'aquestes cavitats, còncretament la de Skjonghelleren, a Aalesund. En aquesta cova, que conté sediments que arriben a tenir 20 m. de gruix, s'han investigat, amb especial deteniment, alguns estrats «diamicton» que contenien ossaments d'animals. Una datació mitjançant carboni radiactiu dels ossos situats en l'estrat més recent, a 2 metres de profunditat, va donar una edat de 29.590 ± 800 anys B.P. La datació per mètodes estratigràfics d'un nivell situat a 6 metres de profunditat revela una edat de-120.000 anys, que coincideix amb l'inici de la glaciació de Weichsel.

RESUMEN

En los últimos años el autor ha explorado numerosas cavidades costeras a lo largo de la costa Atlántica septentrional de Noruega. Todas ellas están situadas frente al mar actual pero muy por encima de la línea de costa postglacial más alta en las zonas estudiadas.

La mayor parte de las cuevas son de grandes dimensiones, esencialmente con longitudes superiores a los 100 m. y alturas alrededor de los 40 m. La más l arga estudiada hasta hoy es Lispingdalskyrka, con 325 m., siendo la de mayor volumen Helvikshulen cuya entrada mide 250 m. de ancho por 80 de altura.

El Dr. Larsen, del Servicio Geológico de Noruega ha efectuado recientemente excavaciones en una de estas cavidades Skjonghelleren en Aalesund. En esta cueva que contiene espesores de 20 m. de sedimentos, se han investigado con especial atención algunos estratos diacmitón contenían osamentas de animales. Una datación mediante carbono radioactivo de los huesos situados en el más reciente de estos estratos, a 2 metros de profundidad, dió una edad de 29.590 ± 800 años bp. La datación por métodos estratigráficos de un nivel situado a 6 metros de profundidad revela una edad de-120.000 años, lo que significa el comienzo de la glaciación Weichsel.

SUMMARY

During the last years several coastal caves along the northern Atlantic coast of Norway have been researched by the author. All of these caves are facing the present sea, but are situated well above the highest postglacial shoreline in the researched areas.

The caves are mostly of gigantic sizes, mostly measuring a lenth of more than 100 m, and a higth around 40 m. the longest cave so far studied is the Lispingdalskyrka, 325 m long, and the most voluminoues is Helvikshulen with an entrance measuring: width 250 m, and higth 80 m.

One of the caves Skjonhelleren at Aalesund has recently been excavated by dr. E. Larsen, Geological Survey of Norway. In this cave, containing 20 m thick layers of sediments, several diamicton layers containing animal bones have been researched. A radiocarbon date from bones in the upper of these layers, 2 m down in the sediment pack, gave an age of 29,590 ± 800 yrs. B.P. stratigraphical datings of a diamicton layer 6 m down, indicates an age of-120.000 years, which means the beginning of the Weichsel glaciation.

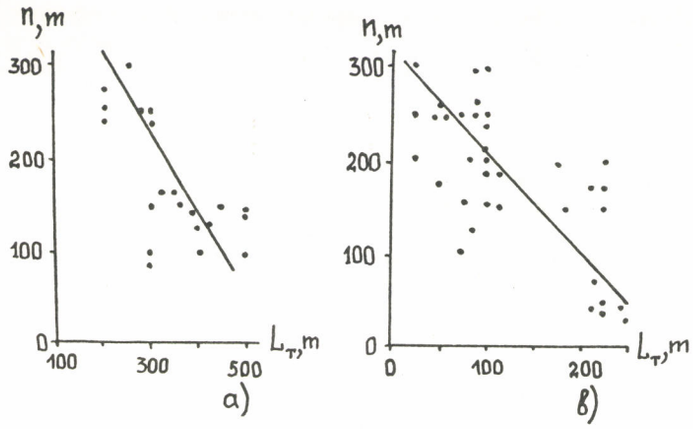

Fig. 5. Interconnection between the common length of joints per 1.000 m^2 of the massif surface (L_j, m) and average width of failures (N, m) for the areas of Palancares (a) and Cañada del Hoyo (b).

Let consider the scheme of jointing and karstification distribution in Palancares area. Three zones differing in dissection by tectonic jointing are distinguished in the area: highly (L_j-500m); medium (L_j-200-500m) and slightly dissected ($L_j < 200$ m). General strike of the zones coincides with the orientation of tectonic jointing revealed by A. Eraso. The scheme shows that the absolute majority of failures are associated with highly and medium dissected zones. Dimensions of failures developed in medium dissected zones are greater than that associated with highly dissected zones.

The same regularities in distribution of jointing and karstification are observed in Cañada del Hoyo area (Fig.4b). However this area is found to have lesser degree of dissection by tectonic jointing. Dimensions of failures are the same as in Palancares area; this fact can be explained by regional peculiarities of karst process development (stability of the cavities roofs through which the failures are occurred, hydrogeological conditions, etc) The values of L_j in highly, medium and slightly dissected zones are 175, 175-50 and 50 m, respectively. Gudzon Polje occupies medium dissected zone developed in the central part of the area. Configuration of L_j isolines coincides with the main direction of failures on the left and on the right sides of the polje. In our opinion A. Eraso was true to suppose that destruction of a great number of failures was due to lateral development of polje.

The plots of dependence of average width of failures (N, m) on the degree of dissection by tectonic jointing (L_j, m) for the both areas show that with the increase of values of L_j, dimensions of failures are decreased. When comparing the plots of dependence of diametrical parameters of karst cavities and failures on jointing one should mention that dimensions of chambers in Novo-Afonskaja Cave are several times greater than that in the areas of Palancares and Cañada del Hoyo: in slightly dissected zones ($L_j = 200$ m) it makes 15 times, while in highly dissected ($L_j = 500$ m) it is as much as 2 times lesser, this fact gives grounds to conclude that the process is more intensive in highly dissected zones. It takes long geological period of time to develop failures even over the largest cavities and even in the zone with the highest degree of L_j.

The above said makes it possible to conclude that in the zones highly dissected by tectonic joints the number and velocity of growth of karst cavities are several times greater than that in medium and slightly dissected zones and dimensions of the cavities and failures over these voids are greater in medium and sometimes slightly dissected zones since these are the zones where conditions for karst cavities development are found to be the most favourable. Joints provide aggressive water inflow into the massif, while insignificant jointing contributes to stability of the arches of large cavities.

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Deforestation on limestone Slopes, Vancouver Island, B.C.

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RESUM

Els efectes de la deforestació en les vessants calcàries seran investigats a la zona nord de les illes de Vancouver. S'utilitzaran zones de bosc verge com a emplaçaments de control de les vessants, las quals: (i) se'ls ha permès que la vegetació es regeneri espontàniament, i (ii) han rabut intervenció humana per a aquest procés de regeneració.

Les zones hipogees (p. e coves) si bé es poden esmentar, el principal objectiu de la conferència estarà relacionat amb els efectes superficials de la deforestació, tals com: l'erosió del sòl, aflorament de la roca mare i la naturtalesa de la vegetació.

RESUMEN

Los efectos de la deforestación en vertientes calizas serán investigados en la zona norte de las Islas de Vancouver. Se utilizarán zonas de bosque virgen como emplazamientos de control de las laderas, las cuales: (i) se les ha permitido que se regenere naturalmente la vegetación y (ii) han recibido ayuda humana para el proceso de regeneración.

to continuous over the northern half of Canada today and extends hundreds of metres deep in the northern islands.

type is limited to truly preglacial cave systems. Normally they will be truncated and left relict by glacial action but their surviving

Las zonas hipógeas (por ej. cuevas) pueden merecer atención, aunque el principal objetivo de la conferencia estará relacionado con los efectos superficiales de la deforestación, tales como: erosión del suelo, exposición del lecho de rocas y la naturaleza de la vegetación.

morphology may display no effects of glacial action or of proglacial fluvial action. 2) *Postglacial karst* - this type includes many caves, karren types and some smaller solution dolines. The form develops after ice retreat and has no glacial morphologic component within it although glacial morphology may help to determined its location.

There are two categories of polygenetic landforms; 3) *Glaciokarstic landforms* are karts landforms subsequently modified by glacial erosion or deposition. 4) *Karstiglacial landforms* are glacial landforms, such as scour holes, that are adapted and modified by subsequent karst solution. In many glaciated karst terrains it is evident that large forms (big dolines, turloughs, dry valleys, etc.) are complex polygenetic features. For example, interglacial karst action may convert an earlier glacial depression into a polje which is then highly modified in one or more later glaciations.

A final and more unusual category is the 5) *Permafrozem (paleo) karst of Subglacial Origin.* This type widely represented in the arctic islands of Canada where it occurs as series of karst solution corridors. They are large and sometimes form intersecting paterns. Most are partly filled with glacial till. They are permafrogen. There can be no Kant solution of their lower walls and their floors because these lie below the limit of summer thaw water penetration. They are a paleokarst form. They were created by meltwater dissolution when glaciers buried the rock, insulating it to permit geothermal heat to warm it and the ice base to the pressure melting point of the ice.

The general conclusion is that, whether one studies dissolution processes or surface and undergroud morphology or grounater systems (aquifers), the effects of glacial action in a karst area can be most varied. They are not simply predictable in many instances.

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Karst phenomena in disaggregated carbonate rocks

S. Dzulynski and J. Rudnicki

RESUM

Les roques carbonatades recristal-litzades' són parcialment disgregables, essent el resultat final una massa de partícules cristal-lines esmicolades. La circulació de l'aigua a través d'aquestes roques origina unes formes càrstiques característiques. En l'origen d'aquestes formes hi juga un paper molt important la corrosió, per la qual cosa la sorra resultant és transportada per les aigües subterrànies arribant a constituir una gran part dels dipòsits subterranis. Els límits de les roques desagregades i les discontinuïtats inherents a la seva formació són alguns dels factors que condicionen la forma i l'estructura dels fenòmens càrstics considerats.

RESUMEN

Las rocas carbonatadas recristalizadas son parcialmente disgregables siendo su resultado final una masa de partículas cristalinas desmenuzadas. La circulación de las aguas a través de estas rocas origina unas formas kársticas particulares. En el origen de tales formas juega un papel muy importante la corrosión, por lo que las arenas resultantes son transportadas por las aguas subterráneas y pueden constituir una gran parte de los depósitos subterráneos. Los límites de las rocas desagregadas y las discontinuidades inherentes a su formación son algunos de los factores que condicionan la forma y estructura de los fenómenos kársticos considerados.

SUMMARY

Recrystallized carbonate rocks are prone to disaggregation, the end product of which is a friable and/or loose mass of crystalline grains. The transfer of aqueous solution through the disaggregated rocks gives rise to specific underground karst features. In the development of such features an important role is played by corrasion wehereby the detached grains are redistributed by underground waters and may constitute a significant part of cave deposits. The boundaries of disaggregated bodies and the discontinuities inherent to the formation of such bodies are among the factors controlling the form and structure of the karst features under consideration.

Introduction

Dolomites and, to a lesser extent, limestones are prone to solutional disaggregation and are transformed into a friable and porous mass of grains through recrystallization and subsequent dissolution of crystal edges. Such transformation results from a slow nonintegrated movement of aqueous solutions of any origin and temperature and is commonly promoted by the disprupting action of crystallizing salts. The disaggregated carbonates are usually referred to as «sanded» /Lovering et al., 1949/ or, more properly, «pulverulent» /Jackucs 1977/. The solutional disaggregation operates under different conditions and may be part of karst phenomena. The disaggregated carbonate rocks are seen to envelope hydrothermal karst conduits /Jackucs 1977/. They have also been reported from various karst terranes where the disaggregation is associated with surficial processes /Zogović 1966, Monroe 1976, Franco 1978/. The disaggregated carbonate rocks are sites of specific cavity-meaking processes which fall into the realm of karst phenomena. The literature concerning the formation of caves in disaggregated carbonates is scarce and it is only recently and notably in Poland that some work has been done on this subject /see references/. The aim of the present paper is to give a short résumé of these studies

Stages of disaggregation.

The disaggregated portions of the rocks involved occur in the form of variously shaped bodies made up of a porous mosaic of crystals with abundant dissolution vugs along the crystal edges. The «sanded» bodies exhibit various stages of disaggregation. The incipient stages are characterized by the appearance of small

isolated patches or spaces filled with the mosaic of crystals /fig. 1,A/. These spaces are irregular and variously sized but are volumetrically subordinate to the unaltered rock. In more advanced stages of alteration, the disaggregated portions become mutually interconnected to form an irregular, closely-spaced «sanded branchwork» /fig. 1,B/. In a further development the disconnected relics of still unchanged and hard rock become suspended in the disaggregated carbonate /fig. 1,C/. The relics exhibit irregular surfacesetched by recrystallization but retain most of their original petrologic properties. The contacts between the unaltered rock and the recrystallized portions may be abrupt or transitional over short distances. The ultimate development of disaggregation leads to a total transformation of hard carbonate rocks into a structureless and friable mass of crystalline grains in which all vestiges of primary structures and textures are obliterated /fig. 1, D /Dzulynski and Kubicz 1971, Dzulynski and Sass-Gustkiewicz 1985/.

Development of caverns in disaggregated carbonate Being highly porous the disaggregated portions offer an easy acces to percolating underground waters and aqueous solutions. If interconnected, such portions tend to intercept and integrate the underground circulation. This results in an increased dissolution of grains and their removal by mechanical means. Consequently, the interconnected «sanded» bodies are transformed into transmissive system of conduits which differ from typical karst cavities in that the corrasion plays an important and, sometimes, dominant role in their formation. The detached grains are readily moved by underground waters and redeposited in cavities in which they may constitute an essential part of internal sediments/see eg., Kendall 1960, Bogacz et al. 1973/. Another effect of water circulation is solutional thining of disaggregated carbonates due to the settling of particles reduced in size by dissolution. This, has an important bearing on the development of karst cavities.

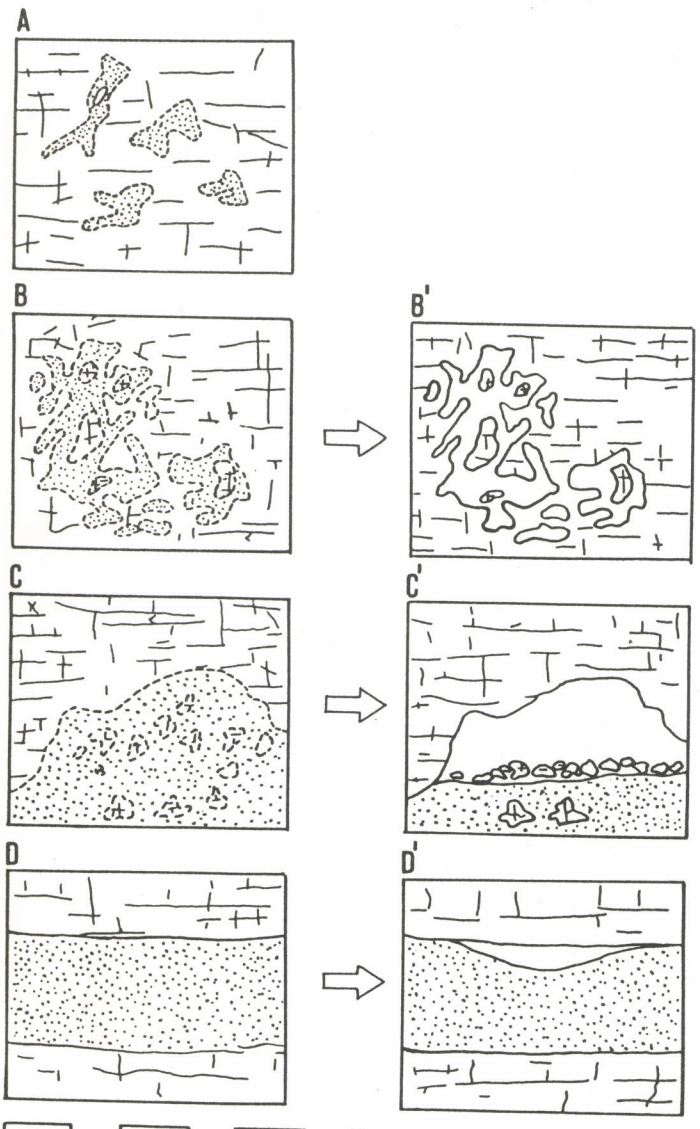

Fig. 1. Development of cavern in disaggregated carbonate rocks. A-B-C-D various stages of disaggregation B',C',D' caverns, 1– solid lithified carbonate rocks, 2– disaggregated carbonate rocks, 3– relics of lithified carbonates, 4– empty caverns. Modified after, Dzulynski, Sass-Gustkiewicz, 1985.

The boundaries of sanded bodies are among the most important factors controlling the development of caverns in disaggregated carbonates. The removal of detached grains from sanded branch-works brings about the appearance of «branchwork cavities» The wolls of which coincide with the boundaries of sanded bodies /fig. 1, B'/. Good examples of such cavities have been reported from disaggregated Muschelkalk limestone of Upper Silesia /Dzulnynski and Kubicz 1971/, where there are all possible transitions between the sanded branchworks and the branchwork cavities. The pattern of such cavities is similar to that of spongework cavities. It is possible that some of the spongework cavities in carbonate rocks might have evolved from branchwork cavities. This conclusion, however, cannot be generalized.

With more extensive disaggregation, large caverns tend to develop along the upper boundaries of sanded bodies. The development of such caverns is initiated by solutional thinning of the disaggregated bodies induced by the settling of solutionally diminished grains. With roughly convex upper boundaries of sanded bodies, the incipient openings are irregularly dined /fig. 1C'/. This is the case with the Pleistocene karst caverns in disaggregated Muschelkalk limestones of Upper Silesia which are filled with both the detached limestone grains and fluvioglacial sediments /fig. 2./.

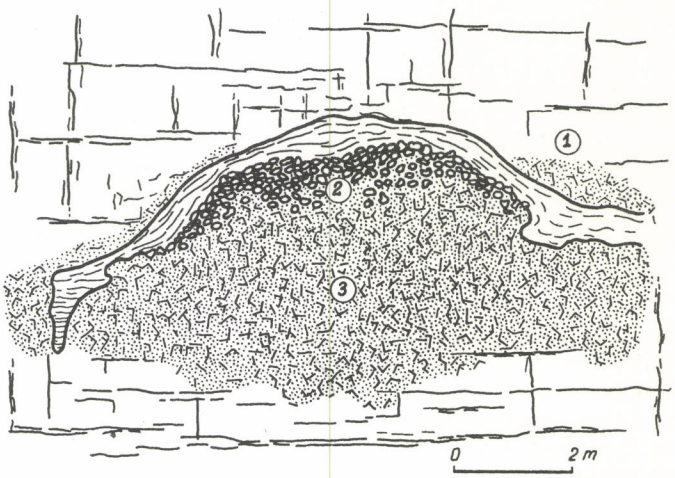

Fig. 2. Cavern developed at top of sanded limestone. 1– clay, 2– accumulation of relics, 3– disaggregated limestone with relics, Kamien Slaski. After Dzulnski, Kubicz, 1971.

Where the upper boundaries of sanded bodies are flat, the karst openings produced may acquire plano-concave crossections /fig 1D'/. This is the case with underground paleokarst features developed in ore-bearing dolomites of Triassic age in Upper Silesia /fig. 3/. The channel-like shapes of the caverns resulted presumably from mechanical removal of sanded grains by solutions intercepted and integrated in the incipient cavities produced by settling of dolomite grains.

As noted, the solutionally diminished dolomite and/or calcite crystals constitute an essential part of autochthonous clastic sedi-

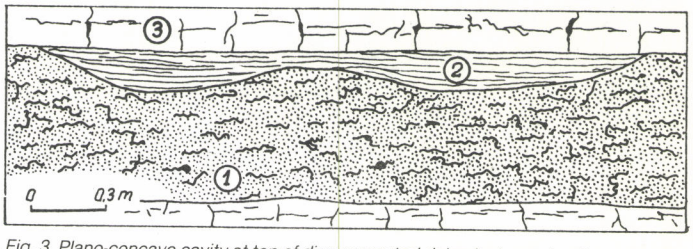

Fig. 3. Plano-concave cavity at top of disaggregated dolomite layer. 1– disaggregated ore brearing dolomite with galena/black/, 2– cave filled with redeposited dolomite grains, 3– hard dolomite. Kata. Modified after, Bogacz, Dzulunski, Haranczyk 1973.

ments laid down in caverns developed in disaggregated carbonates. In addition to coarse debris produced by massive or piecemeal roof failures of caverns such sedimenta contain also accumilations of rock fragments which do not fit into the generally accepted categories of cave deposits. Reference is here made to relics of still lithified rocks which originally were suspended in a porous and friable mass of crystals. With successive removal of such crystals, the relics accumulated at the bottom caverns to produce a specific type residuals which are seldom if ever present in karst caverns developed in non disaggregated carbonate rocks /Dzulynski and Kubicz 1971, see also fig. 1C' and 2 in this paper/.

Where the recrystallization and disaggregation processes affected extensive bodies of carbonate rocks, transforming them into a homogeneous mass of crystalline grains, the rhythmic difussion bands /Liesegang rings/ may influence the development of caverns. An interesting example of such caverns has been recently described from Miocene limestones of Central Cuba /Dzulynski and Rudnicki –in press/. The rhythmic diffusion bands, atributed to alternating episodes of drying and wetting occur here in the form of irregularly curved, semi– concentric or concentric bands /fig. 4/. Some of these bands were dissolved to produce

Fig. 4. Concentric pattern of diffusion bands in disaggregated limestones. Güira de Melena, Cuba.

narrow sheet-fissures the walls of which became hardened by recementation. This resulted in the appearance of a solid framework within a soft mass of crystalline grains. In a further development, the uncemented grains were removed by corrasion and dissolution exposing the framework of parallel hard strips in much the same way as it is the case with boxwork structures /fig. 5/.

Fig. 5. Exposed solid framework and cavities produced by removal of disaggregated calcite crystals. Tres Marias, Cuba.

Concluding remarks

From the foregoing considerations it appears that the formation of karst caverns in disaggregated carbonates differs from that observed in massive compact limestones and dolomites. The dissolution, while initiating the integration of underground circulation, thereafter plays a subordinate role, the main work on cavity making being done by corrasion. The pattern of caverns in disaggregated carbonates is chiefly determined by the distribution and shape of sanded bodies. The role of joints and bedding surfaces is here of lesser importance. The solutional thinning in disaggregated carbonate is promoted by the settling of individual grains which is seldom if ever observed in compact limestones or dolomites. Finally, with very advanced disaggregation, and «homogenization» of the rocks involved, the diffusion rings may become important factors influencing the pattern and distribution of caverns.

The cavity-forming processes discussed lie on the margin of the karst phenomena proper. It is realized, however, that the dissolution is here constantly attending the mechanical removal of particles. Moreover, the cavities once produced may serve as passageways for underground waters and undergo further enlargement and modifications in much the same way as it is the case with typical karst cavities.

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Contributo ad una classificazione genetica delle doline murgiane

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RESUM

Constatada l'absència d'una relació i d'una classificació morfogenètica de les dolines de la Puglia, els autors es proposen de fer una sèrie de puntualitzacions sobre el grau de coneixement actual d'aquesta fenomenologia càrstica superficial.
En el present treball s'examinen les dolines més representatives de la Murgue (zona càrstica més representativa de la Puglia), les quals, a la part septentrional, adopten la denominació de «puli» (Pulo de Altamura, Pulo de Molfetta, etc.).
Es per això que, en un quadre, representem les característiques litològiques, estratigràfiques i tectòniques de l'àrea examinada i alhora debatim els problemes relacionats amb l'origen i l'evolució d'aquests fenòmens càrstics, proposant un criteri per a la seva classificació genètica.

RESUMEN

Revelada la falta de censo y de una clasificación morfogenética de las dolinas de la Puglia, los Autores se proponen puntualizar sobre el grado actual de conocimiento de esta fenomenología kárstica superficial.
En el presente trabajo se examinan las dolinas más representativas de la Murge (zona kárstica más representativa de la Puglia), las cuales en la parte septentrional toman la denominación característica de «puli» (Pulo de Altamura, Pulo de Molfetta, etc.).
Por esto viene representado un cuadro de las características litológicas, estatrigráficas y tectónicas del área examinada y se discuten los problemas que siempre conciernen al origen y la evolución de estos fenómenos kársticos, proponiendo un criterio para su clasificación genética.

RIASSUNTO

Rilevata la mancanza di un censimento e di una classificazione morfogenetica generale delle doline pugliesi, gli Autori si propongono di fare il punto sull'attuale grado di conoscenza di queste fenomenologie carsiche superficiali. Nel presente lavoro, vengono esaminate le più rappresentative doline delle Murge (area carsica centrale della Puglia), che nella parte settentrionale prendono la caratteristica denominazione de «puli» (pulo di Altamura, Pulo di Molfetta, ecc...).
Viene quindi presentato un quadro delle caratteristiche litologiche, strtigrafiche e tettoniche dell'area in esame e si discudono i problemi che tuttora riguardano l'origine e l'evoluzione di questi fenomeni carsici, proponendo un criterio per una loro classificazione genetica.

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A Theory of Rillenkarren Formation

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RESUM

El lapiaz es forma a la part superior i a l'aresta d'un bloc, on la profunditat de l'aigua d'escorrentia és petita. Més avall, on la velocitat de l'aigua d'escorrentia és més gran, desapareix el lapiaz. El laboratori de simulació ha formulat una teoria per a explicar aquests fenómens en blocs de guix, seguint la tècnica de Glew and Ford (1980). L'impacte de la gota sobre una pel·lícula d'aigua farà que aquesta s'obri camí a través de l'extensió laminar, causant de la turbulència i d'una solució d'acceleració. Això tindrà lloc a una profunditat crítica, més enllà de la qual solament és perturbada la superfície de circulació, però l'extensió laminar de la superfície de la roca segueix imperturbable. Les dimensions del lapiaz format dependran, doncs, de l'equilibri entre l'energia de les gotes (en relació amb el tamany i la rapidesa) i el volum d'aigua (en relació amb la intensitat de la pluja).

RESUMEN

Los lapiaces se forman en la parte superior y en la arista de un bloque, donde la profundidad del agua de escorrentía es pequeña. Más abajo, donde la profundidad del agua de escorrentía es mayor, desaparecen los lapiaces. El laboratorio de simulación ha formulado una teoría para explicar esto con bloques de yeso, siguiendo la técnica de Glew and Ford (1980). El impacto de la gota sobre una película de agua, se abrirá un camino a través de la extensión laminar, causante de la turbulencia y una solución en aceleración. Esto se presentará en una profundidad crítica más allá de la cual solamente es perturbada la superficie de circulación, pero la extensión laminar en la superficie de la roca sigue imperturbable. Las dimensiones de los lapiaces formados dependerán pues del equilibrio entre la energía de las gotas de agua (en relación con el tamaño y la rapidez) y el volumen de agua (en relación con la intensidad de lluvia.)

RESUME

Les Rillenkarren se forment au sommet de l'arrête d'un bloc, où la profondeur d'eau d'écoulement est petite. Plus bas, les rillenkarren disparaissent, où la profondeur d'écoulement est plus grande. Une théorie pour expliquer cela a été formulée et testée par le laboratoire de simulation avec des blocs de gypse, suivant la technique de Glew and Ford (1980). L'impact de la goutte d'eau sur une pellicule d'eau, va se frayer un passage à travers l'étendue laminée, causant de la turbulence et une solution en accélération. Ceci va se présenter à une profondeur critique au delà de laquelle seule la surface d'écoulement est perturbée, mais l'étendue laminée sur la surface de la roche demeure imperturbée. Les dimensions des rillenkarren formés vont alors dépendre de l'équilibre entre l'énergie des gouttes d'eau (relatif à la taille et à la rapidité) et le volume de l'eau (relatif à l'intensité de pluie).

Rillenkarren form on the top edge of a slab where the depth of runoff is small. Further down, where the depth of flow is greater, rillenkarren fade out. A theory to explain this is formulated and tested by laboratory simulation with gypsum blocks following the technique of Glew and Ford (1980). Raindrop impact on a film of water will break through the laminar layer, causing turbulence and accelerating solution. This will occur up to a critical depth beyond which only the surface of the flow is disturbed but the laminar layer on the surface of the rock remains undisturbed. The dimensions of the rillenkarren formed will thus depend on the balance between the energy of the raindrops (related to velocity and size) and the volume of water (intensity of rainfall).

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The Utilisation of remote sensing in the Bohemian Karst

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RESUM

Un conjunt selectiu de fotoalineacions obtingudes a partir de la interpretació de les fotos còsmiques del Kosmos i del Landsat, en relació a un marc tectònic conegut, a part de constituir una demostració geofísica d'una sèrie de deformacions de l'estructura geològica, permet detectar anomalies geofísiques i establir les direccions de les seccions de les xarxes fluvials i les direccions principals de la carstificació.

El fonament d'aquestes correlacions es basa en el supòsit de què les fotoalineacions ens indiquen la direcció d'algunes falles,de sistemes de falles o, sovint, de sistemes de diaclasses referides a espais tectònics actius. Podem definir amb certes garanties aquestes discontinuïtats pels mètodes normals de cartografia geològica, però hi ha parts sobresortints com la morfoestructura lineal.

Les proves que avalen aquestes investigacions ens demostren una estreta relació entre els sistemes de fractures, xarxes fluvials i procesos de carstificació. Això ens indica l'important paper que juguen les fractures en les calcàries fortament estratificades.

Les seccions de xarxes fluvials (passos 2 i 5 Km.) i les cavitats formades al llarg dels sistemes de diaclasses tenen una gran permeabilitat.

RESUMEN

Un conjunto selectivo de fotoalineaciones obtenidas de los análisis de las fotos cósmicas por el Kosmos y Landsat, está en relación con un marco tectónico conocido, la demostración geofísica de deformaciones de la estructura geológica, anomalías geofísicas, direcciones de secciones de la red de valles y las direcciones principales de la karstificación.

La base para estas correlaciones es la suposición de que las fotoalineaciones indicaban el curso de algunas fallas, sistemas de fallas, o frecuentemente sistemas de diaclasas sobre los espacios tetónicos activos. Podemos definir con seguridd estas discontinuidades por métodos normales de cartografía geológica, pero existen partes sobresalientes como la morfoestructura lineal.

Las pruebas de conformidad demuestran la relación especialmente entre los sitemas de fracturas, red de valles y karstificación. Esto indica el importante papel de las soluciones de discontinuidad en calizas fuertemente estratificadas.

Secciones de red de valles, (pasos 2 y 5 Km.) y cavidades formadas a lo largo de sistemas de diaclasas, que tienen una gran permeabilidad.

SUMMARY

Selective collection of photolineations acquired from analysis of the cosmic photos by Kosmos and Landsat is correlation with known tectonik frame, geophysical demonstration of structural-geological deformations, geophysical anomalies, directions of sections of valley network and main directions of the karstificaction.

The basement for these correlations is supposition that the photolineations presented the course of some faults, system of faults or frequently systems of associated joint above tectonically active space. We can hardly state this joints of current methods of geologic mapping, but they are outstanding like the linear morphostruktures.

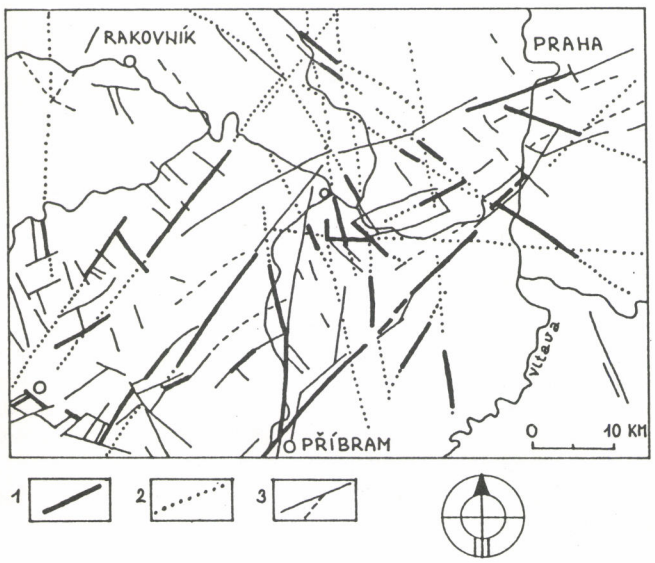
The test of conformity demonstrate the correspondence especially among the system of joints, valley network and karstification. This indicate important role of joints in highly jointed limestones. Sections of walley network/steps 2 and 5 km/ and caves formed along systems of joints, which has high permeability.

The Bohemian Karst is situated between Prague and Zdice in the central Barrandien region. The best known sedimentary basin of Old Paleozoic is defined as a linear, tectonically predisposed depresion which was of a rift character/Havlíček 1981/. The Bohemian Karst represents the area of the Siluro-Devonian boundary formations, which are characteristized by a complete sequence in the carbonate facies. The sediments were intensively folded into a system of folds and overthrusts with an expresive vergence. The intensity of the folding declined gradually to the SW. The develpment of Karst phenomena depended on the lithological and structural conditions in the isolated limestones zones. The various types of primary and secondary Karst phenomena are mainly concentrated to vertical and subvertical joints. Directions N-S, NW-SE and ENE-WSW are predominants and determined the development of studied forms of Karst. The large horizontal caves are unknowning. For example the largest cave system/Koněprusy caves/with total lenght about 2.000 m is only 200 m long at of a single directions. One of the most reasons can be the neotectonic activity or the short cours of joints systems.

Therefore we prepared the structural scheme of photolineaments acquired from analysis of the cosmic photos/ Lysenko 1983/. This scheme is compiled on the basis of decoding of space imagery from different sources/Kosmos 912, 1033, Landsat from May 1973, 1975-1976/. Selective collection of photolineations is corelated with known tectonic frame, geophysical indications of fault discontinuities, geophysical anomalies, directions of sections of valley network/Lysenko, Jančar.35ík 1984/and main directions of the karstification.

The results of correlation

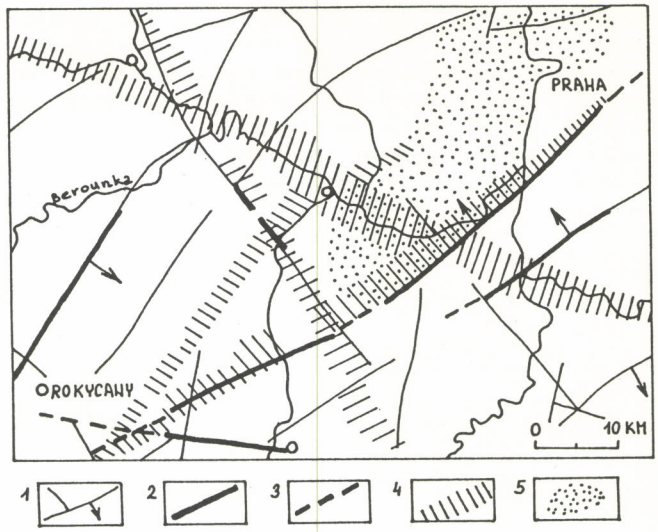
a/ A good correlation exists in the course of the tectonic linear structures of the fundamental faults, faults systems, flexures with system of photolineaments. Photolineaments identify the cours of these elements even outside segments proved by the geological mapping/Fig.1a/.



1-lines identical with faults, 2-continuation of photolineaments exceeding known fault segments, 3-faults, flexures.

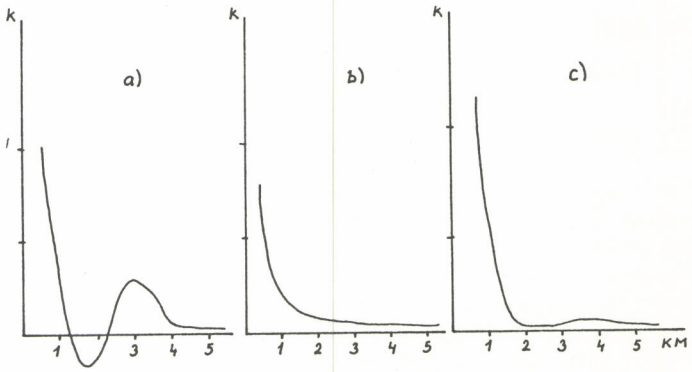
b/ The central part of the Barrandien, between Beroun and Prague is the area of negative gravity anomaly limited by geophysically well indicated linear structures: the deep fault systems Kladno et NW and By Závist overthrust at SE. Corresponding photolineaments are traceable in longer distance than single faults, and the area of anomaly is delimited more perfectly by them.

c/ For test of conformity we employed the steps 2, 5, 10 and 20 km long/Jančařík, Lysenko 1985/. The linear structures of N-S, WNW-ESE and ENE-WSW directions are typical of the short steps/

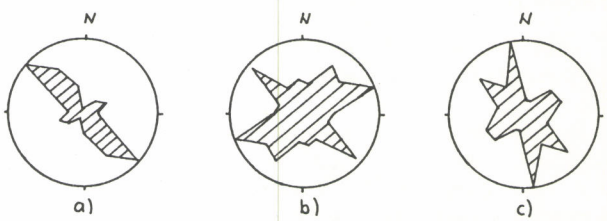


1-indications of systems of linear discontinuities with supposed discontinuity dip, 2-photolineaments identical with linear discontinuities, 3-continuations of photolineations exceeding known segments of linear discontinuities, 4-expressive zone of photolineations, 5-negative gravity anomalies in the area of Bohemian Karst.

to 5 km/. The NE-SW system of photolineaments predominates to long steps. The tectonic lines in the studied area and system of photolineaments are mutually displacement by 3 km in diametre /Fig 2a./.



a-photolineations and tectonics, b-sections of valley network/Berounka river/and photolineations, c-sections of valley network and tectonics.



a-tectonics of the Bohemian Karst, b-photolineaments, c-directions of karstification.

d/ Good correlation exist in the course of system of photolineaments and of linear tectonic structures with the direction of single segments of valley network for River Berounka. The most numerous directions of course valley network and photolineaments corresponded. Outside Bohemian Karst the valley network of other rivers have only the poor coincidance.

Disscusion

The rose diagrams of linear structures and main directions of the karstification shows the difference of frequency. The majority of the cave was developed along fissures of direction N-S/3a/, the tectonic lines and photolineaments are most frequent along directions NW-SE and NE-SW. This discrepancy was explained in part by test of conformity. The test showed that N-S directions

predominate especially by the short steps. They represents probably the system of short joints with higher permeability.

These joint systems influenced the direcitons of short segments of valley network and played the most important role during the origin of caves. The majority of underground cavities was developed along them, but the lenght of horizontal karstification is only minimal therefore.

I suppose that the pressented method can be used for the better indentification and classification of linear structures in the regions of karst.

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Interstratal (subsurface) karst in the cretaceous lloydminster sub-basin (western interior plains, Alberta and Saskatchewan, Canada)

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Husky Oil Operations Ltd.

RESUM

L'estudi geològic del Cretaci Inferior del Mannville Group, a la zona de petroli dens de Lloydminster, ha posat de manifest que gran part del desenvolupament de l'estructura de Mannville fou degut a la carstificació interestratal (dissolució sub-superficial) de les roques paleozoiques subjacents.

El Mannville Group està constituït per sèries d'arenisques, roques sedimentàries, pissarres i vetes de carbó que recobreixen de forma discordant els carbonats erosionats del Devonià Superior i que es troben alhora coberts de sediments clàstics del Colorado Group: Grans (10^0 – 10^1 Km. de diàmetre i a més de 120 m. de profunditat) i petits (de 10^2 – 10^3 m. de diàmetre i entre 5 i 45 m. de profunditat); sinformes subcirculars i allargats persisteixen des de la disconformitat fins a la sèrie completa de Mannville i és freqüent de trobar-los dins l'àrea. S'ha pogut comprovar que els sinformes amples són cavitats d'enderrocament desenvolupades arran de la carstificació interestratal de les evaporites del Devonià Mitjà que es troben sota els carbonats del Devonià Superior, mentre que els sinformes ('sinkholes' associats principalment amb estructures carbonatades superiors) es poden haver desenvolupat com a resultat de la carstificació interestratal dels carbonats. Tant les formes d'enderrocament petites com les més grans són posteriors al Mannville.

RESUMEN

El estudio geológico del Cretácico inferior del Mannville Group en la zona de petróleo denso del Lloydminster, ha revelado que gran parte de la estructura de Mannville, cuyo desarrollo fué debido a la karstificación interestratal (solución subsuperficial) de las rocas Paleozoicas subyacentes.

El Mannville Group son series de areniscas, rocas sedimentarias, pizarras y vetas de carbón que recubren de modo discordante los carbonatos erosionados del Devónico Superior y están a su vez recubiertos por sedimentos clásticos del Colorado Group. Grande (10^0 – 10^1 km. de diámetro. y superior a 120 m. de profundidad) y pequeño (10^2 – 10^3 m. de diámetro, 5 – 45 m. de profundidad) sinformes subcirculares y alargados persisten desde la disconformidad hasta la completa serie de Mannville y se encuentran comunmente en el área. La evidencia indica que los sinformes anchos son huecos de derrumbamiento que se desarrollan debido a la karstificación interestratal de las evaporitas del Devónico Medio que se encuentran debajo de los carbonatos del Devónico Superior, mientras que los sinformes ('sinkholes'; principalmente asociadas con estructuras carbonatadas altas) pueden haberse desarrollado como resultado de la karstificación interestratal de los carbonatos. Tanto las formas de hundimiento pequeñas como las grandes son posteriores al Mannville.

SUMMARY

Geological study of the Lower Cretaceous Mannville Group in the Lloydminster heavy oil area has revealed that much of the Mannville structure developed due to interstratal karstification (subsurface solution) of underlying Paleozoic rocks.

The Mannville Group is a series of sandstone, silstone, shale and coal beds which unconformably overlie eroded Upper Devonian carbonates and are in turn overlain by clastic sediments of the Colorado Group. Large (10^0 – 10^1 km in diameter and up to 120 m deep) and small (10^2 – 10^3 m in diameter, 5 – 45 m deep) subcircular and elongate synforms persist from the unconformity through the entire Mannville sequence, and are commonly found in the area.

Evidence indicates that the large synforms are collapse hollows which developed due to interstratal karstification of Middle Devonian evaporites underlying the Upper Devonian carbonates, whereas the smalls synforms ('sinkholes'; mainly associated with carbonate structural highs) may have developed as a result of interstratal karstification of the carbonates. Both the large and small subsidence synforms are post-Mannville in age.

Introduction

Lower Cretaceous (Albian) Mannville strata infilling the Lloydminster sub-basin (Orr et al., 1977) of east-central Alberta and west-central Saskatchewan display a variety of structural features (Gregor et al., 1985; Klovan et al., 1986). These features include large (10^0 – 10^1 km in diameter and up 130 m deep) and small (10^2 – 10^3 in diameter, 5 – 45 m deep) subcircular and elogate synforms, isolated or arranged in complex patterns, which persist from the base to the top of the Mannville. It can be observed that the large synforms are restricted to the Saskatchewan side of the sub-basin, whereas the small synforms occur in both Alberta and Saskatchewan.

This study attempts to outline the genesis of both the large and small synforms in the Lloydminster heavy oil area (Fig. 1) of

Fig. 1. Location map of the study area.

the Lloydminster sub-basin. The area comprises ca. 22.000 km^2, extending from Township 042 to 054, and Range 17W3 to 07W4M. The study is based on geological data gathered from some 11.500 wells drilled in the area prior to January 1, 1986 and incorporated in a computerized data base. The maps presented in this study were all produced using the Interactive Surface Modeling (ISM) program developed by Dynamic Graphics Inc., California.

Stratigraphy, basin configuration and geologic setting

The Mannville Group in the study area is a 60 – 220 m thick series of sandstone, siltstone, shale and coal beds which unconformably overlie eroded Upper Devonian (mostly Frasnian) carbonates and are in turn overlain by clastic sediments of the Colorado Group. Rocks subcropping at the pre-Cretaceous unconformity include limestones and dolomites (both massive and interbedded), calcareous shale, and shale. Total thickness of the Upper Devonian strata ranges from 300 to some 1.000 m. The Upper Devonian strata are underlain by the Middle Devonian Elk Point Group which, in the study area, is represented by up to 400 m thick

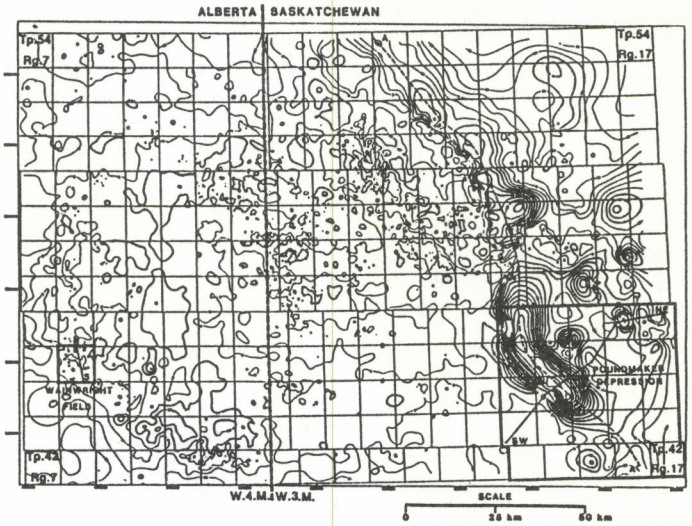

Fig. 2. Structural configuration of the top of the Mannville, a second order residual surface. Contour interval 10 m. The main «salt» collapse belt is identified by a dashed line (A-A'). Lines marked SW-NE and N-S indicate the orientation of structural cross-sections shown of Fig. 4 and 7 respectively.

evaporites of the Prairie Fm., and underlying carbonates of the Winnipegosis Fm. The Winnipegosis carbonates unconformably overlie older (Ordovician and Cambrian) rocks which rest on the Precambrian basement.

The pre-Cretaceous unconformity is an irregular erosional paleotopographic surface which may be described as an ancient, relatively mature, river dissected landscape. In the study area this surface includes a system of generally NW-SE trending structural highs ('ridges'; Fig. 3) separated by lows ('valleys'); total relief may exceed 100 m.

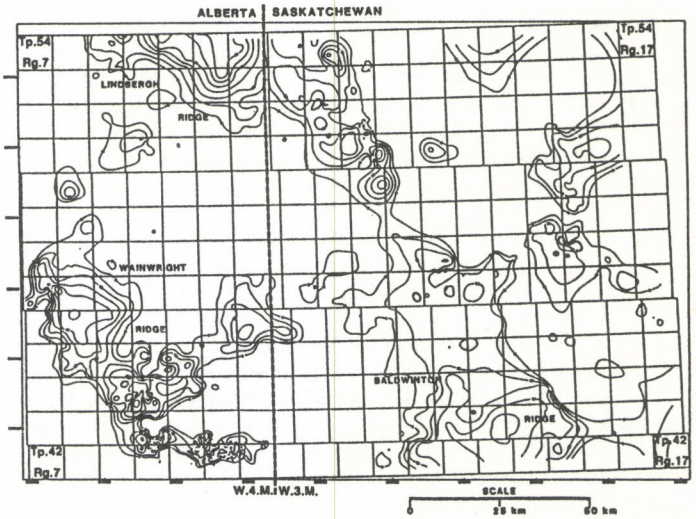

Fig. 3. Structural configuration of the pre-Cretaceous unconformity, a second order residual surface. The map is filtered to show positive relief only. Contour interval 10 m.

The unconformity surface is criss-crossed by sets of NE and NW oriented linears. The linears persist from the basement through the entire Paleozoic and Mesozoic sedimentary sequence, and are correlatable with major photolineaments observed in the study area. It is suggested that the NE striking linears are of wrench and/or oblique-slip fault nature. Episodic (Precambrian to Recent) movements along these linears may have generated and/or reactivated sets of NW striking orthogonals –normals faults and open fractures– which in turn provided conduits for concentrated fluid flow.

Interstratal karst related to evaporite dissolution

The term 'interstratal karst' (Quinlan, in Sweeting, 1973) describes karst developed in subsurface, beneath a thick, solid, non-

soluble, non autochthonous overburden. (Note: this type of karst differs from that developed under a soil cover, either autochthonous or allogenous, which is termed 'covered karst'). Subsidence synforms (collapse hollows), formed either slowly or rapidly, are the most typical features of interstratal karst (Sweeting, 1973).

Stratigraphic and seismic evidence indicates that the large synforms occurring in the Mesozoic strata of west-central and southern Saskatchewan (inclusive of the study area) are subsidence structures which have resulted from interstratal karstification (subsurface dissolution and removal) of evaporites of the Prairie Fm.; subsidence has been documented to have occurred over a long span of time (DeMille et al., 1964; Holter, 1969; etc.). Inspection of intra and supra Mannville isopach maps (not included) indicates that subsidence commenced in pre-Cretaceous time, probably in the Late Devonian (Wilmot, 1984). Another notable phase, comprising at least two discrete subphases, occurred during Early Cretaceous (Mannville) time. However, the main phase of interstratal karstification of the Prairie Fm., which accounts for much of the Mannville solution-related structure, is post-Colorado in age (Klovan et al., 1986). Pleistocene phases of evaporite dissolution have been documented southeast of the study area (Christiansen, 1970). It can be demonstrated that, on a regional scale, evaporite dissolution-generated synforms become progressively younger toward the southeast.

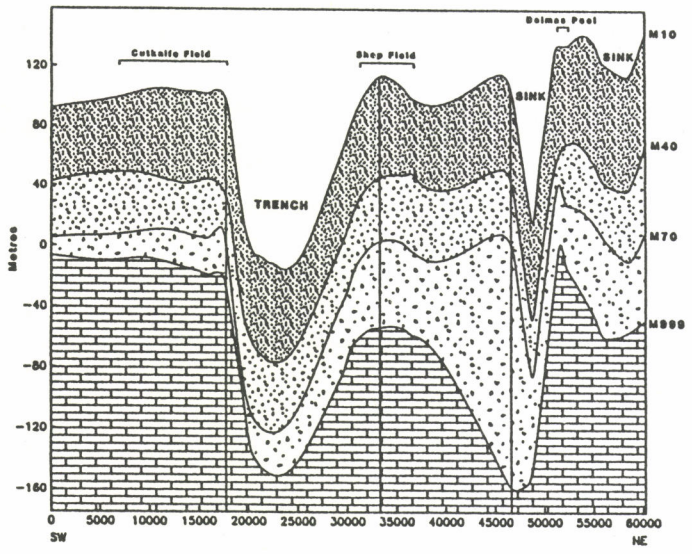

Fig. 4. Structural cross-section (SW-NE) of the Poundmaker depression area (courtesy of G. S. Jones, Husky Oil). Scale in meters. M10 –top of the Mannville; M999– pre-Cretaceous unconformity; M40 and M70 –intra– Mannville markers.

Figure 2 portrays the structural configuration on the top of the Mannville Group in the study area by means of a second order residual surface (this surface removes the effect or regional tilting and accentuates structural variations). A major, generally NW-SE trending, trough-like structure (A-A') is evident in the eastern (Saskatchewan) portion of the study area. The structure represents the middle portion of the main 'salt' collapse belt, a regional structure which extends beyond the study area, toward both the N-NW and S-SE, and, according to some authors (e.g. Holter, 1969), is associated with the eastern edge of the Prairie Fm. (Note: a SW-NE oriented cross-section and a three-dimensional view of the prominent Poundmaker depression in the SE portion of the structure are on Fig. 4 and 5 respectively) The orientation of the structure seems to reflect the influence of deep-seated, NW-SE oriented tectonic trends and, thus, support the concept of episodic, or episodically culminating, tectonically controlled dissolution (Klovan et al,. 1986). According to this concept, dissolution phases may possibly be related to episodes of reactivation of basement structures due to orogenic movements, postorogenic adjustments, or other causes. Thus, it can be postulated that the pre-Mannville (late Devonian) dissolution phase was related to the Antler orogeny, the intra-Mannville phases to Columbian movements, and the major, post-Mannville (post-Colorado) phase to the Laramide orogeny and/or postorogenic movements. The Pleistocene dissolution phase(s) may reflect basement adjustments resulting from drastic changes in thickness of the overburden caused by Pleistocene glacial events.

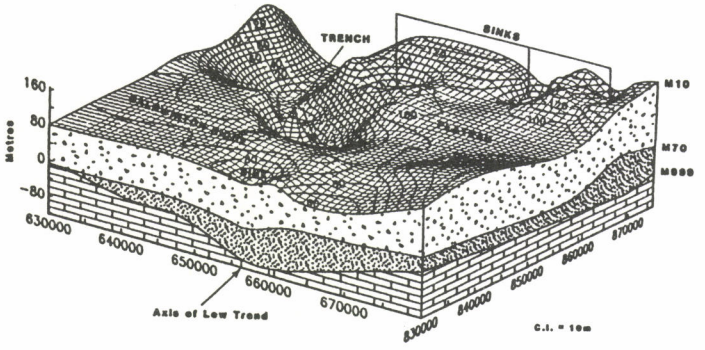

Fig. 5. Block diagram of the Poundmaker depression area (courtesy of G. S. Jones, Husky Oil). Scale in meters. M10 –top of the Mannville; M999– pre-Cretaceous unconformity; M70 –an intra– Mannville marker.

Interstratal karst related to carbonate dissolution

Detailed structural mapping of the Mannville Group in the Wainwright oil field (Fig. 6 and 7) and some other areas discloses the presence of a variety of small-scale features which persist from the base to the top of the Mannville. These include:

(a) small (10^2 – 10^3 m in diameter and 5 – 45 m deep) isolated synforms, subcircular or elongated, strongly resembling solutional and collapsed karst dolines (sinkholes);
(b) dendritic, valley-like patterns of structural lows, resembling the morphology of karst valleys originating by the amalgamation of karst dolines (sinkholes); and
(c) isolated conical antiforms, remotely resembling cupolas of tropical conical karst ('kegelkarst').

Most of these features seem to be associated with major structural highs ('carbonate ridges') observed on the pre-Cretaceous unconformity surface (Fig. 3). Because there is no evidence of evaporite dissolution and removal beneath the highs and, more importantly, the dendritic, valley-like patterns do no seem to fit the evaporite dissolution mechanism, it is suggested that these features may have developed as a result of two distinct phases of carbonate dissolution:

(1) an early, pre-Mannville, subaerial phase;
(2) a late, post-Mannville, interstratal phase.

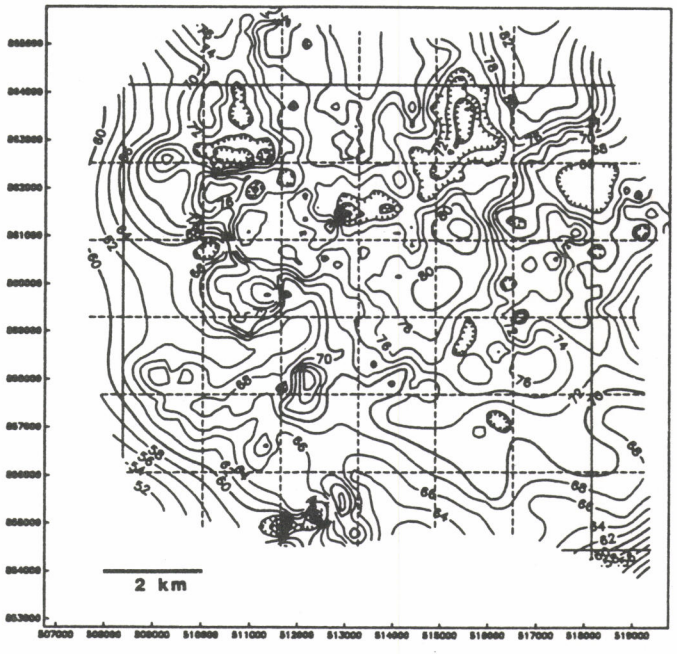

Fig. 6. Present day structure on the top of the Mannville, the Wainwright oil field Contour interval 2 m.

In support of this hypothesis are the following facts:

(a) the highs are actually low relief carbonate plateaux, with low to moderately dipping slopes. Assuming favourable climate, subaerial dissolution-related karst could have developed over these plateaux during the pre-Cretaceous period of non-deposition and erosion.

(b) Impure limestones and dolomites are abundant at the pre-Cretaceous unconformity surface. These lithologies, when exposed to atmospheric effects, give rise to fluviokarstic relief (Sweeting, 1973). Note that the topographic assemblage on the top of the Mannville mimics fluviokarstic relief more than any other type.

(c) Paleokarst, developed in Mississippian Madison limestones and covered with autochthonous materials, termed the Residual Zone, is known to occur at the unconformity surface south of the study area (White, 1972).

(d) Lost circulation problems are often encountered when drilling into the Upper Devonian strata, especially in the Wainwright oil field. This indicates the presence of extremely well developed zones of porosity and permeability which in turn are indicative of karstification of these rocks.

(e) The only mechanism, besides subsidence caused by interstratal carbonate dissolution, which could account for upward transmission of the pre-Mannville karst topography, is differential compaction. However, this notion can be discounted for the following reasons:
   - to account for the up to 45 m relief observed on some of the synformal features on the top of the Mannville would require about 120 m of shale (assuming 30 % compaction) juxtaposed against a totally non-compacting lithology; there simply is not that much shale in the Mannville Group. Computer-generated maps show that there are only minor differences between regional Mannville structures based on a compacted and an uncompacted Mannville sequence.
   - One of the features of structures caused by diffrential compaction is that the diminish in relief upward, usually much more drastically than those observed in the Mannville (Fig. 7) and attributed to carbonate dissolution.

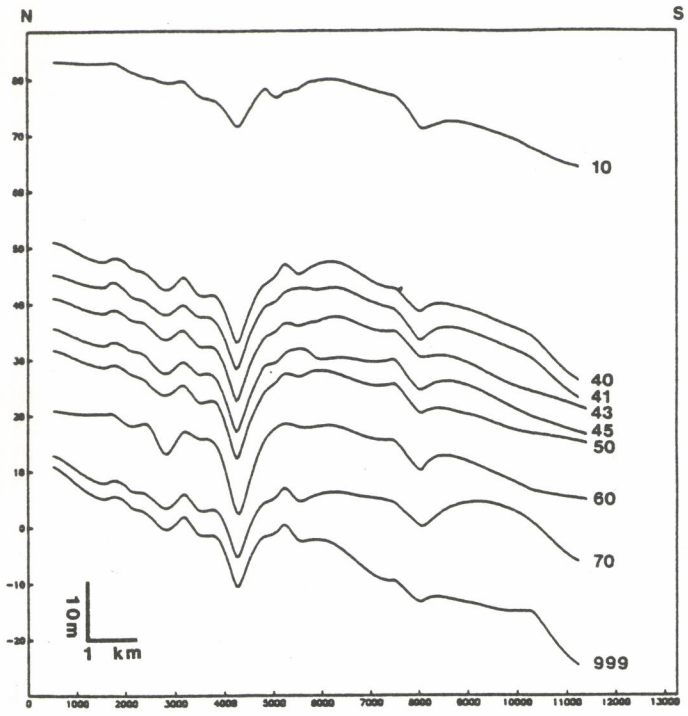

Fig. 7. Structural cross-section (N-S) of the Wainwright oil field. 10 –top of the Mannville; 999– pre-Cretaceous unconformity; 40 to 70 –intra– Mannville markers.

Although the interstratal karstification phase may have commenced as early as the upper Mannville, the presence of the carbonate dissolution-generated synforms on the top of the Mannville suggests that most of it took place after Mannville deposition.

Hydrological aspects of interstratal karstification

Hydrological aspects of interstratal karstification of both evaporites and carbonates in the study area are poorly understood.

Roberts (1980) suggested that the dissolution of evaporites is the result of leaching by meteoric waters that flowed down-dip (i.e. towards the southwest) along the Paleozoic-Precambrian contact which subcrops north and east of the study area. This flow direction is opposite to the general, northeasterly oriented subsurface flow direction illustrated by Hitchon (1969a, b). However, Hitchon, too, assumes the presence of westward oriented flow seem sub-system. The westward oriented flow seem to be of paramount importance since the water is relatively fresh and, thus, capable of dissolving evaporites as welll as carbonates. The fact that the solution-affected rocks lie above the Paleozoic-Precambrian contact can be explained by cross-formational flow (waters ascending along normal faults and in open fractures). Downward moving recharge waters are also considered to have contributed to the dissolution of evaporites and carbonates along the updip edge of the Devonian formations. Drawdown associated with major rivers (e.g. the North Saskatchewan River, flowing through the study area) is active at great depths and Hitchon (1969a) considers this to have been another important factor in the development of the evaporite dissolution-related structures.

Recent work on the distribution of stable isotopes (Hitchon et al., 1971) suggests that large amounts of fresh water entered Paleozoic aquifers in a series of pulses which can be correlated with major phases of uplift and erosion. This notion seems to be in agreement with the previously mentioned concept of episodically culminating, tectonically controlled dissolution.

Conclusions

Two types of interstratal (subsurface) karst have been recognized in the study area:

(1) interstratal karst related to evaporite dissolution, and

(2) interstratal karst related to carbonate dissolution.

Both types of dissolution have had substantial effect on the topography of the pre-Cretaceous unconformity and the structural setting of the overlying Mannville Group. Since structural features of the Mannville strata play a significant role in hydrocarbon entrapment, the study of interstratal karstification in the Lloydminster region can be regarded as an important and economically justified project.

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10229

Quantitative Analysis of depression Morphology near Browns Town, Jamaica and Bedrock Factors Influencing Cockpit or Doline Development

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RESUM

Models en sèries dobles de Fourier de dues dolines i d'altres dos paisatges càrstics de torres, cadascún amb una superfície de 2 X 2 km., permeten explicar un 92 % i 90 %, i un 73 % i un 58 % de la variança en les dades topogràfiques, mentre que les 10 més significatives expliquen un 74 % i 76 %, i un 61 % i 58 % de la variança. Estudis de fotografia aèria indiquen que hi ha més factors horitzontals i verticals d'importància a les zones de torres (49 i 53), que en els terrenys de dolines (26 i 19). Mesuraments de camp demostren que el gruix mitjà dels estrats és més gran a les zones de torres (1,3 m. en comparació a 0,5 m.) i que les fractures menors són més comuns a les zones de dolines. Això explica la topografia dels camps de dolines i per què aquestes tenen major longitud i amplada que les que hom necessita per a fer un model de carst de torres. Els resultats ens indiquen que a les zones tropicals humides les dolines es formen en calcàries d'estrats de poc gruix i molt fracturats, si bé que amb poques fractures importants, mentre que el carst de torres apareix en calcàries amb estrats de guix més gran, en general amb menys fractures, però amb un nombre més elevat de fractures importants.

RESUMEN

Modelos en series dobles de Fourier de dos dolinas y otros dos paisajes de karsts de mogotes, cada uno con una superficie de 2 x 2 km., explican un 92 % y 90 %, y un 73 % y un 58 % de la varianza en los datos topográficos, mientras que las diez más significativas explican un 74 % y 76 %, y un 61 % y 58 % de la varianza. Estudios de fotografía aérea indican que hay más factores horizontales y verticales de importancia en las zonas de torres (49 y 53), que en los terrenos de dolinas (26 y 19). Mediciones de campo muestran que el espesor medio de los estratos es mayor en las zonas de torres (1,3 m. en comparación a 0,5 m.) y que las fracturas menores son más comunes en las zonas de dolinas. Esto explica porque son necesarias menos curvas para explicar la topografía de los campos de dolinas y porque éstas son de mayor longitud y amplitud que las necesarias para hacer un modelo de karst de torres. Los resultados sugieren que en las zonas tropicales húmedas, las dolinas se desarrollan en calizas con estratos de poco espesor y muy fracturados, con pocas fracturas importantes, mientras que el karst de torres se desarrolla en calizas con estratos de mayor espesor con menos fracturas en general pero un número más elevado de fracturas de importancia.

SUMMARY

Double Fourier series models of two doline and two cockpit landscapes, each 2 x 2 km in area, explanied 92 % and 90 %, and 73 % and 58 % of the variance in the topografic data, the ten most significant waves explanied 74 % and 76 %, and 61 % and 58 % of the variance. Aerial photograph studies indicate that there are more horizontally and vertically persistent fractures in the cockpit areas (49 and 53) than in the doline terrains (26 and 19). Field measurements show that average bed thickness is greater in cockpit areas (1.3 m compared to 0.5 m) and that low-persistence fractures are more common in doline areas. This explains why fewer waves are needed to explain the doline topographies and why fewer waves are of greater wavelength and amplitude than thore needed to model Cockpit tenain. Results suggest that in humid tropical areas dolines may develop in heavily-fractured, thin-bedded limestones with few extensive fractured while cockpits develop in thicker-bedded limestone with fewer fractures overall but with larger numbers of persistent fractures.

Introduction

In order to test the usefulness of double Fourier series analysis in modeling karst landscapes, in differentiating between karst styles, and in assessing the influence of bedrock characteristics on karst landform morphology, field, map, and aerial photograph studies werre carried out in areas of doline and cockpit karst in a region 13 km east to west and 11 km north to south near Browns Town, northern Jamaica (fig. 1). The northern part of this area is characterized by doline karst developed on well-bedded, Lower Miocene Montpelier Chalks of the White Limestone Formation. Cockpit Karst has developed in the sourthen part of the area on Late Eocene-Miocene rubbly limestones of the walderston and Browns Town Membres of the White Limestones.

Double Fourier Series Analysis

In double Fourier series analysis a complex three-dimensional surface is modeled as the sum of two intersecting sets of two-dimensional sinusoidal wave forms, each containing many harmonics of differing amplitudes and phase angles. In this study the dependent variable was topographic elevation and the independent variables were the geographic map coordinates. The distribution of topographic elevation across the map area was considered to be a function of a linear trend in the data, various periodic components, and a random error.

Two areas of cockpit karst and two areas of doline karst, each 2 × 2 km, were selected for study. A 20 × 20 grid placed on 1:12,500 scale topographic maps of the areas was used to obtain X_1,X_2, and Y (elevation) coordinates of 441 data points. Linear trends in the Y values were removed by regression analysis and then residuals were subjected to Fourier analysis using a program described by Liang (1983).

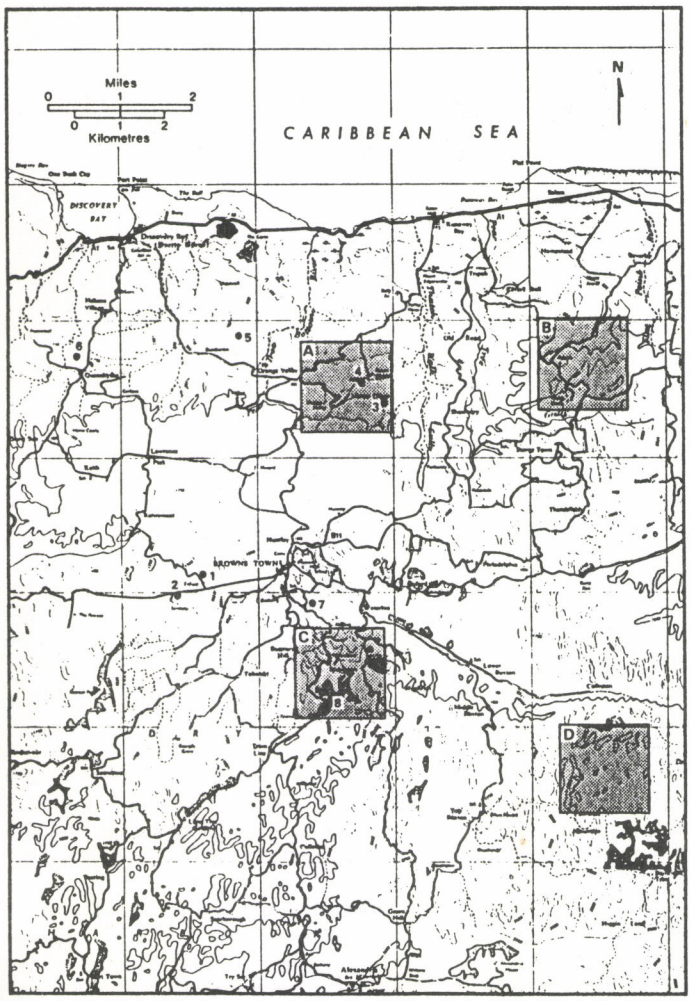

Fig. 1. The Study Area Near Browns town, Northern Jamaica Showing Areas Subjected To Fourier Analysis (A-D) and Depressions Examined in the Field (1-8).

The Fourier models generated for areas A, B, C, and D explained 92 %, 90 %, 73 %, and 58 % of the variance in the original topographic data, respectively. The four most significant frequency pairs of each model accounted for 53.3 %, 58.0 %, 37.9 % and 36.4 % of the topographic variability explained by the model and the ten most significant frequency pairs 74.5 %, 76.0 %, 60.7 %, and 58.3 % of the variability (Table 1).

Data in Table 1 reveal similarities and differences between the Fourier models of the doline and cockpit areas. The models are similar in that three wave trougth orientations (NW, NE, and E) are common to the 6 most significant frenquency pairs of each model. That these directions parallel major fault orientations in northern Jamaica (Versey 1972) suggests a strong degree of structural control on topographic development. The models differ in that the wavelengths and amplitudes of the 10 principal waves in the doline karst models appear to be greated than in the cockpit karst models. Of the 10 major frequency pairs in the doline models, 5 have wavelengths ≥ 1,000 m and in areas A and B

Frequency Pair Rank	(k1,k2)	Amplitude (m)	Wavelength (m)	Wave Trough Direction (°)	Portion of Fourier Model Accounted For (%)*	Cumulative Portion of Model Accounted For (%)
AREA A, DOLINE KARST (R^2=0.92)						
1	(0,1)	12.2	2000.0	90	20.7	20.7
2	(0,2)	11.3	1000.0	90	17.7	38.4
3	(-1,1)	7.7	1414.2	45	8.3	46.7
4	(1,1)	6.9	1414.2	315	6.6	53.3
5	(1,2)	6.5	894.4	296.6	6.0	59.3
6	(1,0)	5.9	2000.0	0	4.8	64.1
7	(-1,2)	4.8	894.4	63.4	3.2	67.3
8	(2,1)	4.6	894.4	333.4	2.9	70.2
9	(-2,1)	3.9	894.4	26.6	2.2	72.4
10.	(-2,2)	3.9	702.1	45	2.1	74.5
AREA B, DOLINE KARST (R^2=0.90)						
1	(1,1)	14.0	1414.2	315	20.5	20.5
2	(0,1)	13.4	2000.0	90	18.9	39.4
3	(-1,1)	10.3	1414.2	45	11.1	50.5
4	(-3,2)	8.4	554.7	33.7	7.5	58.0
5	(0,2)	6.9	1000.0	90	4.9	62.9
6	(-4,1)	5.8	485.1	14	3.5	66.4
7	(2,1)	5.7	894.4	333.4	3.4	69.8
8	(1,2)	4.8	894.4	296.6	2.4	72.2
9	(4,1)	4.4	485.1	346	2.0	74.2
10	(2,0)	4.1	1000.0	315	1.8	76.0
AREA C. COCKPIT KARST (R^2=0.73)						
1	(-1,1)	11.2	1414.2	45	15.3	15.3
2	(1,1)	9.2	1414.2	315	10.3	25.6
3	(2,3)	7.4	554.7	303.7	6.6	32.2
4	(0,2)	6.8	1000.0	90	5.7	37.9
5	(2,1)	6.5	894.4	333.4	5.1	43.0
6	(1,3)	6.2	632.5	288.4	4.7	47.7
7	(-2,1)	5.4	894.4	26.6	3.5	51.2
8	(2,4)	5.1	447.2	296.6	3.2	54.4
9	(1,4)	5.1	485.5	284	3.2	57.6
10	(-3,1)	5.1	632.5	18.4	3.1	60.7
AREA D, COCKPIT KARST (R^2=0.58)						
1	(1,1)	8.5	1414.2	315	12.7	12.7
2	(-1,1)	7.8	1414.2	45	10.7	23.4
3	(-2,1)	6.3	894.4	26.6	7.0	30.4
4	(1,0)	5.9	2000.0	0	6.0	36.4
5	(1,2)	5.1	894.4	296.6	4.6	41.0
6	(0,2)	4.9	1000.0	90	4.2	45.2
7	(-4,3)	4.4	400.0	36.9	3.4	48.6
8	(0,3)	4.4	666.7	90	3.3	51.9
9	(-3,2)	4.3	554.7	33.7	3.2	55.1
10	(3,2)	4.3	554.7	326.3	3.2	58.3

*This value is the power of the frequency pair expressed as a percentage of the sum of all frequency pair power values.

Table 1. Double Fourier Series Analysis Results, Areas A-D.

account for 58.1 % and 57.2 % of the topographic variation explained by the respective Fourier models. The models of cockpit areas C and D include only 3 and 4 waves, respectively, with wavelengths ≥ 1,000 m; these waves account for only 31.3 % and 33.6 % of the topografic variation explained by the Fourier models of these areas. Waves with amplitudes > 10 m account for 38.4 % and 50.5 % of fourier model explanation in the doline areas A and B, and only 15.3 % and 0.0 % of model explanation in cockpit terrains C and D.

Bedrock Characteristics, Depression Morphology, and the Fourier Models

Possible relationships between bedrock characteristics, depression morphology, and the nature of the Fourier models were examined through map and aerial photograph studies of areas A-D and through field studies in 4 dolines and 4 cockpits (1-8 in Fig. 1). Fracture traces and closed depression long and short axes were mapped on 125,000 scale aerial photographs of areas A-D (Fig. 2). Fracture trace and depression long axis orientations and lengths were measured and the data grouped in 10 ° orientacion classes; length-weighted values were converted to percentages (Fig. 3). Average depression diameters were calculated as half the sum of the long and short axes; depression depths were determined from 1:12,500 scale topographic maps. Slope angles in depressions 1-8 were measured in the field in the long axis and short axis directions, mean slope angles were calculated by averaging the four measurements. Bed thicknesses were measured in depressions 1,2,3,4, and 8, bedrock was not exposed in depressions 5-7.

In Figure 3 fracture trace and depression long axis orientation data are compared with the trough orientations of the 10 most important frequency pairs of the Fourier models. Clear correlations between peaks in the three data sets suggest a strong structural control of topography in all four areas, with perhaps the structural control being slightly more marked in the two cockpit terrains. This structural control is reflected in the orientations of the principal frequency pairs of the Fourier models. Therefore, it appears that Fourier analysis can provide data on fracture orientations in karst bedrock, and that it can be used to assess the impact of particular structural trends on topographic development.

Closed depression characteristics in the two doline areas are very different from those in the cockpit areas. The average depression number, depth, diameter, and depth/diameter ratio in the two doline areas were 2.5, 34 m, 519 m, and 0.07, respectively, comparable figures in the cockpit areas were 7.5, 64 m, 285 m and 0.22. Therefore, in the areas studied, depression densities are three times greater in cockpit areas, cockpits are, on average, about twice the depth and half the diameter of dolines, and depth/diameter ratios for cockpits are three times those for dolines. These data suggest that cockpits should have steepler

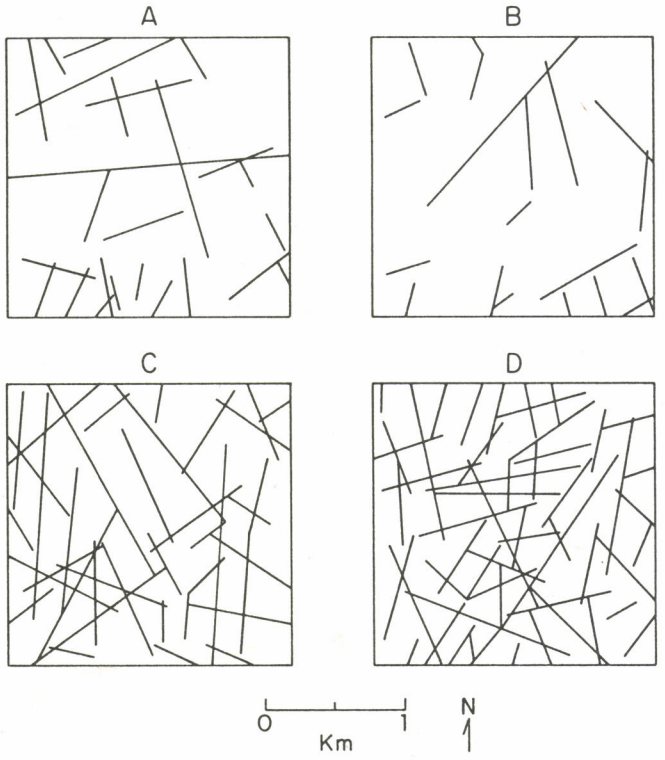

Fig. 2. Fracture Traces in Areas A-D.

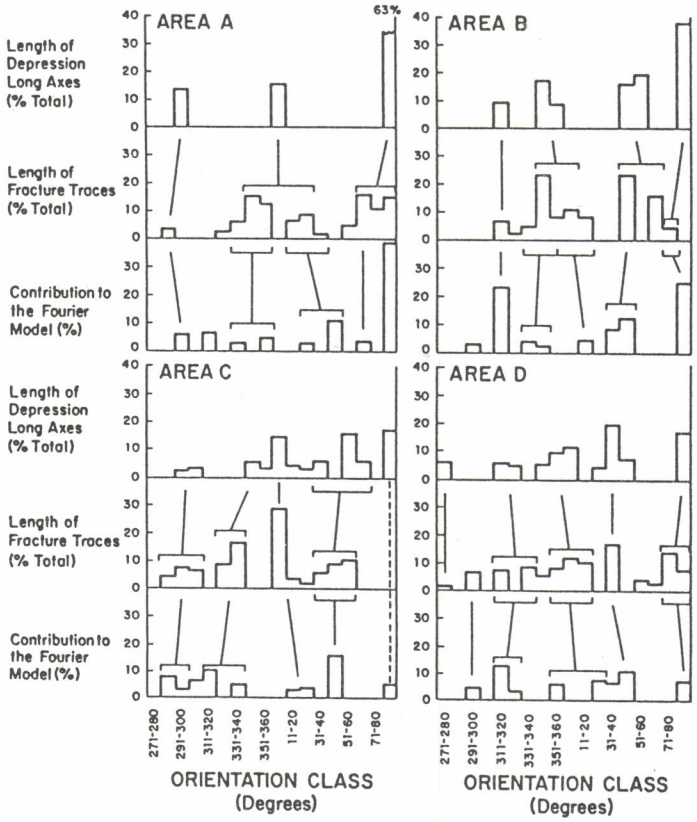

Fig. 3. Comparison of Fracture Trace, Depression Long Axis, and Fourier Wave Trough Orientations, Areas A-D.

slopes– a fact confirmed by field measurements. The average slope in cockpit 1-2 and 7-8 was 28.6 ° and in dolines 3-6 was 16.3°. As thicker limestone beds can maintain steeper stable, slopes, one possible reason for the steeper cockpit slopes is the more massive nature of the Walderston and Browns Town Members. Measured bed thickness in cockpits, 1, 2, and 8 averaged 1.3 m and in dolines 3 and 4 averaged only 0.5 m. Greater depression densities in the two cockpit areas and the increased importance of frequency pairs of, shorter wavelength and smaller amplitude in the Fourier models, are clearly a reflection of the larger numbers of persistent fractures in the Waldeston and Browns Town limestones compared to the Montpelier chalks (Fig. 2).

Discussion

Double Fourier series analysis, by achieving a high degree of topographic explanation, appears to be an effective approach to the modeling of karst landscapes. The method provides information on topographic complexity (R^2 values), on the orientations of bedrock fractures that have influenced topographic development (major frequency pair orientations), and information on depression and bedrock fracture densities (major frequency pair wavelengths). Higher R^2 values for models of doline karst in northern Jamaica (0.92 and 0.90) than for models of cockpit karst (0.73 and 0.58) attest to the greater complexity of the cockpit karst style. The greater importance of frequency pairs of long wavelength in the doline karst models suggests that there are fewer horizontally and vertically persistent fractures controlling topographic development on the Montpelier chalks than on the Walderston and Browns Town limestones-a fact confirmed by fracture trace mapping (Fig. 2).

The well-bedded and thinly-bedded nature of the Montpelier chalks compared to the massively-bedded, and in places unbedded, Walderston and Browns Town rubbly limestones may be responsible for the observed differences in the densities of significant fractures and ultimately responsible for the development of dolines on the one lithology and cockpits on the

other. Under tectonic stress thinner-bedded rocks tend to develop a higher density of joints than thicker-bedded sequences but develop fewer horizontally and vertically persistent fractures which later might influence topographic development.

It is likely that the massive bedding and the dense network of persistent fractures in the rubbly limestones promoted the rapid vertical movement of water underground with the result that solutional denudation was concentrated along the major fracture zones. Consequently, the original surface was deeply dissected and a cockpit karst evolved. By contrast, the numerous shallow joints and the well-developed bedding of the Montpelier chalks encouraged the rapid absorption of water into the surficial rock layers and the lateral migration of that water towards the relatively infrequent persistent fractures which channeled it deeper underground. As a result, solutional denudation of the Montpelier chalks was more evenly distributed across the landscape and a gently rolling doline terrain evolved.

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10155

CO_2 - Content of glacial environments and the likelihood for subglacial karstification

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RESUM

La intensitat de creixement dels conductes càrstics està en funció de l'agressivitat de l'aigua (contingut de CO_2) i de la importància del fluxe hídric. Segons anàlisis fetes a l'Antàrtida, Groenlàndia, Suïsa, Canadà i Noruega, les aigües del medi subglacial profund, originades per fusió basal i glacial, tenen sovint un contingut de CO_2 superior a 1 ordre de magnitud menor que el contingut que presenten les aigües superficials glacials. Tenint en compte la pressió hidrostàtica i que es tracta d'un sistema tancat, les condicions subglacials profundes ens donaran un grau de dissolució inicialment elevat (p. ex. 1,7 E-7 mMols cm^{-2} seg^{-1}), però amb una capacitat total certament limitada (13 ppm. $CaCO_3$). La distància efectiva de penetració en les esquerdes i coves inicipients serà relativament curta. El desenvolupament de les cavitats o espeleogènesi sensu stricto *es considera menys efectiva en ambients subglacials que no pas en sistemes oberts, en conexió amb l'atmosfera. D'altra banda, els conductes de coves preexistents, que poden comportar-se como a vies-N extremadament estable a través dels diferents gradients hidràulics subglacials, poden mantenir importants cabals d'aigua i per tant un nivell de dissolució clarament invariable, pròxim al nivell inicial de 1,7 E-7 mMols cm^{-2} seg^{-1}.*

RESUMEN

La intensidad de crecimiento de los conductos kársticos es una función de la agresividad del agua (contenido de CO_2) y de importancia del flujo hídrico. Según se ha medido en la Antártica, Groenlandia, Suiza, Canadá y Noruega, las aguas del medio subglacial profundo originadas por fusión basal y glacial, *tienen a menudo un contenido de CO_2 superior a 1 orden de magnitud menor que el contenido en las aguas superficiales glaciales. Teniendo en cuenta la presión hidrostática y un sistema cerrado, las condiciones subglaciales profundas darán una proporción* inicial *relativamente elevada (p. ej. 1,7 E-7 mMols cm^{-2} seg. $^{-1}$) pero con una* capacidad *total realmente limitada de 13 ppm. $CaCO_3$; la distancia efectiva de penetración en grietas y cueva incipientes será relativamente corta. El desarrollo de cavidades o espeleogénesis* sensu stricto *se ve como menos efectiva subglacialmente que en los medios ambientes que están en un sistema abierto en conexión con la atmósfera. Por otro lado los conductos de cueva preexistentes, que pueden conducirse como vías-N extremadamente estable a lo largo de gradientes hidráulicos subglaciales pueden mantener importantes caudales y por ello un nivel de disolución* claramente invariable, *acercándose al nivel inicial de 1,7 E-7 mMols cm^{-2} seg.$^{-1}$.*

SUMMARY

The rate of karst conduit enlargement is a function of the aggressiveness of the water (CO_2 - content) and of the rate of flow. As measured in Antarctica, Greenland, Switzerland, Canada and Norway, the waters of the deep sub-glacial environment, originating from basal or en-glacial melt, is often more than 1 order of magnitude less in total CO_2 - content than surficial glacial waters. Taking account of the hydrostatic pressure, and a closed system, the deep subglacial conditions will give a relatively high initial *reaction rate (i.e. 1.7 E-7 mMoles cm^{-2} sec^{-1}), but with a very limited total* capacity *of 13 ppm $CaCO_3$, the effective penetration distance in cracks and incipient caves will be relatively short. Cave initialization, or speleogenesis* sensu stricto, *is regarded as less effective subglacially than in environments which are in an open system connection with the atmosphere. On the other hand, pre- existing cave conduits, which may act as extremely stable N- channels along sub-glacial hydraulic gradients, may maintain high rates of flow, and therefore a high* steady state *dissolution rate, approaching the initial rate of 1.7 E-7 mMoles cm^{-2} sec^{-1}.*

1. Introduction

The possibility of sub-glacial speleogenesis was advocated as early as by Horn (1935). It was later differentiated in terms of open and closed systems by Ford (1977, 1979), identified as a paragenetic agency by Lauritzen (1983) and related to glacier hydrology by Smart (1983). A more general concept or ice- contact speleogenesis may also be inferred for relict caves in certain topographic positions (Glazek et al. 1977, Lauritzen 1986). The present report will discuss these phenomena closer in hydrochemical terms.

The general condition of ice- contact speleogenesis may be subdivided into the following 3 cases:

Case 1: Sub-glacial speleogenesis *(sensu stricto).* The entire formation of a mature conduit (diameter 1 m or more) from joints, fractures or bedding planes.

Case 2: Sub-glacial conduit modification. Pre-existing cave conduits (diameter $\geqslant 0.1$ m) are enlarged under the hydraulic gradient of a superimposed glacier.

Case 3: Pro-glacial speleogenesis. The condition when ice-dammed vadose water is directed into higher topographic positions by glaciers. Many large, vadose invasion caves within impossibly small catchment areas of to-day belong to this type.

Hydrochemical conditions

2.1 *Rate of reaction*

The rate of calcite (limestone) dissolution is described by the Plummer, Wigley and Parkhurst (PWP) equation (1978):

$$dC/dt = A/V\,[k_1 a_{H^+} + K_2 a_{H_2CO_3} + K_3 a_{H_2O} + K_4 a_{(Ca^{2+})}\, a_{(HCO_3^-)}]$$

the modification presented here describes the rate dependence of hydrochemistry and the area to volume ratio (i.e. conduit size). Initial reaction rate is mainly dependent upon the two first terms, the activities of H^+ and $H_2CO_3^0$, whilst the reverse reaction, dependent on the activities of Ca^{2+} and CO_3^{2-}, becomes important when the system approach equilibrium.

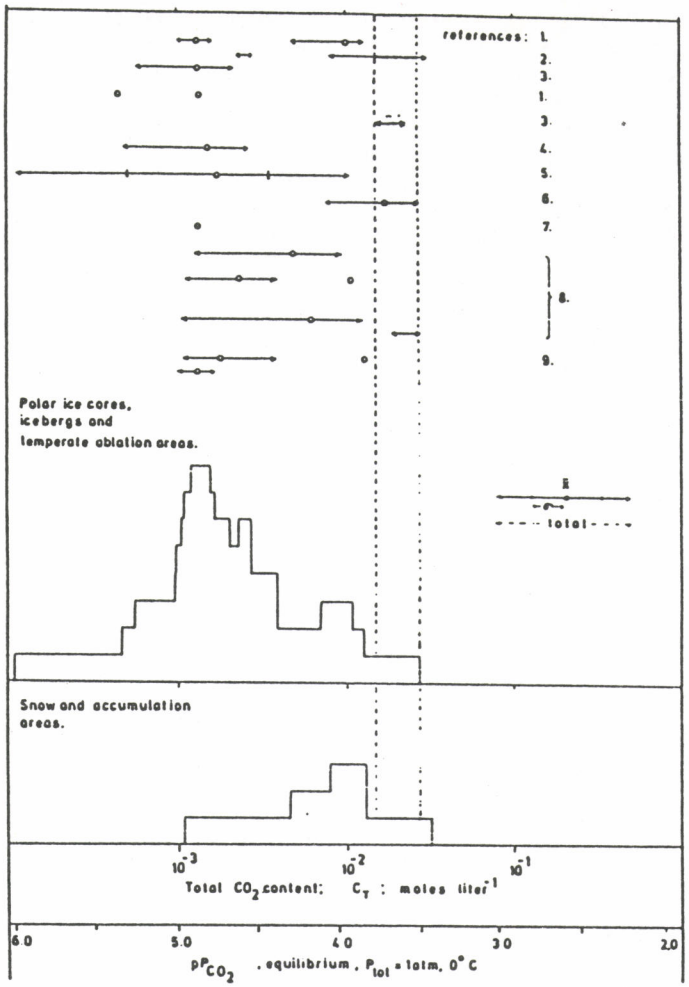
2.2 *CO_2- concentrations of glacial environments*

Numerous studies have analysed the CO_2- content of glacier ice. The available data, covering more than 100 samples, are compiled in Figure 1. There is a significant difference in the CO_2 to water ratios between snow/accumulation areas and basal ice/ ablation areas. The former environments display values close to air/water equilibrium at 0° C, whilst the latter are depleted, often by almost two orders of magnitude in CO_2/H_2O. Analytical techniques may vary from study to study, but the same effect is also evident within the same study and technique (Berner et al. 1977). Units of CO_2 –concentrations are given as C_T (mMolal inorganic carbon), which is pressure– independent, and as equilibrium P_{CO_2} at 1 atm total pressure (Figure 1).

The phenomenon of CO_2 –depletion is widely known (Ford 1971 and references therein), but poorly understood. CO_2– exclusion by regelation during firnification and compaction, combined with dissolution into intergranular brines (Nye and Frank 1973) may ofter possible explanations.

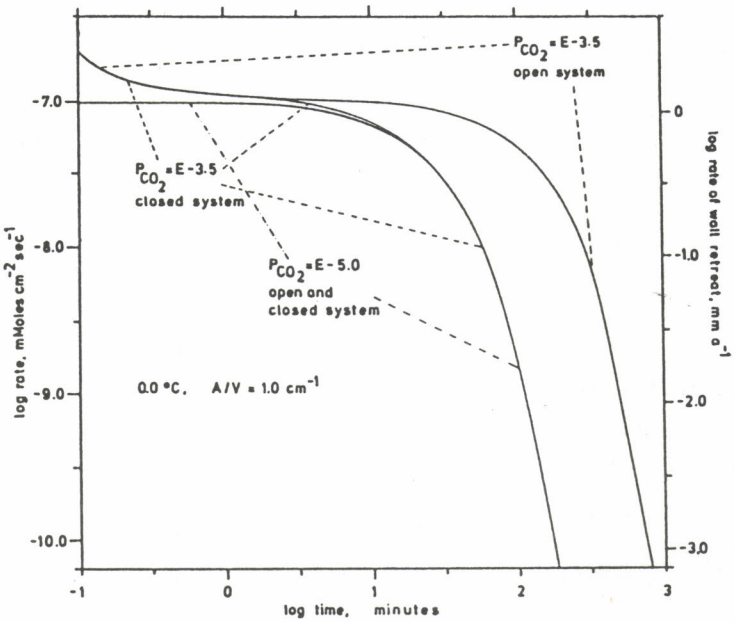
2.3 *Rate- time relationships*

Equilibrium concentrations for all species in the $CO_2/H_2O/CaCO_3$ system was calculated at a given P_{CO_2} and temperature, taking account of charge and mass balance and of activity coefficients, according to the WATSPEC algoritms (Wigley 1971). «H^+» was decreased in increments of 0.001 pH units until equilibrium was reached. Potential corrosion rate was then calculated from the PWP equation, using the Ω-approximation for K_4 of Plummer et al. (1979). Reaction time was estimated through numerical integration over each increment, yielding the graphs of Figure 2. The dC/dt versus t agreed with experimental data within a factor of two (closed system, $P_{CO_2} = E{-}3.5, +20°$ C).



CO_2 – content of glacial environments. Shaded area: range of air/water equilibrium at relevant altitudes. CO_2 – concentrations are expressed both as mMolal inorganic carbon (C_T, pressure independent), and corresponding P_{CO_2} at 1 atm total pressure.

The computer model suffers from several discrepancies, like the assumption of equilibrium conditions between all species and ignoring the diffusivity of dissolved species or the hydraulic conditions, as laminar and turbulent flow regimes. However, bearing this in mind, we may tentatively discuss different P_{CO_2}-situations under otherwise identical hydraulic conditions:



Rate of corroison versus t for closed and open systems at P_{CO_2} ranging from E-5 to E-3.5. Calculated from the PWP equation at one atmosphere total pressure.

1). Except for the initial rates, there appear to be little difference between closed systems of different PCO_2 in the range of E-6 to E-3.5.

2). At low P_{CO_2} ($\leq$E-4.5), closed and open systems do not appear to differ significantly.

3). Open system (disphasic flow) at air equilibrium possess ~ 10 times longer relaxation time than closed (monophasic flow) conditions.

Following the approach of White (1977), the effective penetration distance (EPD) for water in fissures of varying width under different hydraulic gradients was calculated, Figure 3. Relaxation times was set to the time required to reach rate $\leq$ E-10 mMoles cm^{-2} sec^{-1}, corresponding to a wall retreat rate of E-3 mm a^{-1}. 10 mm radial enlargement would then require some 10.000 years.

For tight void planes and sub- glacial water film thicknesses, EPD is in the range of millimeters at best, even at very high hydraulic gradients, Figure 3. However, conduits of $\geq$ 10 cm diameter have EPD's of 1 m to several kilometers. Figure 3 suggets that, under closed conditions and/or with depleted waters, subglacial speleogenesis *sensu stricto* may be very slow and ineffective, whilst subglacial modification may be an effective process, capable of producing significant cave volumes.

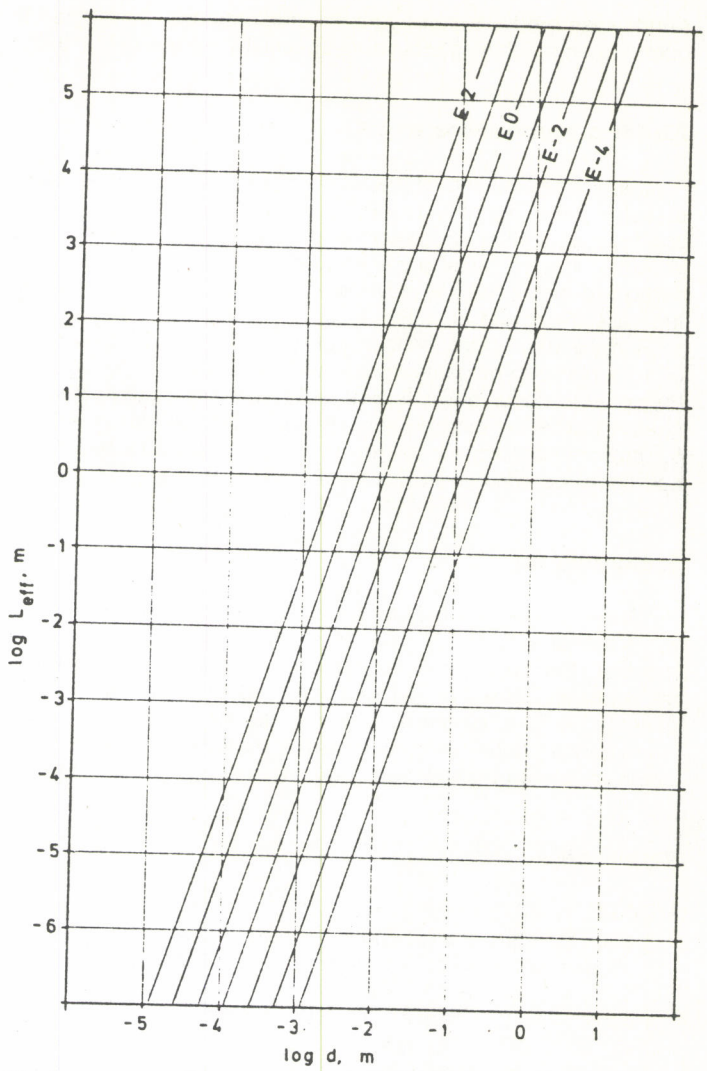
2.4 Effect of ambient pressure

The calculations are done for 1 atm total pressure. Higher pressures do not change the C_T of a closed system, but will affect equilibrium constants. K_1 and K_2 for carbonic acid increase with pressure (Butler 1982). The effect is a higher initial $[H^+]$, approaching $[H^+]=[C_T]$ at very high pressures. Initial rate will then increase, which in turn decrease the relaxation time and EPD somewhat.

2.5 Other effects

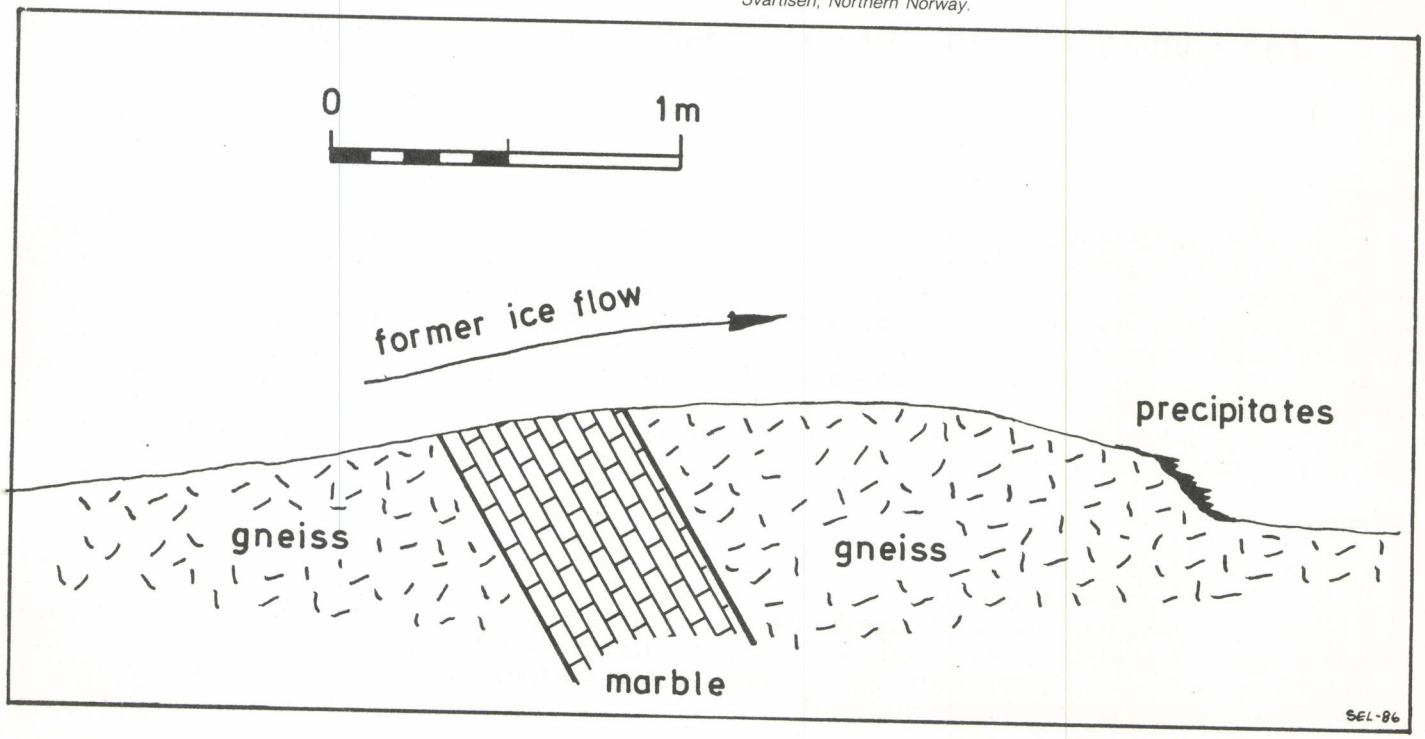
Glacially produced rock flour will increase the A/V ratio enormously, consuming most of the aggressiveness before water may even penetrate fissures or cavities at all. This effect is problaby less effective in provinces of allogenic karst, where the majority of the rock flour is produced from silicate rocks. Large, autigenic karst area will problaby be more strongly inhibited.

Under glacial maxima, large ice sheets will have a low gradient and produce hydrologically stagnant conditions, closed conditions and extensive silting up. On the contrary, glacial advance or



Effective penetration distance as a function of fissure width at hydraulic gradients ranging from E-4 to E-2. P_{CO_2} =E-4.5, temp.=0.0° C, closed system.

Subglacial precipitates apparently produced by corrosive flow over 50 cm marble or less, suggesting that saturation is reached over very short distances. Site at Svartisen, Northern Norway.



retreat may produce high hydraulic gradients and semi- open to open systems with respect to atmospheric CO_2 (Ford 1977, 1979).

2.6 Field observations of EPD

Subglacial precipitates (Hallet, 1976) do occur on the lee sides of sub- glacial roughness, within millimeters from the crests, strongly suggesting that precipitation is practically instantaneous in terms of sub- glacial penetration distance. The reversibility of carbonate equilibria may advocate for that the opposite is also the case (Reddy et al. 1981).

A more direct test for this argument may be the occurence of sub- glacial precipitates produced by allogenic ice, Figure 4. Precipitates occur down- ice of a 50 cm wide marble band in gneiss, indicating that the sub- glacial liquid film had an EPD of 50 cm or less. This is taken as supporting evidence for the approach represented in Figures 2 and 3.

3. Conclusions

Deep subglacial speleogenesis *sensu stricto* is problaby of no practical efficiency. However, if high flow rates might be reached, the system may approach an initial, steady state rate of corrosion, effective enoguh to produce passages of 2m diameter in E3 to E4 years. This corrresponds to cases 2 and 3. The corrosion potencial may, however, be largely masked by the inhibitive effect of glacial rock flour.

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1073

The faulting's control of karst dynamic condition in Taiyuan, China

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RESUM

El control de la carstificació per les fractures estructurals i la condició dinàmica de les aigües càrstiques de Taiyuan (Xina).

No és només la composició química de les roques carbonatades la que intervé en el control de la carstificació de les fractures estructurals i en la condició dinàmica de les aigües càrstiques de Taiyuan (Xina). La carstificació depèn també de les fractures del terreny. La dissolució no es produeix en totes les fractures i la precipitació pot tenir lloc lluny de la part principal. Les causes de la formació de carst estratificat radiquen en els interestrats de desplaçament i en la diferent fracturació que es dóna entre els estrats. Les aigües càrstiques estan condicionades, parcialment o local, per falles creuades degudes a la dislocació de les falles de l'aqüífer carstificat.

A la conca de bloc fallat, l'endocarst serveix per a transportar les aigües càrstiques profundes. A la part més superior d'un relleu de bloc fallat, el West Mount, el carst superficial subministra una condició de gran dinamisme a l'aigua càrstica freàtica.

RESUMEN

No sólo la composición química de las rocas carbonatadas interviene en el control de karstificación de las fracturas estructurales y las condiciones dinámicas de las aguas kársticas en Taiyuan, China.

La karstificación depende de fracturas en el campo. La disolución no tiene lugar en todas las fracturas y la precipitación puede tener lugar lejos de la parte más importante. Las causas de la formación del karst estratificado son los interestratos deslizantes y la diferencia de fracturación entre los estratos. Las aguas kársticas están condicionadas parcial o totalmente por fallas cruzadas por la dislocación de las fallas del acuífero karstificado.

En la cuenca de bloque fallado el endokarst sirve para transportar aguas kársticas profundas. En la parte superior de un relieve de bloque fallado, el West Mount, el karst superficial suministra la condición de movimiento rápido para el agua kárstica freática.

SUMMARY

Not only chemical composition of carbonate rocks, dose structural fracture control karstification and karst water dynamic conditions in Taiyuan area, China.

Karstification depends on fractures in field. Dissolution doesn't happen in all fractures and precipitation may take place far away from the major part. The reasons of the formation of layered karst are the interlayer slipping and difference of fracture networks among layers. The karst water flows are prevented from crossing faults partially or totally because of the fault dislocation of karstified aquifer.

In fault-block basin, endokarst is used to transport deep karst water. On the top of fault-block mountain, the West Mount, shallow previous karst provides the fast-moving condition for phreatic karst water.

Introduction

Taiyuan area is located in the Shanxi Highland of North China and is composed of Mt. West, Mt. East and Taiyuan Basin, which belongs to the middle of Shanxi Graben Zone according to the classifying on structural geology. There developes typical North China type karst and about half of mountain region (2.800 square kilometres) bares carbonate rocks. Karst water is the main groundwater reserves in the area. Through the studying for the water supply of coalmine, the author regards that the faulting plays an important role in controlling karst water dynamic condition in this area.

Karst Water Hydrodynamic Condition in Faults Chinese hydrogeologists' studying about groundwater dynamic condition of faults in bedrocks area can be sumed up as that: compression fault is a permeability barrier, tension fault is a previous interface or a passage and faults with other mechanic property are between them. Lateral fracture of each faults is favourable for storing and moving for groundwater. We should pay attention to that the changing of mechanic property of a fault in space is to lead to the changing of its hydrodynamic condition. The author points out the speciality and adaptability when applying these theories in areas of soluble carbonate rocks terrain.

A good example in Shilin Normal Fault, a compression-shear structure, strike E-W, dip S (to donwstream), fault throw 200 metres, located in the north of Huoxian county. In nature the Hydraulic gradient between Well Hs22 (upper wall) and Well Hs21 (lower wall) is 34.5 ‰. Tracer was put into Hs22 but did not be determinated in Hs21. This fault was regarded as a permeability barrier. However, when the water level in Hs22 drawdowned 0.76 metres during a pumping test, the level in Hs21 responded with a lower of 0.25 metres in 10 hours, which showed a fact, instead of a barrier, this fault is really a transverse previous.

The author considers, in the course of fault shearing or compressing, milling and kinetic metamorphism may make the insoluble material of the composition of carbonate rocks (like silicon) formed impermeable dynamic encrustation. In addition, their tectonites due to their compact texture are permeability barriers, too, but this impermeability effect only exists at some places where there are the strongest shear strain.

On the other hand, all rifts, whatever width or mechanism, are composed of a great number of fractures, large or small, even in compact mylonite there is still a vast amount of structural microcracks. Corrosion experiments (by the author, 1985) has demonstrated that fracture controls karstification and even previous fracture filled calcite vein is still able to help initiate the corrosion again. These favourable factors with increasing solubility of carbonate minerals in the course of mineral kinetic metamorphism, calcite changing into aragonite make it be possible that karst water opens up new store spaces and new paths for itself by means of corrosion. For this reason, it is, as regarded by the author, unnecessary to overemphasize the solubility of rocks. In fact, generally karst lies near the bedding plane of soluble rock and insoluble rock or two kinds of rock formation with different disolubility. It is more favourable for karstification in some locations where there is lower solubility but very good fractures than those where there is higher solubility but better integrity. Though limestone in the main kind of carbonate rocks in Taiyuan area, there are still larger springs (like Xiahuai Springs) out from lower-Ordovician dolomite in some fracture-ridden places.

After karst aquifer featuring layered and relative isolated of layers is displaced, if the aquifer of upper wall just fits into that of lower wall, different layers of aquifers might contact as new continue aquifer and allow karst water flowing, but if the aquifer of upper wall fits into the permeability barrier of lower wall, flow is intercepted partially or totally, which depends on the fitting condition between aquifer and aquifuge or aquitard. In general, tension fault can transport water in vertical and strike itself. In other words, karst water can run across fault from an aquifer layer in a level of upper wall to another of lower wall, so tension fault's blocking effect is not often obvious, but if gaping fault is well filled by outside insoluble material of fault tectonite breccia is very solid because of secondary cementation, it is not favourable for transporting groundwater in vertical, strike and transverse.

An explanation for the first example as follows: The volume passing across the fault reduces due to the shrinking of effective cross-section of karst water path by fault dislocation, then water level rise until the volume passing across the fault equals to the recharged volume and is keeping dynamic equilibrium. There is a «linn» appearance between two sides of the fault. The well is a still well without pumping. Since the tracer was introduced into depth flowing stream only by diffusing, it is too slow to be received in the downstream well in a long time. During pumping in upstream the changing of influent field can produce a response in downstream because of reducing the discharge across fault; vice versa, during pumping in downstream, the response in upstream is slight because of richer recharge there. If lose sight of the difference between the two conditions, it is impossible to make a right view.

In the above-mentioned views, the author analysed a few larger normal faults in Mt. West area and got some results being in accord with that showing on «Mt. West Deep Karst Water Hydroisopiestic Line Map» (by the author, 1985).

Karst Water Hydrodynamic Condition in Modern Active Structure Area

Taiyuan area belongs to a modern active structure area and is divided into many massives by faulting and then these massives are still moving relatively upward or downward. Therefore there are different karst water hydrodynamic conditions because of the differences of faulting actions and geomorphic conditions between block-mountain and block-basin.

1. Shallow Previous Karst on Fault-Block Mountain, Mt. West. Mt. West, has been rising intermittently since Himalayan Orogeny. Mid-Ordovician system of karst terrain in the north of Mt. West has been cut through and separated into many hydrologic insulation masses by gorges which incised down hundreds metres. There are few springs in karst terrain and no permanent rainwater. The general view is that the flow of water infiltrates and mixes into deep karst water systems which are stored and move in Pre-Ordovician system and Cambrian system. But the author has got the other view by analyzing geological structure. Since land mass rises as a whole, fractures and faults do not develope well and aquifuges keeps continuing roughly, so except for some

sectors, shallow karst water hardly infitrats into deeper karst aquifer. It has been documented by recently environmental concentrations determination of isotope Tritium of karst water collected from springs scattered along the floor of main gorge (by Institute of Geomechanics, Chinese Academy of Geological Science, 1982; the author, 1985) which shows little modern water has mixed with the deep karst water.

The author finds out that previous karst which has been developing well in limestone of Mid-Ordovician system and has been raised up to the top of the mountain as fault-blocks up rise plays an important role transmitting most water called perched groundwater and drain them away as suspended springs. In this case, perched groundwater moves easily, drains rapidly and has a very short lag time, with the character of rainwater. Only does part of water infiltrate deeper, then drain slowlly from small fractures of solution crack and form seasonal karst springs having longer lag time in lower horizons. A rough estimate of the discharge of perched groundwater is about two thirds of the recharge of karst water in this region.

Because of the difficulty in mining perched groundwater should be ruled out in the evaluation of karst water reserves and be classified into surface water reserves.

2. Endokarst in Fault-Block Basin, Taiyuan Basin

The climate in North China was warm and wet during Mid-Pleistocene, then has become semiarid. Most of karst springs in Shanxi Highland have been forming since Mid-Pleistocene. In this period, according to a view (Liao Zishen, 1980), karstification has been developing mainly along old channels formed in Quaternary Period, modern channels and groundwater drainage areas located piedmont.

During early and middle periods of Quaternary, old Muma river and old Futuo river flowed southward and emptied into old Jinzhong Lake nearby Taiyuan. By present they have been captured and turned to flow eastward. The old karst Zones along the lower courses of the rivers have been buried at great depths, in Taiyuan Fault-Basin.

As an active structure region, there is higher seismic frequency, greater fracture density and even is geothermal region locally, so it is a very good place for deep-seated karstification. Old karst zones have been well preserved, and developing as main deep karst water passages. «Taiyuan Basin Deep karst Water Hydroisopieslic Line Map» (by the author, 1985) could leave a deep impression about that. Hole 103 met three caves of satuation in 130 metres with the biggest diameter of 4.30 metres. It is found out from wells, Ts2 and Ts5, that the main aquifer is over 600 metres below the regional drainage level and the circulating depth of deep karst water is over 800 metres below the level. A series stealy large outflow water release tests have been perfomed in Ts2 and Ts5, all the tests show not only what a huge volume and a good link the deep-seated karst water reservoir is, but also that deep karst water is circulating relatively actively with its hydrogeochemical types (HCO_3-SO_4 or SO_4-HCO_3).

Concluding Remarks

From lithology angle to deal with mechanism of karsitification is still very common. Actually, karstification mainly depends on faulting in field. We may say, without fractures carbonate rocks has only a little solubility and almost could be regarded as insoluble rocks. Karstification is controled by various scales of structure. The evolution of Karstification is also deeply effected by the development of structure. Therefore, it is necessary to give more effective research to the relation between karstification and faulting and to make concerned corrosion model experiment, which will be helpful to engineering, water supply and oil production.

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10284

Effects of Falling Base Level on Cave Morphology; Evidence From Uranium Series Dating

P.L. Smart, J.N. Andrews, S.L. Hobbs

RESUM

La morfologia general del sistemes de cavitats es troba fortament supeditada pels nivells de base relatius que descenen i per la incisió vadosa de l'interior de les coves, si bé molts altres factors són també importants. On el nivell de base baixa ràpidament es generen grans diferències en la zona saturada i predomina el desenvolupament de galeries freàtiques. On el nivell de base i el grau d'incisió vadosa són equiparables, predomina el desenvolupament de «cañons» vadosos. Finalment, on el descens del nivell de base és molt baix, té lloc un desenvolupament horizontal de «canyons» vadosos. Finalment, on el descens del nivell de base és molt baix, té lloc un desenvolupament horizontal de «canyons» vadosos, originant-se disseccions i eixamplaments de la base. Aquesta teoria es fonamenta en les observacions morfològiques i les proporcions d'incisió derivades de les dades proporcionades per les sèries de l'urani de coves de Yorkshire (Anglaterra), Picos de Europa (Espanya) i Gunong Mulu (Sarawak)

RESUMEN

La morfología general de los sistemas de cavidades está fuertemente controlada por los niveles de base relativos que descienden y la incisión vadosa de las cuevas, si bien muchos otros factores como la estructura geológica son también importantes. Donde el nivel de base desciende rápidamente se generan grandes diferencias principales en la zona saturada y domina el desarrollo de galerías freáticas. Donde el nivel de base y el grado de incisión vadosa son comparables, predomina el desarrollo de cañones vadosos. Finalmente donde el descenso del nivel de base es muy bajo, se produce el desarrollo horizontal de cañones vadosos originando disecciones y ensanchamientos de la base. La teoría se fundamenta por las observaciones morfológicas y las proporciones de incisión derivadas de datos de series de uranio de cuevas en Yorkshire (Inglaterra), Picos de Europa (España) y Gunong Mulu (Sarawak).

SUMMARY

The general morphology of cave systems is strongly controlled by the relative rates of base level lowering and vadose incision within the cave, although many other factors such as geological structure are also important. Where base level falls rapidly, large head differences are generated in the saturated zone and phreatic passage development dominates. Where base level and vadose incision rates are comparable, development of vadose canyons predominates. Finally where base leve lowering is very slow, horizontal development of vadose canyons occurs giving notches and basal widening. This theory is supported by observations on morphology and rates of incision derived from uranium series dates from caves in Yorkshire (England), the Picos de Europa (Spain), and Gunong Mulu (Sarawak).

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Late tertiary paleogeography of Poland: implications of paleokarst studies

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RESUM

Les regions amb fauna de vertebrats del paleocarst del Neogen de Polònia representen tant sols el Miocè Mitjà (zones MN 4-7) i el Pliocè (MN 14-17). Les formes més antigues (MN 14-16) indiquen l'existència d'un clima subtropical, mentre que les més recents (MN 14-16) s'associen a un clima mediterrani sec (MN 14) o humit (MN 15-16) i les més recents de totes (MN 17) a un clima temperat.

La manca de dipòsits que representin les zones MN 8-13 cal atribuir-la a la gran extensió de dipòsits transgressius del Miocè Mitjà, del «Foredeep» dels Carpats, que arriba des del nord de la plana al·luvial fins a les terres baixes poloneses. Aquests dipòsits varen sofrir un procés d'erosió, des dels altiplans de l'arc Metacarpatià, com a conseqüència de la crisi del Messinià i de l'elevació Pliocènica. Es va generar una acumulació de dipòsits que inclouen vertebrats en formes càrstiques exhumades o bé noves. Els habitants de les zones semi-desèrtiques (Gerbillinae, Hystrix) i els de l'estepa es varen estendre per l'Europa Central, a causa de la sequera del Messinià.

RESUMEN

Las localidades con faunas de vertebrados en el paleokarst del Neógeno en Polonia representan solamente el Mioceno Medio (zonas MN 4-7) y el Plioceno (MN 14-17). Las formas más antiguas (MN 4-7) sugieren clima subtropical, mientras las más jóvenes (MN 14-16) se refieren al Mediterráneo seco (MN 14) o húmedo (MN 15-16) y las más jóvenes de todas (MN 17) a clima templado.

La falta de depósitos que representen las zonas MN 8-13 se explica por la mayor extensión de depósitos transgresivos del Mioceno Medio, del «Foredeep» de los Cárpatos, que llega al Norte en la llanura aluvial hasta las tierras bajas polacas. Estos depósitos fueron erosionados desde las mesetas del arco Metacarpatiano como consecuencia de la crisis Mesiniense y el levantamiento del Pliocénico. Resultó una acumulación de depósitos que contienen vertebrados en formas kársticas exhumadas o nuevas. Los habitantes de las zonas semi-desérticas (Gerbillinae, Hystrix) y los de la estepa se extendieron por la Europa Central debido a la sequía Mesiniense.

SUMMARY

Paleokarst localities of vertebrate faunas of Neogene age in Poland represent only the Middle Miocene/zones MN 4-7/and the Pliocene/MN 14-17/. The older faunas/MN 4-7/suggests subtropical climate, while the younger/MN 14-16/are referred to Mediterranean dry/MN 14/or wet/MN 15-16/and the youngest/MN 17/to temperate climate.

The lack of deposits representing zones MN 8-13 is explained by larger extension of the Middle Miocene transgressive deposits of the Carpathian Foredeep passing to the North in alluvial plain of the Polish Lowland. These deposits were eroded from the uplands of the Meta-Carpathian Arch in consequence of the Messinian Crisis and Pliocene uplift. It resulted in accumulation of vertebrate-bearing depostis in exhumed or new karst forms. Semi-desert/Gerbillinae, Hystrix/and steppe inhabitants spread over Middle Europe due to the Messinian drought.

Osservazione dei rapporti esistenti fra le morfologie da modellamento glaciale e i fenomeni carsici profondi del monte Cucco di Pozze

Leonardo Busellato
Gruppo Grotte Schio-CAI

SENSE RESUM
SIN RESUMEN
WITHOUT SUMMARY

L'idea di analizzare i legami esistenti fra le morfologie da modellamento glaciale e i fenomeni carsici profondi ci é venuta osservando la riproduzione delle carte al 25.000 riguardanti l'Altopiano dei Sette Comuni su di un plastico eseguito da un gruppo Scouts di Schio: il plastico riguardava la parte sommitale dell'Altopiano stesso, dalla conca di Asiago agli strapiombi in Valsugana di Cime Dodici, Ortigara, Cima della Caldiera, Castelloni di San Marco.

Quello che colpisce a prima vista in tale plastico é una specie di grande solco che, dalla Val di Nos, sembra tagliare tutto l'acrocoro sommitale, dai Granari di Bosco Seco alle pendici orientali del Monte Forno fino alle propaggini del Monte Cucco di Pozze, per poi piegare bruscamente a Nord-Ovest verso le bastionate Nord del Monte Chiesa. Il grande solco é la traccia evidente di una paleovalle con sezione a U molto aperta, probabilmente occupata, migliaia di anni fa, da una lingua glacialle di notevoli proporzioni.

Le morfologie osservate in tutta l'area sono da collegare ai periodi glaciali del Riss e del Würm e ai successivi periodi interglaciali. Nei periodi glaciali, infatti, tutta la parte sommitale dell'Altopiano dei Sette Comuni era coperta da una spessa calotta glaciale, e imponenti ghiacciai scendevano lungo le valli fino a diffondersi nella piana di Asiago e a collegarsi con il ghiacciaio della Val d'Assa e dell'Astico Quello che maggiormente ha interessato la nostra trattazione é stato il ghiacciaio della Val di Nos (figura 1) che, in periodo wurmiano, scendeva nella piana di Asiago dove ha formato un apparato morenico di un certo rilievo (Bartolomei G. 1964).

Figura 1. Il ghiacciaio della Val di Noss.

La dorsale costituita dal monte Zingarella, dai Granari di Zingarella e dal monte Colombara fa da spallamento, sul lato Sud, alla paleovalle, costringendola ad una marcata deviazione verso Est.

Il ghiacciaio, scendendo lungo la paleovalle, tendeva a superare lo sbarramento e a rovesciarsi nelle piane di Casara Zingarella.

Una massa glaciale, nel superare un marcato argine naturale, subisce una intensa fratturazione che consente il riversarsi in profondità delle acque di fusione glaciale e di ruscellamento. La concentrazione sub-glaciale delle acque correnti fa si che queste esercitino una efficace azione meccanica e una ancor più attiva azione chimica lungo le fratture della massa rocciosa sottostante. Nel nostro caso la massa rocciosa sottostante é costituita da calcari del Lias con strati di potenza metrica, e quindi con rade fratture, perciò le grandi masse d'acqua di fusione esercitano sulle rocce una intensa azione carsica (figure 2-3).

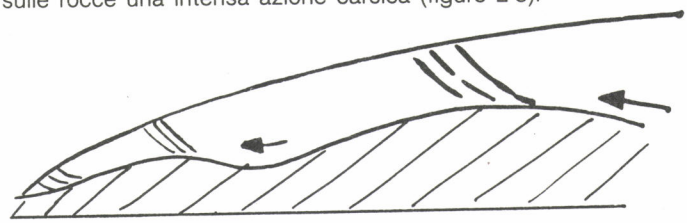

Figura 2. Fratturazione di una lingua glaciale in corrispondenza di un argine naturale.

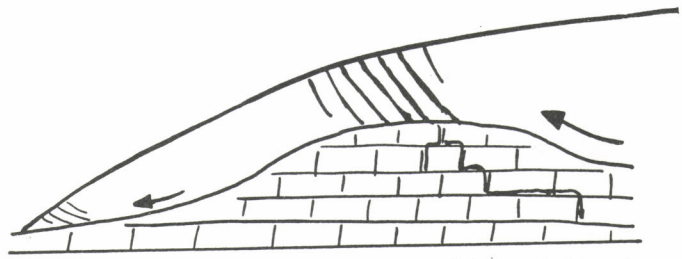

Figura 3. In presenza di rocce carsificabili, le acque di fusione glaciale si riversano in profondità lungo le diaclasi e i giunti di strato.

Infatti sui Granari di Zingarella abbiamo potuto esplorare una bella serie di cavità, anche di notevoli dimensioni, impostate lungo fasci di fratture intersecantesi a circa 90° (figura 4).

In parecchi abisi della zona succitata sono stati notati meandri di notevoli dimensioni con frequenti pozzi-cascata e depositi di riempimento di grandi proporzioni. Sono presenti, tra l'altro, delle occlusioni in frana con grossi massi che presentano tracce di intensa fluitazione.

Questi fenomeni sono perfettamente osservabili negli Abissi I°, II° e III° di Zingarella e in modo particolare nel Buso della Neve di Zingarella, nonchè in una decina di pozzi minori.

Collegando la formazione dei grandi abissi dei Granari di Zingarella alla presenza della paleovalle di origine glaciale succitata, abbiamo cercato di verificare l'esattezza delle nostre deduzioni conducendo una ricerca sistematica in altre aree con condizioni morfologiche analoghe.

La scelta é caduta sul monte Cucco di Pozze che, per disposizione orografica, sembrava avere le stesse caratteristiche riscontrate sui Granari di Zingarella.

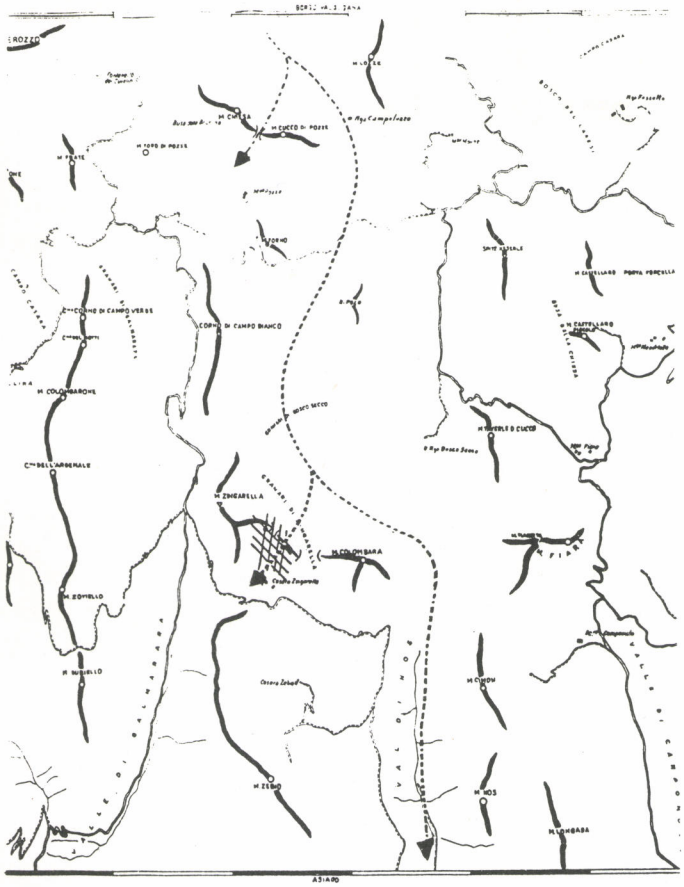

Figura 4. Granari di Zingarella. La presenza di fasci di fratture intersecantesi a circa 90° ha condizionato la formazione di una serie di cavità, anche di notevoli dimensioni.

Ci troviamo nella parte Nord-Occidentale dell'Altopiano dei Sette Comuni, nell'area compresa fra Cima Dodici a Nord-Ovest, il monte Ortigara a Nord, il monte Lozze a Nord-Est ed i monti Forno e Corno di Campo Bianco a Sud.

Il monte Cucco di Pozze può essere considerato parte integrante dell'entità orografica del monte Chiesa, di cui rappresenta una espansione sul versante orientale, elevata per circa cinquanta metri al di sopra delle spianate calcaree che costituiscono, su questo lato, i contrafforti del monte Chiesa stesso. Lo sperone del monte Cucco é limitato a Sud-Est dalla depressione detta Busa della Crea, a Nord da una serie di grandi gradinate, rotte da avvallamenti e doline, che degradano verso malga Campoluzzo, a Nord-Ovest dalla Busa dell'Orco ed a Ovest da una sella che raccorda il monte Cucco di Pozze con il versante sommitale del monte Chiesa.

La natura litologica del Cucco é rappresentata da calcari dolomitici del Giurese Inferiore (Lias) a strati di potenza metrica immersi a Sud-Est con una pendenza di 5-7 gradi. La zona sommitale del monte é coperta da ravaneti dovuti alla discarica di materiale di scavo di una cintura di gallerie e di camminamenti, disposti su tre piani sovrapposti, eseguita durante la Grande Guerra. Estesa risulta la copertura vegetale, tra cui primeggia il pino mugo che ricopre abbondantemente i versanti. Dal monte Cucco di Pozze al monte Chiesa si estendono ampie spianate calcaree a debole pendenza, interessate da una intensa carsificazione superficiale e a fitta copertura di mughi. La sella e le spianate calcaree contigue sono segnate da un fascio di fratture sub-parallele, con andamento Nord-Sud, che, a Sud, sembrano interessare anche la immensa depressione di Malga Pozze, fino alle pendici occidentali del monte Forno, e a Nord un complesso tabulare che fiancheggia Busa dell'Orco.

Fasci di fratture anolaghe a quelle sopra descritte si possono rilevare anche lungo le spianate calcaree poste a Est di monte Cucco, in direzione del vallone, di probabile origine glaciale, che costituiscono la conca di Malga Campoluzzo (figura 5). La disposizione Nord-Ovest/Sud-Est del monte, i fasci di fratture ben distanziate e ben marcate, la modesta elevazione della sella fra il monte Cucco di Pozze e il monte Chiesa rispetto ai valloni glaciali evidenti sul lato Nord lasciavano pensare che ci fossero tutti i presupposti per una verifica delle nostre deduzioni teoriche.

Un lavoro minuzioso di ricerca condotto con metodicità e con grande impegno dei soci del gruppo ha dato risultati che superano ogni più rosea aspettativa.

Quattro sono stati gli abissi, di notevoli dimensioni, localizzati lungo la dorsale del monte Cucco di Pozze e tutti aperti in posizioni per le quali sono ampiamente verificate le condizioni supposte in via teorica.

L'Abisso del monte Cucco, l'Abisso della Pernice Bianca e il Busecca sprofondano per un centinaio di metri e, specialmente nei primi due, sono presenti numerosi pozzi-cascata come pure grandi gallerie a forra.

L'Abisso del Nido, che supera abbondantemente i quattrocento metri ed é il secondo abisso del Vicentino, oltre a splendidi pozzi-cascata serviti da grandi gallerie a forma, mostra anche tutta una serie di depositi di riempimento molto interessanti. Aggiungiamo fra l'altro che l'andamento sotterraneo di questo abisso, concorde con l'immersione degli strati, si sviluppa al di sotto degli altri abissi, e la notevole circolazione d'aria presente in tutte le cavità lascia supporre il collegamento di esse in un unico enorme complesso.

L'esperienza fatta ci consente di affermare tranquillamente che l'osservazione delle morfologie da modellamento glaciale hanno permesso la localizzazione di un sistema carsico profondo di prima grandezza per le nostra zone.

Ringraziamenti

Devo un vivo ringraziamento per il lavoro svolto sul monte Cucco di Pozze a tutti i soci del Gruppo Grotte Schio CAI, e in particolare a Cesare Raumer, Roberto Munari, Gino Dalla Costa, Flaviano Masetto, Mirco Calgaro, Ruggero Soliman, Norberto Marzaro ed Enzo Balasso, che sono stati i veri protagonisti delle scoperte, delle esplorazioni e dei rilevamenti fatti lassù.

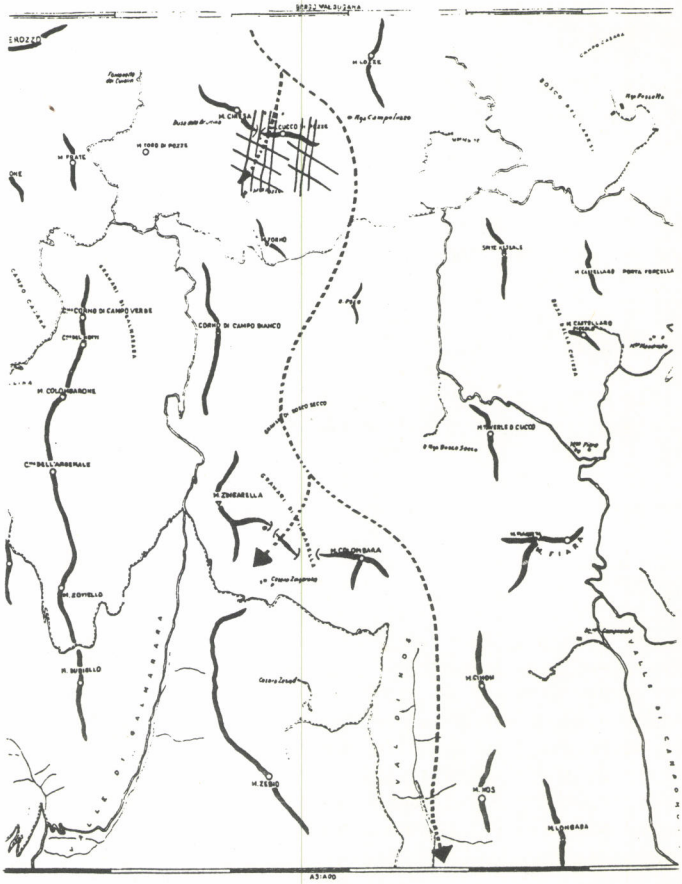

Figura 5. Monte Cucco di Pozze. Il marcato argine naturale e l'intensa fratturazione analoga a quella riscontrata sui Granari di Zingarella, hanno permesso la formazione di un complesso carsico di notevoli proporzioni.

Two unique mountain karst scenic spots in southwestern China

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RESUM

El congost de Jiu Zai Gou i el congost de Huan Long Gou són dos excel-lents exponents del paisatge càrstic xinès. La longitud de la vall de Jiu Zai Gou (mitjana i inferior) té un total de 20 km. i l'altitud oscil-la entre els 2.100 m. i els 2.900 m. sobre el nivell del mar. Hi ha uns 110 llacs de diferents formes i extensió. Són també freqüents les cascades i cataratas entre els llacs i embassaments naturals formats per travertins calcaris de naturalesa orgànica.

El congost de Huang Long Gou es troba situat a 32º 44' de latitud N. i a una altitud de 3.100-3.550 m. sobre el nivell del mar. En aquesta vall, l'amplada de la qual és de 200 m. i amb una longitud de 4.000 m., s'hi han depositat nombrosos travertins, que han configurat variades formacions càrstiques de gran bellesa. Aquestes consisteixen en 3.400 pintoresques «piscines», «tufa shods», cascades de travertins i tres cavitats. Les formes d'aquestes pintoresques «piscines» són molt semblants a les «rimestone pools» de les cavitats. Hi ha també grans extensions de selva primitiva, amb ocells i animals exòtics, sobretot pandes gegants i mones daurades.

RESUMEN

La garganta de Jiu Zai Gou y la garganta de Huan Long Gou son dos excelentes lugares de paisaje kárstico. En la garganta de Jiu Zai Gou media e inferior, la longitud totaliza 20 km. y la altitud va desde los 2.100 m. hasta los 2.900 m. sobre el nivel del mar: hay unos 110 lagos de varias medidas y formas. Entre lagos hay cantidad de cascadas y cataratas y muchos embalses naturales formados por travertinos calcáreos biológicos.

La garganta de Huang Long Gou está situada a 32º 44' de latitud N. con una altitud de 3.100-3550 m. sobre el nivel del mar. En esta garganta, cuya anchura es de 200 m. y la longitud 4.000 m. se han depositado numerosos travertinos constituyendo variadas formaciones kársticas de gran belleza. Estas consisten en 3.400 lagunas, canales, de toba cascadas en travertinos y tres cavidades. Las formas de estas pintorescas lagunas son muy parecidas a los gours de las cavidades. Hay también vastas extensiones de selva primitiva, con pájaros y animales raros, especialmente pandas gigantes y monos dorados.

ABSTRACT

Jiu Zai Gou Ravine and Huang Long Gou Ravine are escellent scenic spots. In the middle and lower Jiu Zai Gou Ravine, the length totalling 20 km and the altitude ranging from 2.100 to 2.900 above sea level, there are about 110 lakes of varied size and shape. Between lakes there are a lot of waterfalls and cataracts and many specific natural biological calcareous tufa dams.

Huang Long Gou Ravine is situated at latitude 32º44' N with an altitude 3.100-3.550m above sea level. In this ravine, is deposited, forming various beautiful karst forms. They consist of 3.400 colour pools, tufa shods, tufa waterfalls and three caves in tufa. The forms of these colour pools are very like rimestone pool in caves. There are also vast extent of primitive forest, rare birds and animals, especially giant panda and golden monkey.

Introduction

Located in the northen part of Sichuan Province Jiuzaigou Ravine and Huanglonggou Ravine are excellent karst scenic spots (Fig. 1). Since 1984 these two spots have been formally open to tourists as state protection region. In 1985 the total number of tourists from home and abroad was more than 100.000.

Jiuzaigou Ravine

jiuzaigou Ravine scenic spot is located 103º54' east longitude and 33º12' north latitude. It covers an area of 620 square kilometres with 42.6 % being forest. The area open to visitors is about 50 km^2, with an altitude ranging from 2.100 to 2.900m above sea level. Here the annual average temperature is 7.3ºC and precipitation about 600mm. The scenic spot is composed of 118 high mountain lakes, five shoals and a lot of waterfalls . Excepting a few lakes bloked by landslide or mud-rock flow, more than 110 are barrier lakes being blocked by specific natural biological calcareous tufa dams. The shoals and waterfalls also consist of tufa. These lakes vary in size and shape, among them over 20 lakes cover more than 5.000m^2 each. All of them strech for 20km along the middle and lower Jiuzaigou Ravine. The karst landscape is similar to Plitvice Lakes Park in Yugoslavia in many ways (Pepeonik, 1977).

The dominant strata around Jiuzaigou Ravine are carbonate rocks from Devonian to Triassic Period, mainly pure limestone. The carbonate rocks cover about 1.000km^2. There are several caves and some springs in the ravine (Fig. 2). The diameter of the caves ranges from 1 to 3m and the average discharge of the largest spring is 200-300 l/s while the maximum is 725 l/s. The total dissolved solids is generally more than 0.25 g/l. The springs provide lakes not only with water, but also with material for formings dams. These tufa dams vary in height. One of them, Nuorilang waterfall dam, is 15m high and 200m wide while an abandoned old tufa dam, near Swan Lake with an altitude 2.900m above sea level, is 30-50m in height and 200-300m in width.

It is mainly biokarst process that results in the tufa dams. First, there is dense forest, mainly coniferous-broadleaf mixed forest, in the whole basin. An abundence of CO2 in soil air and cold water intensify limestone solution, so there is considerable concentration of CaCO3 in the spring water and the lake water. Second, there are a lot of various algae and mosses in lakes. When the vegetation and microorganisms take photosynthesis, they absorb quite numbers of CO_2 from surrounding circumatance (H_2O+CO_2+light energy *chlorophyll*–HCOH–+O_2), therefore the water become supersaturated and $CaCO_3$ precipitate. Third, the area is tectonic active one with broken formations. Softer and

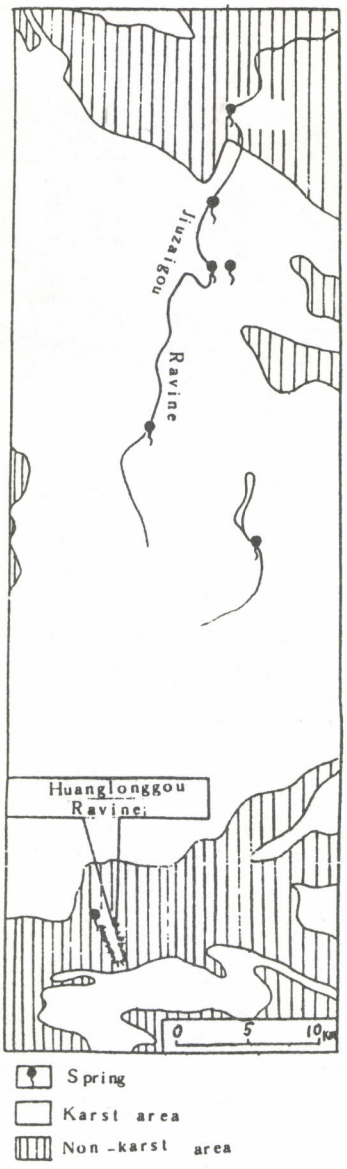

Fig. 1
Schemtic map showing of hydrogeology of Jiuzaigou Ravine and Huanglonggou Ravine.

harder rocks interlayered and there are numerous small cascades on the ravine bed. It is on those points with greater slope that first of all tufa was deposited. As the tufa deposited, algae and mosses would be buried and order to adapt to this sort of conditions they reacted by vigorous growth. Because of a competition between the growth rate of algae and mosses and the rate of carbonate deposition (Golubic, 1969), tufa dams grow up vertically and a series of lakes form behind them. In addition, as the relative height difference between the bed and the divide is up to 2768m in Jiuzaigou Ravine, the slope mass movenment processes are very active and some rock fragments can be seen in tufa dams. The primitive relief and the emergence variations of the springs lead the lakes and the tufa dams to be different each other in size and altitude, consequently it is very popular that sometimes some upstream dams were flooded and several lakes were conected together as downstream dams grew up quicker. «The prone dragon» in the Prone Dragon Lake is such a flooded tufa dam.

In Juizaigou Ravine there are not only vast extent of primary forest, but also rare birds and animals, especially giant panda and golden monkey.

Huanglonggou Ravine

Huanglonggou (Yellow Dragon) Ravine scenic spot is situated at latitude 32° 44' N and 103° 49' E with an altitude 3.100-3.550 m above sea level. The linear distance from Huanglonggou Ravine to Jiuzaigou ravine is only about 40km, but 160km along the highway.

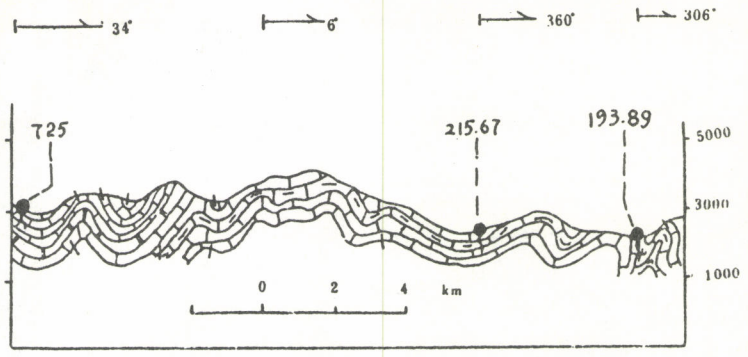

Fig. 2
Hydrogeological profile of Jiuzaigou Ravine

The climate of Huanglonggou Ravine is cold, with an annual average temperature 1.1° C(the highest 29.5°C and the lowest -28.1° C) and average annual precipitation of 758.9mm, 70 % concentrated in the rainy season from May to September.

The dominant strata in the scenic spot is non-carbonate rocks of Triassic System, which interbedded with a few limestone, and quartzite and sandstone of Devonion System (Fig. 3). The great Xue Shan Fault acrosses the scenic spot and the width of broken formation is some hundred metres.

There is a clear vertical zonality of vegetations. The coniferous forest is 3.100-3.600m above sea level, mainly fir, dragon, spruce, Chinese hemlock, azalea etc., and mountain bush and meadow are 3.700-4.000m above sea level. Over 3.000m above sea level algae and mosses are very luxuriant.

For karst water there is a distribution of 10km limestone in area above the scenic spot. The highest peak of the recharge area is 5.588m above sea level. Huanglonggou Ravine scenic spot has high concentration of $CaCO_3$ (Table 1), SC = 0.254. When the spring water emerges to the surface numerous Ca CO_3 are precipitated because of the increasing temperature effect decreasing pressure and biokarst process.

TABLE 1
Data of water analysis

Spring	T°C		Total dissolved solids (g/l)	Ca^{++} (mg/l)	Free CO_2 (mg/l)	PH
	Air	Water				
Huanglong Si	6	6	0.64	216	121	6.8
Huanglong Dong			0.55	168	68.2	6.9

The thickness may be more than 50m. Various deposition forms constitute a wonderful karst landscape of travertine precipitate. The main landforms are;

1. Great travertine shoals.

The shoals stretch from north to south for 2.500m with a width of 30-70m ard show a riot colour, mainly light yellow and bright yellow. During warm season there is a thin layer of water flowing on the surface of the shoals. In the distance it looks like a yellow dragon leaping vividly. Shoal slopes are 15°-20°. The textur of the travertine shoals is similar to cave sheet in caves excepting a lot of algae and mosses on the former.

2. Flowstone dams and coloured pools in groups.

The flowstone dams coloured pools in groups are mainly distributed on the top part and both sides of the shoals, each group contains several hundred of coloured pools. In Huanglonggou Ravine the coloured pools totaled over 3.400 emerge in groups and are scattered from several sq. m. to several hundred sq. m. in area in a form of rimestone pool in caves. The height of the flowstone dam is up to 7.2m while the greatest depth of the coloured pool is 3.4m. The water is very clear and pools show multicoloured (milky white, light yellow, emerald green, dark blue etc.) due to varieties of depths and species of algae and mosses.

3. Travertine caves

The greatest travertine cave is Huanglong Cave with an altitude 3.500m above sea level. The cave is a hall, the height is over 10m and the width about 20m. There is water flowing on the

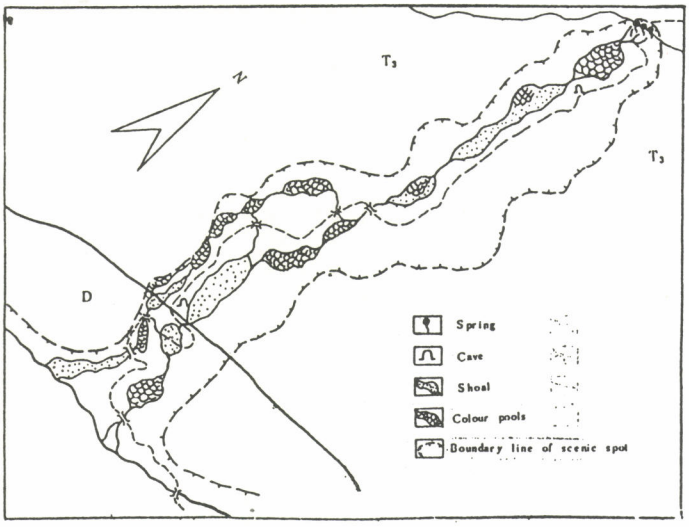

Fig. 3
Sketch map of Huanglonggou Ravine

Fig. 4
Stone tablets and stone towers in coloured pools

bottom and there are various stalactites, stalagmites, curtains, etc.. There are ice stalactites and ice stalagmites from December to next April.

4. Travertine waterfalls.

The highest travertine waterfall in Huanglonggou Ravine is 7m and 33m wide. There is another waterfall with a height of 93m near Huanglonggou Ravine.

It has been identified by C^{14} dating that the age of early procipitated travertine is 30.000yr at least. The deposition rate has been rather quickened since last centuries. For example, two stone tablets and two stone towers (Fig. 4), which were built in 1.620, have been buried by travertine. The heights of buried parts are 1.8-2.0m, according to the data the rate of travertin deposition is 5-6.5mm/y during the last 300 years.

Concluding remarks

Jiuzaigou Ravine and Huanglonggou Ravine are beautiful karst landscapes of paranormal mountainous type. It is suggested that the origin of the landscapes has some relations to the specific climatic, geomorphological, biological, geological conditions. Some compositive scientific researches are being progressed. It has been decided that limited tourism for the two scenic spots will be developed on the basis of natural protection. In Huanglonggou Ravine the landing stage totale 3.000m and some view platforms have been built. In Jiuzaigou ravine 200.000 trees have been planted, the sewage conduit system has been established. The two karst scenic spots have boundless prospects.

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Application of controlled source AFMAG method to speleology

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RESUM

A fi i efecte de poder situar amb precisió els sistemes de cavitats de la regió càrstica de Moravia, s'ha utilitzat un aparell AFMAG, distribuït comercialment per a mesurar l'angle d'inclinació d'un camp electromagnétic generat per una font situada dins de terra. En aquest treball es comenta l'intrumental utilitzat, la interpretació dels resultats, els efectes atribuïbles a l'ambient i les interferències, així com la influència de la manca d'homogeneitat en la conducció elèctrica.

RESUMEN

Con el fin de situar con precisión los sistemas de cavidades en la región kárstica de Moravia, se ha utilizado un aparato AFMAG, distribuido comercialmente para medir el ángulo de inclinación de un campo electromagnético generado por una funete situada bajo tierra. En este trabajo se comenta el instrumental, la interpretación de los resultados, los efectos debidos al ambiente y las interferencias, así como la influencia de la falta de homogeneidad en la conducción eléctrica.

SUMMARY

Commercially available AFMAG apparatus was successfuly applied for dip angle measurement of the electromagnetic field generated by controlled source placed underground for the purpose of localization of the cave systems in the Moravian karst region. Instrumentation, interpretation of the results, ambient field effect and noise problem as well as conductive inhomogenities influence discussed.

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19290

Consideraciones mofométricas y genéticas sobre perforaciones cilindroideas en el lapiaz. Estudio comparativo en el karst español.

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RESUMEN

Las perforaciones cilindroideas constituyen uno de los elementos más característicos de la morfología kárstica superficial, citadas en numerosos karst por diversos autores.

Mediante la compilación bibliográfica y observaciones realizadas por los autores de esta comunicación, se comparan los resultados en diversas zonas de España, para conocer las características morfológicas y genéticas de estas formas del lapiaz.

RESUM

Les perforacions cilindoïdees constitueixen un dels elements més característics de la morfologia càrstica superficial, citades en nombrosos carsts per diversos autors.

Mitjançant la compilació bibliogràfica i les observacions realitzades pels autors d'aquesta comunicació, es comparen els resultats de diverses zones d'Espanya, per a conèixer les característiques morfològiques d'aquestes formes de lapiaz.

RÉSUMÉ

Les perforations cylindroïdes constituent un des éléments les plus caractéristiques de la morphologie karstique superficielle, elles sont citeés para divers auteurs dans de nombreux karsts.

Á travers la compilation bibliographique et des observations réalisées para les auteurs de cette communication, on compare les résultats dans plusieurs zones d'Espagne, à fin de connaître les caractéristiques morphologiques et génétiques de ces formes du lapiaz.

1. Introduccion

El término perforación cilindroidea fue introducido por MONTORIOL POUS (1954) para referirse a pequeñas depresiones centi y decimétricas subcirculares y de profundidad muy variables, que caracterizaban el micromodelado del lapiaz de Garraf (Barcelona).

ULLASTRE (1970) analiza con mayor rigor estas perforaciones de Garraf y llega a diferenciar, en base a un análisis estadístico de sus parámetros dimensionales, dos tipos morfogénicos distintos que denomina alveolares y fistulares, según que la relación profundidad/diámetro medio sea menor o mayor que la unidad, respectivamente.

En realidad esta diferenciación se encuentra suficientemente determinada en la actualidad, y corresponde, por una parte a las conocidas kamenitzas (SWEETING, 1972; GEZE, 1973; MAIRE, 1980), también llamadas solution basins (SWEETING, 1972), kamenitze o vaschette di corrosione (PERNA, 1978), lapiés en nids de poules (MAIRE, 1980), kaménicas o pilones (FERNANDEZ RUBIO et al., 1975); y, por otra a las perforaciones cilindroideas propiamente dichas (fistulares de ULLASTRE, op. cit.) o karrenrohren (SWEETING, op. cit.) micropozzi (PERNA, op. cit.), lapiaz à trous (GEZE, op. cit.), lapiaz tubular (PEZZI, 1977).

2. Encuadre geológico de las distintas estaciones

En la figura 1 se ha señalado la ubicación de las distintas poblaciones de perforaciones cilindroideas comparadas.

–Macizo de Garraf (Cadenas costeras catalanas): el lapiaz se halla instalado en calizas del Cretácico. Los datos proceden del artículo de ULLASTRE (1970), con una población de 90 elementos, tanto alveolares como fistulares.

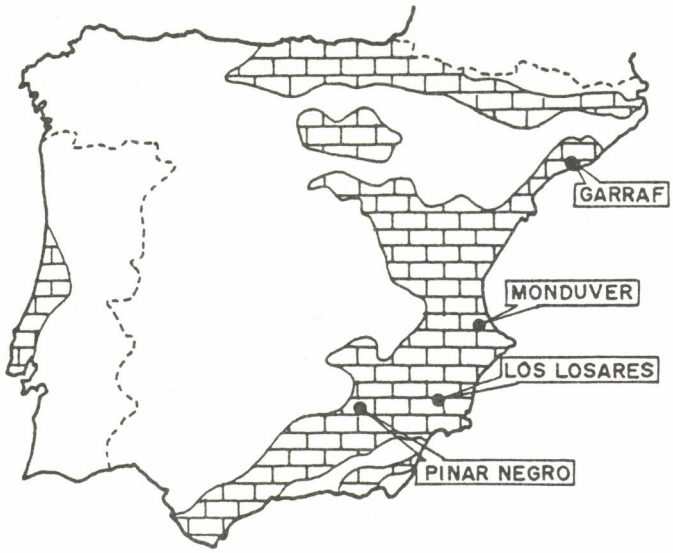

Figura 1. Situación de las cuatro poblaciones de perforaciones cilindroideas.

–Los Losares: localizada en la provincia de Murcia, en el área de los Losares se produce el contacto entre el frente N. de la zona Sub-bética y el Prebético. El campo de lapiaces se ha desarrollado en los nivles calizos del Cretácico superior (Prebético). El lapiaz ha sido estudiado por SANCHEZ SANCHEZ y VALENZUELA (1972-73), con una población de 200 fistulares.

–Macizo del Mondúver (GARAY, 1983): se sitúa en la zona de interferencia entre los dominios Ibérico y Prebético, dentro de la provincia de Valencia. Las formas kársticas estudiadas se ubican en la llamada «formación Creu» (Cretácico superior) en la que predominan tanto calizas como dolomias. La población es de 30 elementos fistulares y alveolares.

–Pinar Negro (LOPEZ LIMIA, 1985): constituye el límite más occidental del dominio Prebético Interno (Jaén). El lapiaz se desarrolla en materiales carbonatados del Cretácico superior (calizas y dolomías). Han sido medidas 405 formas entre alveolares y fistulares.

Morfometría

3.1. Perforaciones cilindroideas fistulares.

Los resultados morfológicos son similares en las estaciones de Garraf, Mondúver y Pinar Negro: los valores se agrupan en torno al intervalo 5-10 cm. para el DM (diámetro medio), (54 %, 46,6 % y 51 % respectivamente), siendo ocasionales los casos en los que se sobrepasan los 30 cm. En los Losares se observa una disminución en los procentajes de los intervalos inferiores, alcanzándose DM que superan los 40 cm. Esta aparente anomalía puede deberse a que en este sector, entre las perforaciones muestreadas, se descartaron las de menores dimensiones, por lo que el número de formas con DM comprendidos entre 5-20 debiera ser mayor.

Este tipo de perforaciones tiene su máximo desarrollo en profundidad, con valores que, en casos excepcionales, alcanzan hasta los 80 cm. (Pinar Negro). Las semejanzas entre Garraf, Mondúver y Pinar Negro son significativas, con un predominio de profundidades comprendidas entre 10-40 cm. (82 %, 76,6 % y 88,9 %) respectivamente.

En general, las perforaciones cilindroideas fistulares presentan un perímetro elíptico subcircular, con un mínimo de formas propiamente circulares.

ULLASTRE observó como la relación DM/Profundidad era de tipo lineal, según el muestreo de 38 perforaciones del macizo de Garraf, obteniendo un coeficiente de correlación r=0,76. GARAY, partiendo de la muestra de 30 elementos, localizados en calizas, ha obtenido un coeficiente de correlación r=0,79. En Pinar Negro, LOPEZ LIMIA llega a resultados semejantes en una muestra de 328 perforaciones, r=0,76.

Las perforaciones cilindroideas fistulares presentan, pues, un mayor desarrollo en profundidad (10-40 cm.) que a favor de los diámetros (5-10 cm), con un perímetro preferentement elíptico subircular, condicionado por su implantación a favor de fisuras y leptoclasas de la roca carbonatada, (fig. 2).

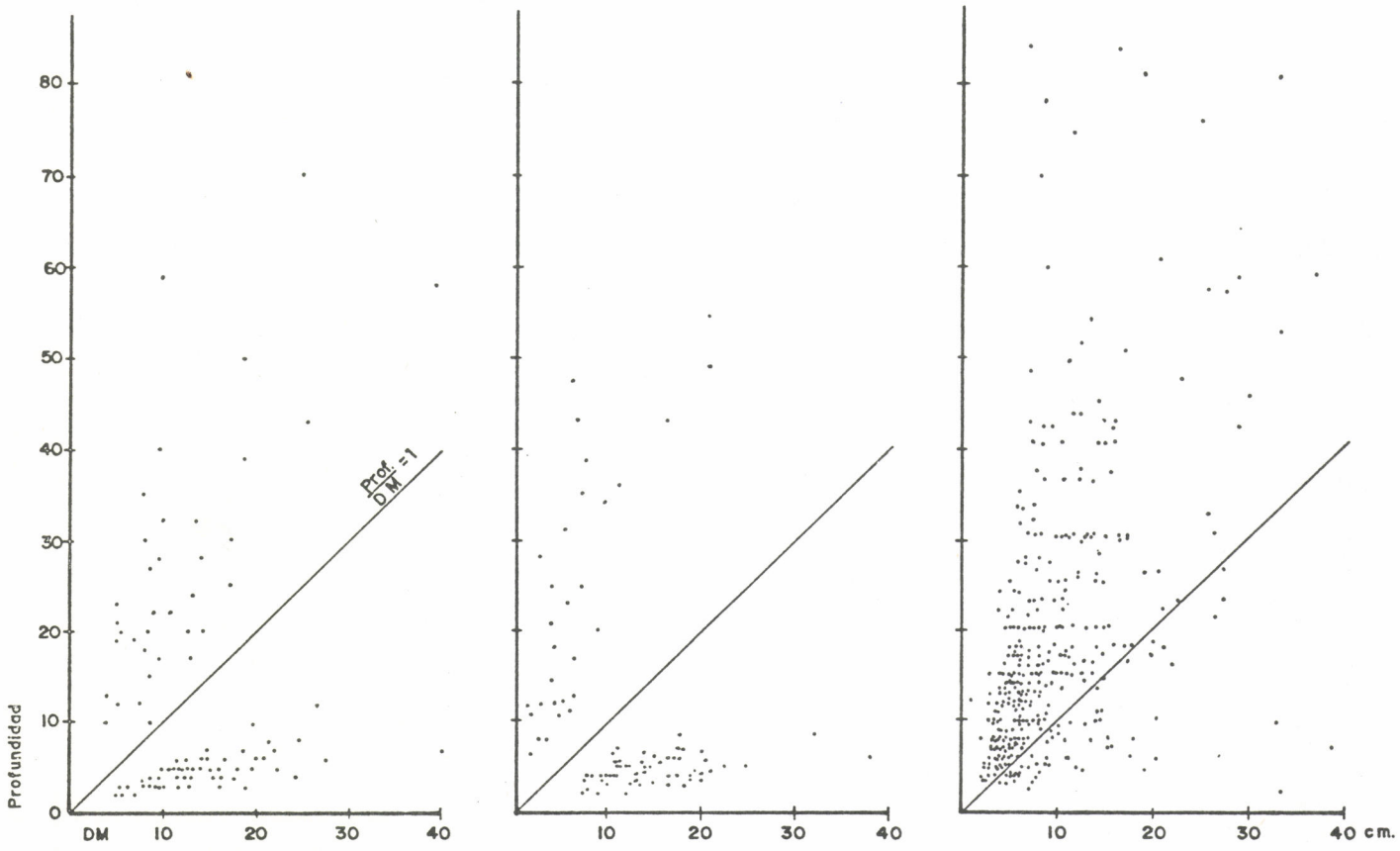

Figura 2. Familias de perforaciones cilindroideas según la relación Profundidad/ Diámetro medio.

3.2. Depresiones alveolares (kamenitzas)

Para el análisis de las kamenitzas se han comparado sólo tres sectores: Garraf, Mondúver y Pinar Negro, ya que el muestreo de los Losares no contempla esta microforma.

Al igual que en el caso anterior, los resultados obtenidos son similares en los tres casos. Las kamenitzas son más anchas (10-15 cm.: Garraf 42 %, Mondúver 44,5 % y Pinar Negro 38,9 %) y poco profundas (5-10 cm: Garraf 52 %, Pinar Negro 40,2 %; 5 cm.: Mondúver 56,7 %), con contornos subelípticos subcirculares a menudo complejos e irregulares.

Partiendo de la diferenciación establecida por ULLASTRE, y a la que ya se hizo referencia anteriomente, en Pinar Negro habría que considerar un tercer tipo que, aunque incluido en el grupo de las kamenitzas por ser la relación DM/Profundidad inferior a 1, difiere morfológica y genéticamente de éstas. Se interpretan como perforaciones fistulares en las que su desarrollo se ha visto truncado por diversos factores, o perforaciones fistulares en un estadio incipiente de su evolución.

A través de la representación de los dos parámetros considerados, se obtiene una función aritmética cuyo coeficiente de correlación es más bajo que en el caso de las fistulares y fluctúa en torno a 0,5: Garraf r=0,51, Pinar Negro r = 0,51, Mondúver, cuatro poblaciones de 30 elementos cada una: r = 0,54 (en dolomía), r = 0,53 (en caliza), r = 0,52 (en caliza dolomítica) y r = 0,63 (en caliza). Ello es debido, según ULLASTRE, a que el diámetro de las kamenitzas está determinado por el perímetro de la depresión de la roca a partir de la cual se genera y, por tanto, a una falta de relación kamenitza-fisuración.

4. Teorías sobre la génesis de las perforaciones cilindroideas

A continuación resumimos las principales características de diversos mecanismos genéticos relativos al desarrollo de las perforaciones cilindroideas, según diversos autores, con una discusión posterior basada en nuestras propias observaciones.

a) Teoría de MONTORIOL POUS (1954)

Esta autor aduce un origen «físico-químico» a partir de pequeñas depresiones de la superficie de la caliza que se llenan de agua tras las lluvias. El perímetro del embalsamiento de agua determina, en principio, el diámetro de la futura perforación. No existen relaciones con las soluciones de continuidad de la roca. El agente acidificador es el CO_2 de origen atmosférico asimilado a la lluvia. La evacuación del CO_3Ca disuelto se produce por renovación del agua embalsada, lo que da lugar a pequeños canales emisarios que se originan en el borde más deprimido.

Cuando la capacidad de embalse hídrico de la perforación es tal que no resulta posible su renovación por la limitada pluviometría de la zona, ésta no sigue desarrollándose ya que el agua tan sólo es evacuada por evaporación. En este momento cesaría su progresión en profundidad.

b) Teoría de ULLASTRE (1970).

Acepta la teoría de MONTORIOL POUS pero, con la salvedad de que en las perforaciones fistulares sí existe un claro condicionamiento microestructural en su desarrollo genético. En consecuencia admite que la renovación del agua contenida en la perforación es posible no sólo por desbordamiento superficial, sino también por evacuación en profundidad, en el caso de las fistulares. Por lo tanto, la profundidad de estas últimas es bastante mayor que la alcanzada en las perforaciones alveolares.

c) Teoría de SWEETING (1972) y otros para kamenitzas.

Esta autora admite que las kamenitzas pueden formarse por acción del agua pluvial cargada de CO_2 atmosférico, especialmente en climas frios, pero en general defiende que el principal agente acidulador es el CO_2 aportado al agua encharcada por la acción biológica de algas endolíticas, así como de materia orgánica de origen vegetal y animal aportada circunstancialmente.

d) Teoría de PERNA (1978) para perforaciones fistulares

PERNA describe un mecanismo inverso o remontante, según el cual el proceso de crecimiento de la perforación (micropozzi) se inicia a partir de una junta de estratificación hacia arriba, aprovechando alguna incisión o microfisura de la roca por la que el agua puede ascender, inicialmente, por capilaridad. Esto explica el hecho repetidamente observado de que las perforaciones suelen terminar en profundidad en un joint horizontal.

Nuestra experiencia personal nos demuestra que tanto las perforaciones fistulares como las kamenitzas pueden coexistir tanto sobre dolomías como sobre calizas en un mismo macizo kárstico, a diferencia de otras micromorfologías del lapiaz que suelen ser exclusivas de uno u otro tipo de roca. Este hecho ha sido interpretado aduciendo al agente biológico (fitokarsismo de PERNA) como fuente principal del aporte de CO_2 al agua, además de otros posibles compuestos acidificantes orgánicos (GARAY, 1983).

Sin descartar la acción individual de las aguas meteóricas aciduladas como único agente formador de kamenitzas, tal como propuso MONTORIOL POUS, pero en condiciones climáticas determinadas, hemos podido constatar repetidamente la presencia de algas, y casi siempre también de restos orgánicos de presencia ocasional (hojas, insectos...), viviendo a expensas del agua contenida en la kamenitza, o sus restos cuando éstas se encontraban secas. Tanto en el macizo del Mondúver como en el macizo de Candina (Liendo-Cantabria) se ha podido determinar la presencia de algas de los géneros Nostoc y Volvox (determinaciones debidas a J.J. Herrero-Borgoñón y A. Sendra, de la Universidad de Valencia).

Estamos completamente de acuerdo con ULLASTRE en la evacuación del agua en profundidad pero, no por ello dejamos de reconocer la validez del modelo genético de PERNA. Efectivamente, los cortes y desmontes artificiales producidos en canteras o el trazado de carreteras a menudo permiten observar en detalle la morfología de las perforaciones en profundidad, y como éstas que, en principio aparentan ser verticales o subverticales, adquieren trazados más o menos irregulares que suelen prolongar a favor de joints tectónicos o sedimentarios, con cualquier inclinación.

Este mecanismo concuerda con las observaciones realizadas y recopiladas por FREYTET y PLAZIAT (1982), según los cuales la causa principal de estas morfologías sería la biocorrosión asociada a Microcodium (fig. 3). Es éste un fósil constituido por prismas monocristalinos de calcita que se agrupan en elementos alargados de sección poligonal-subcilíndrica de estructura radial, con un canal o vacuolo central y con unas dimensiones de 100 a 800 mm. de longitud y unos 20 a 70 mm. de anchura. También se encuentran constituyendo láminas planares u onduladas.

Su origen no se encuentra bien determinado pero, aunque en un principio fue referido a ambientes marinos, en la actualidad se ha constatado su franca relación con ambientes edáficos vadosos, ya asociados al karst, a canales fluviales, a suelos carbonatados o a suelos hiperalcalinos (FREYTET et a., op. cit.). Los microorganismos responsables de los Microcodium podrían ser bacterias tipo Actinomyceta, aunque otros autores opinan que un mismo

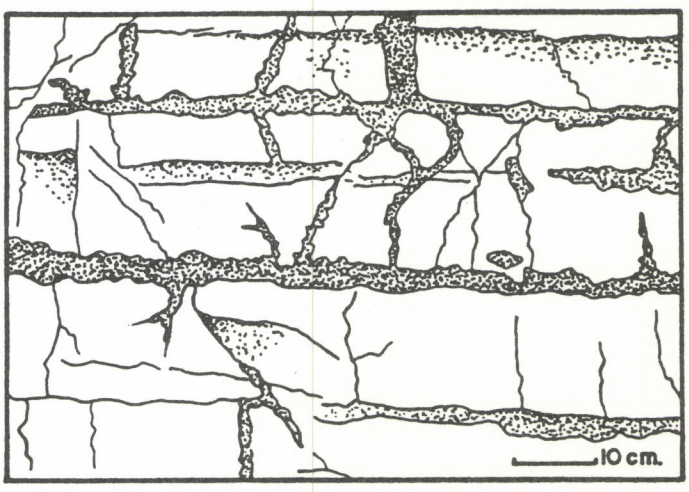

Figura 3. Distribución del Microcodium sobre la superficie de erosión Masstrichtense según FREYTET and PLAZIAT (1982).

organismo difícilmente puede realizar la doble función de ataque y síntesis de la calcita, por lo que sugieren una asociación de ciertos hongos y bacterias filamentosas como agentes biocorrosivos y otros tipos de bacterias como sintetizadoras del fósil en sí.

No defendemos que la biocorrosión asociada a Microcodium sea la causa única de la formación de perforaciones fistulares, pero parece evidente que ésta puede jugar un papel fundamental en el desarrollo en profundidad de aquéllas.

En nuestra opinión, lo más acertado para explicar la formación y crecimiento de las perforaciones cilindroideas fistulares parece ser la recurrencia a un mecanismo mixto de biocorrosión por microorganismos en profundidad, bajo el nivel de colmatación arcillosa de la microcavidad, y una acción más directa por el agua meteórica y la fitokarstificación, en el tramo subaéreo de la perforación.

5. Conclusiones

El análisis morfométrico comparativo de varios muestreos de perforaciones cilindroideas (sensu lato) en diversos emplazamientos de la Península Ibérica, así como el análisis de diversas teorías genéticas contrastadas con observaciones personales, han permitido llegar a las siguientes conclusiones:

Bajo el término perforaciones cilindroideas se agrupan diversos tipos de micromorfologías del lapiaz entre las que se encuentran las kamenitzas y las perforaciones fistulares (karrenrohren) entre otras posibles formas más complejas.

La relación entre la profundidad y el diámetro medio resulta característica para las perforaciones cilindroideas, pudiendo establecerse con este parámetro la diferenciación entre kamenitzas y perforaciones fistulares, tal como apuntaba ULLASTRE (1970), habiéndose obtenido coeficientes de correlación lineal en torno a $r = 0,75$ para las perforaciones fistulares y alrededor de $r = 0,5$ para las kamenitzas, en todos los casos contemplados.

El origen de las kamenitzas responde fundamentalmente a la corrosión producida por el agua pluvial encharcada sobre la roca carbonatada (caliza o dolomía), con el concurso de una acidez anexa debida a las colonias de algas que en dicha agua se encuentran instaladas, así como a la ocasional presencia de otras materias orgánicas tales como hojas en descomposición o insectos.

En la formación de las perforaciones fistulares, aparte de la propia acidez del agua pluvial interviene el CO_2 contenido en los pequeños depósitos de terra rossa, la fitokarstificación producida por musgos y líquenes y la acción corrosiva de elementos bacterianos relacionados con la formación de Microcodium.

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The north-western part of the Karst of Sagada (Mountain Province, Luzon, Philippines)

*Claude Mouret**

RESUM

Presentem aquí la part nord-occidental del carst de Sagada, explorada del 1979 al 1984 per equips francesos. Es descriuen les principals cavitats, així com els corrents d'aigua subterranis que es van trobar. Es precisen també les característiques locals de la morfologia subterrània. Finalment, se situa novament la morfologia de superfície en el context propi i en relació amb el medi subterrani. El carst de Sagada es troba situat al voltant dels 1.500 m. d'altitud (la part estudiada) i, aproximadament, a 17° 05' de latitud nord.

RESUMEN

Se presenta la parte noroccidental del Karst de Sagada, explorada de 1979 a 1984, por equipos franceses. Se describen las principales cavidades, así como las corrientes de agua encontradas. Se precisan características locales de la morfología subterránea. Finalmente se sitúa nuevamente la morfología de superficie en el contexto propio y en relación con el medio subterráneo. El karst de Sagada está situado alrededor de 1.500 m. de altitud en la parte estudiada y aproximadamente a 17° 05' de latitud Norte.

RÉSUMÉ

La partie nord ouest du karst de Sagada, explorée de 1979 a 1984 per des équipes, est présentée. Les principales cavités sont décrites, ainsi que les circulations d'eau rencontrées. Des caractéristiques de la morphologie souterraine locales sont précisées. Enfin, la morphologie de surface est replacée dans son contexte propre et dans ses rapports avec le miliev souterrain. Le karst de Sagada est situé vers 1500 m d'altitude dans la partie étudiée, et vers 17° 05' de latitude Nord.

The karst of Sagada, investigated from 1979 to 1985 by french explorers** (1,4,5), has been already the matter of several papers. This one is a synthesis of the knowledge, still partial, over a part of this karst, corresponding to the watershed of the Ambasing spring, the second largest one for its flow. The oligocene limestones range in elevation from 1020 to 1636 m, and more specifically from 1400 to 1500 m for the main underground streams of the studied area. The efficient rainwaters are estimated to be of 1660 mm/year.

Underground features
Description of the caves

Several caves with running or dormant waters, explored from 1979 to 1984 (1,4,5), will be briefly described, dowstreamwards (see maps attached).

Latang cave (I)

This cave is a wide tunnel 1500 m in elevation, 270 m long, 3 to 12 m wide and 7 to 40 m high, followed by the Latang River (around 30 l/s at low waters), which originates from a non karstic watershed. Both ends of the cave are widely opened to the free air. Large hanging fossil passages and chambers, moderately dipping towards the top of the passage containing the river, were used as burial yards.

Latang 3 cave (I)

It is a small tributary of the main Latang River, possibly originating from local dolines. Its opening is located around 80 meters downstream the Latang Cave. The diameter of the passage is around 1.2 m.

Unnamed swallow holes (I)

The Latang River disappears into a cave with a low opening. A bit more downstream, there are two other openings, looking onto the river, which «probably terminates by sumps».

Caves of «the Canyon»

«The Canyon» is very likely a collapsed cave, as explained further on. It contains three caves. Matogbog cave has a shaft floored by a pool of dormant water. An upper passage, unexplored, may be possibly either a fossil main passage, or a dry tributary. Polikakao cave has two passages partially filled up by dormant water, which surface was lower in March 1983 than in October 1984. The water surfaces of Matogbog and Polikakao are at the same elevation.

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The Tunnel, cave very modified by roof and wall collapses, occupied by numerous bulky boulders, has two entrances in the main canyon and another one in a doline elongated along a fracture parallel to the Canyon. It seems to be followed by a stream, during the flooding periods, when the dormant waters of Polikakao rise enough.

Unnamed cave between boulders (around 80 m south of the Tunnel)

A short cave carved by erosion and corrosion between boulders extends over a few tens of meters. It may be followed by a stream only when the flow is specially large in the Tunnel.

Dinit Ahan cave

This cave may be the place of a stream during the highest floods. Its upstream entrance is hanging over both the cave floor and the land outside. The downstream openings are all of them the result of a huge collapse of the roof and of the walls of the cave, as proved by the angular shapes of these openings and by the very bulky boulders lying in the cavern. The downstream openings are sunk during the large floods and possibly also evacuate waters towards the outside. Maybe, the dormant waters which are lying in the cave during the normal periods, may be fed not only by the surface stream (Dinit Ahan Creek) originating from the Tunnel, but also by some underground reserve of water, connected or not to some underground flow.

Dinit Ahan cave is interpreted as the former upstream continuation of the Ige cave, described after, separated from it because of a huge collapse, located where the Dinit Ahan Creek in its E-W part, intersected the passage. The temporary creek presently flows in a relatively narrow and V-shaped valley, deeper downstream the cave where it turns into a canyon. The collapse is due to both the thinning of the roof of the cave and the lateral decompression linked to the deepening of the valley in its part parallel to it.

Agoyo-Ige and Agoyo-Lomyang caves

Separated by a few meters only, they are likely two parts of a single cave. The main passage is followed by a stream (around 30 l/s at low waters), which originates from both a lateral narrow passage, to the West and another one smaller in diatemer and in flow (around I l/s) located close to the collapsed area near Dinit Ahan. The western flow is probably the one coming from Latang (similar magnitude), plus the very small stream ($\simeq$ 2 l/s) of the Sagada Lost River (see after), plus the river of Aati Cave, when it flows; all those rivers are allochtonous to the karst. During the efficient rains, there is also a drainage from miscellanenous dolines where small surface streams form and disappear into some absorption point (see pits and gulfs described further on), and the normal drainage from the different other parts of the karst.

The main passage sumps at the end of the Agoyo-Ige cave and reappears shortly only in the passages of the Lomyang sink, where it sumps again. Then, it can be seen only some 10 m upstream the Ambasing spring. This flow can be traced without any dye, just using the sedimentated garbage originating mostly from the Sagada Lost River and the Aati cave but also from the Latang River.

Before the sump of Agoyo-Ige, is the small tributary of Agoyo ($\simeq$ 1 l/s) at low waters, carryng allochtonous waters, at least during the floods. A fossil passage of the Agoyo tributary connects with the Lomyang sink. Two sumps can be seen in this latter cave; the relation between their dormant waters and the main flow of the cave are still unknown.

Concerning the Dinit Ahan Creek, its temporary waters first infill the upstreammost entrance of Ige cave, then, when the charge is enough, the next opening, located after a rising step.

Two types of passages can be clearly distinguished, the old ones, low but wide, partly filled up by coarse sediments (sands, pebbles), and the younger ones, actually higher than wide with a smaller section, but also floored by the same coarse sediments.

The old passages extend from the Dinit Ahan area to the chamber generated by collapse and located in front of the Sogong cave. As this latter cave has morphological characteristics rather similar, it is very likely the former continuation of the old passages of the Ige cave. However the passages in Ige are interpreted as rejuvenated by the present permanent and temporary flows. Around the aven of Ige, generated by collapses around former small passages, there are also two passages, located to the east of the main one. The northernmost one, very dismantled by wall collapses, but still recognizeable, has normally dormant waters in some parts; during the flooding periods, they may rise enough to generate a flow towards the Sogong cave. The second eastern passage, more fossil (abundant calcite deposits) probably flows very seldom.

Between the chamber in front of Sogong and the terminal sump of the Agoyo-Ige cave, the main passage is typically formed along fractures; it has been carved by corrosion and erosion, probably specially during the floods, when a lot of particles are carried in suspension in the water. The secondary passages of the Agoyo area, in both Agoyo-Ige and Agoyo-Lomyang caves are «meander» shaped, i.e. much higher than wide.

Sogong-Dokiw cave

The Sogong cave, wide passage partly filled up by coarse sediments, locally contains specially bulky boulders; it ends as a normal passage at the aven of Sogong, located just behind the Upper Dokiw 1 entrance. More to the south, all the passages are between bulky boulders resulting either of successive sudden collapses, such as at the aven itself, or of a slow dismantling of the whole hill, after the phenomenon was initiated around a former large passage. In Dokiw, many boulders are still in connection, i.e. might be reassembled by the mind. Probably, the collapse phenomenon begun when the former large passage of Sogong became near enough from the ground surface, because of both the underground and surface erosion, i.e. when a general decompression of the hill took place.

A small ($\simeq$ 1 l/s) permanent (?) flow exists in Dokiw. During the floods, the whole cave of Sogong-Dokiw is sunk in its lower part, specially in the collapsed areas. The water comes from the Ige cave and carries a lot of garbage: specially plastic pieces, materials, iron items, and woods. More downstream, a similar garbage was observed in the upstreammost part of the Latipan cave (3), between boulders. Probably, the two caves were formerly a single one later on cut through by the collapse of the doline of Lomiyang.

Aati cave

A temporary allochtonous river disappears into it. This relatively short (around 150 m) and slopy (around 25 deg.) cave has two parallel passages, connected at the end of the surface talweg, and also by a narrow and low passage just before the final sump. The passage to the south exists mostly only between bulky boulders.

Sagada Los River = Dukkong cave

A permanent (?) flow ($\simeq$ 2 l/s) enters this short cave and, after a few shafts, sumps at a narrow pool specially rich in garbage, the shoes being very abundant! A big silicified wood was found in the parallel passage at section w.

Three gulfs

The «P 12» and Marwaka gulfs, not deep, drain each of them a doline; they are choked at the bottom. Kitungan Kampus Pit

is a single shaft, also without any passage at the bottom; maybe, its bottom full of garbage is flooded during the heavy rains.

Other caves

Small other caves are known, either fossil such as Latang 2(1), or collecting very temporary waters from dolines, such as Nangunogan.

The water flows and their specificities

The different underground and surface temporary or permanent flows have been mentionned above, and the places with dormant waters as well. The main feature is the existence of a likely single main stream, from Latang to Ambasing, collecting miscellaneous flows coming from the western edge of the karst and, for many of them, originating from non karstic watersheds. The main underground flow is therefore THE collector of the upper western part of the karst of Sagada, in relation not only with the sufrace sunk streams, but also with the different subsystems of the karst, such as the cracks of the «unsaturated» zone or the different «saturated» parts, lying behind faults uprising the impervious basement.

During the floods, the waters of the collector partly escape into the Sogong cave, i.e. into a different karstic watershed, the one of the Balangagan spring, much lower in elevation than Ambasing (1400 m). It appears through this fact, the younger features of the passage in Ige cave downstream the chamber in front of Sogong, and the relatively unevoluted amphitheater at the bottom of which the Ambasing spring is lying, that this latter spring has been created by the derivation of the former flow normally continuing into Sogong after Ige. The time when the spring developed probably also follows the erosion of the edge of the karst in the N-S Ambasing valley. This spring, therefore, is probably recent (no blind valley); the Agoyo tributary may have played some role in the capture of the waters from Ige.

Due to their flow which may be large during the floods (up to several cubic meters probably), and due to the related high speed of the waters, the allochtonous rivers are able to bring into the karst large quantities of solid particles, sand and pebbles which may reach up to 20 cm or even more. These have a very strong effect for the erosion of the passages flooded. Moreover, the waters are undersaturated in calcite and therefore agressive. These facts may be placed in regard with the general large size of the passages, old enough in this part of the karst. Carbonated deposits, here very rare, are related only to autochtonous small flows.

A spectacular effect of the floods occured between March 1983 and October 1984. Close to the chamber in Ige cave located in front of Sogong, a passage formerly completely choked by big pebbles, sands and silts, has been completely reopened over more than 10 m long. The passage existing close to it has been mostly filled up by sands and muds. Between the opening of the cave next to those two passages and the Sogong cave, the ground of the surface canyon has been also completely changed. In 1983, the flow coming from the Northernmost eastern passage of Ige entered partly Sogong and partly Ige again, close to the chamber, at least at the end of the last flood. In 1984, according to the morphological changes, the water gushed out of all the openings of Ige to enter Sogong. Probably, the pressures generated by the flood were much higher than before, but the pressure distribution probably also depends on the ratio between the different tributaries of the collector.

A cooling effect of the allochtonous waters exists in the karst. This is probably due to the fact that the waters overheated in the rice-paddies upstream the caves quickly reequilibrate when underground. In March 1983, the temperature was 23 °C at the paddies, then 21.0 and 20.6 in the surface river, 20.2 at the upstream entrance of the Latang cave, entered by this river, 17.9 at the other opening of the cave and 17.7 at the Ambasing spring. This cooling effect may play some role for the dissolution of the rock.

Surface morphology

A main feature is the elevation of the northern and northwestern parts of the karst high above the talwegs. To the North, the deep valley of Amlusong has placed the limestone in a hanging position. To the West, a N-S gently sloping «valley» follows the karst. This «valley» is actually splitted into several sub-units by morphological secondary highs corresponding to the crests separating the different streams entering the karst. The main one is in Ambasing, upstream the spring; downstream of it, the general slope of the valley is higher, but there is the permanent creek issued from the spring. The numerous paddies covering the whole «valley» have obviously some impact on the karts function, as they significantly reduce the quantity of water entering the karst, and as they play as regulators of the inputs.

To the East, the Latang area is boardered by a large outcrop of dacitic andesites, which may be a part of a basement high around which the limestone deposited, or a flow in valley of the limestones.

Another main feature is that the limestones are unconformably overlain, first by a basal conglomerate, 1 m thick more or less, then by clays, marly clays and Sendestones. In most of the NW part of the karst, this impervious cover has been already eroded. It may be found as reworked detrital sediments, in the dolines, which may be more or less filled up and choked at the bottom, in the different fractures of the rock which have not yet been made empty by the erosion, and also as big boulders of sandstone in those collapsed areas of the caves which developed up to the ground surface.

The surface of the karst shows four main significant types of landscapes, which cannot be studied without the underground features are taken into account.

Doline-Dominated areas

They extend mostly in the northern part of the karst, where the underground flows are beginning and still entirely autochtonous. Some others can be found in the gently sloping areas, more or less well-preserved between the talwegs of the karst; a typical one is lyiny to the SW of Sagada proper, between the canyons in the karts and its slightly hanging edge.

The dolines have different shapes. Most of them are not regular, but most have an evident low point. Certain are conic; many elongate along fracture trends. Many have a gently sloping bottom, some are flat-bottomed, because of sediments. More or less, the most sedimentated ones are located in the areas higher in elevation, i.e. closer from the former impervious cap-rock. Those closer to the canyons or other talwegs are usually deeper and have a sharper low point. However, close to the central part of the karst, in the Mabahat area, there are talwegs with dolines rich in sediments.

Canyon-dominated areas

The canyons are located mostly to the East and to the Sout-East of Sagada proper, around numerous caves, which are in a more or less close connection with the main underground stream Latang-Ambasing. The upstreammost canyon is located upstream the Latang cave, where the allochtonous river enters the karts. Then, there is one downstream the cave, up to the place where the river disappears again into the ground, at the foot of a high of the bottom of the canyon; it is boardered by a limestone cliff to the West, by a slope to the North, by a dacitic andesite cliff to the East, and to the South by the high previously mentionned. At the other end of the high is the narrowest part of the canyon, called the «Canyon», followed by a western and by a eastern cliff. The Tunnel cave is its southern limit; Polikakao and Matogbog caves are also located in it.

After the Tunnel, the canyon quickly enlarges, before it narrows again, in front of the Dinit Ahn cave. There, another bottom high stops it again, but the V-shaped valley of the Dinit Ahan surface

Creek prolongates it, westwards. In this part, there is a vertical cliff to the West, and a lesser steep one in front of it. The «cave between boulders» is located in this part; parallel to the Tunnel, is the doline-canyon parallel to it and connected whit the main canyon.

Downstream of Dinit Ahan cave, a the V-Shaped valley transforns into a parallel canyon which quickly enters Ige cave. Another canyon, but relatively large, in the axis of the one between the Tunnel and Dinit-Ahan, terminates downstream by a third main bottom high, after it narrows southwards up to the Sogong entrance, in front of the chamber in Ige cave.

The large doline of Lomyang, which is the result of a huge collapse (3) through a narrow valley can be considered as the end of the canyons in the studied part of the karst. The permanent flow on its bottom may be the one encountered in the Dokiw cave.

With a permanent flow restricted to the upstream Latang area, the bottom of the other canyons or parts of canyons are therefore older, with streams only during the main flooding periods, when the underground waters under pressure rise up to the necessary elevation (8 m in Polikakao, 5 m in Ige). These exceptionnal flows outside may correspond in elevation more or less to a former level of caves, now collapsed. This could be proven, on one hand by the existence of caves in the axis of the Canyon, with the same width: the Tunnel –still crossed through by waters during the floods-and Matogbog and on the other hand by the alignement with a third cave: Polikakao, where the Canyon is at its narrowest. Those former passages may have extended up to the Dinit Ahan cave, besides which the canyon narrows again.

The canyon parallel to Ige cave to the West has possibly formed from the surface only, but further observations are still to be done in this area. At Dinit Ahan cave, the V-shaped valley, rather unparallel to the cave it crosses through, has also slopes reaching much higher than the cave and no special feature of a former cave; therefore, the canyon just previously mentionned may have a similar origin. However, its deepening may have been enforced by the water possibly gushing out the trepaned Dinit Ahan-Ige passage now collapsed.

The part of the canyon between the two opposite openings of Ige and Sogong is probably due to a collapse; it has been shown previously that the two caves have very similar features, and this can be also supported by the transfer of water from Ige into Sogong during the floods.

Areas with numerous shafts

Two areas only seem to be significantly the place of a higher density of holes, shafts and other gulfs: one corresponds to the very decompressed relief between the canyons boardering Ige cave. The existence there of decompression-opened fractures has been shown already (2). The area around the aven of Sogong and Dokiw caves is the other one.

Areas with numerous pinnacles

Numerous pinnacles are encountered along the lands boardering the top of the canyons, between the canyons and the main dolines, near the edge of the karst, i.e. in all the areas where the conditions for an efficient washing of the different possible fillings of the fractures were encountered. The limestone blocks between the fractures were therefore ready to be corroded at the surface of the karst. There are subrectangular towers, bearing rillenkarren, and specially pinnacles, most of the time 7 to 8 m high, but even up to 15 m in the Latang area. The most spectacular pinnacle areas are in this Latang area, to the E-SE of Sagada proper and above the aven of Sogong.

Conclusions

The studied area is a typical exemple of tropical karst lying around 1500 m in elevation. The main surface features, well-defined, are towers and pinnacles, dolines, canyons and shafts. Below the ground surface, there is a fast and strong evolution of the passages, made easier by large allochtonous inflows of water. This underground evolution greatly interfers with this one of the surface, both being the cause of the canyons, several dolines and more indirectly towers and pinnacles.

This part of the karst of Sagada shows also a good exemple of a possible capture of an underground watershed, the waters being detoured in Ige cave from the main Balangagan spring drainage area, for the benefit of the Ambasing one. We plan to investigate more in detail the whole of this small tropical Karst, for a better understanding of it.

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Addendum

Between the 22 December 1985 and the 10 January 1986, new explorations took place. For the area concerning the present paper, they were performed by the author and Jessie DEGAY, with a nice and fruitful cooperation with Antonio DE VIVO for Nangunogan cave. Latang cave, connected with Mabinoso cave (a fossil level of Latang) and with Matangkib cave (also a fossil level), Latang 2, Latang 3, Bawen (with quick sands), the new «Hospital cave» (upstream part of Latang 2, not yet connected), Nangunogan, Aati and the new «Lomiyang Hanging cave» and «Lomiyang Pines cave» have been mapped. Other caves have been explored: Kahunugan (swallow hole of allochtonous waters), Tolong and Kanawkaw (autochtonous waters). The explanations in this paper are not significantly changed by these new results. A note will follow in Spelunca Bulletin and a paper as well.

Les pertes de la Bordure Nord du Gunung Sewu (Java)

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RESUM

Carst clàssic de turons cònics (Kedelkarst), el Gunung Sewu es presenta al S. de Wonosari com una barrera de calcàries miocèniques, orientada d'est a oest, paral·lelament a la costa, amb una desena de quilòmetres d'amplada i que culmina en aquest lloc, prop de 250 m. sobre el nivell del mar. El Gunnung Sewu voreja, al nord, amb un pla de topografia uniforme i amb uns quants centenars de metres d'altitud, modelat sobre les margues del Miocè superior. Una xarxa hidrogràfica dendrítica serpenteja de nord a sud. Quan s'endinsen per les calcàries, els rius s'escolen per amples coves i profunds avencs. La seva morfologia ve especialment determinada per la naturalesa litològica de la roca encaixant. La seva secció en forma de canó, és testimoni d'un enfonsament continuat i regular del riu, conseqüència d'un moviment tectònic d'elevació lenta i sense ressalts importants. Pel contrari, els massisos estalagmítics corroïts, submergits dins l'aigua dels sifons, l'enfonsament permanent de les grans galeries i un dèbil gradient de la superfície piezomètrica fins l'oceà, ens indiquen una recent subsidència.

RESUMEN

Karst clásico de colinas cónicas (Kedelkarst), el Gunung Sewu se presenta al S. de Wonosari como una barrera de calizas miocénicas, orientado este-oeste paralelamente a la costa, con una decena de km. de ancho y culminando en este lugar cerca de 250 m. sobre el nivel del mar. El Gunung Sewu está bordeado al norte por un llano de topografía uniforme con algunos cientos de metros de altitud, modelado sobre las margas del Mioceno superior. Una red hidrográfica dendrítica serpentea del norte hacia el sur. Los ríos se pierden cuando penetran en las calizas por vastas cuevas y simas. Su morfología está especialmente determinada por la naturaleza litológica de la roca encajante. Su sección en cañón, testimonio de un hundimiento continuo y regular del río, consecuencia de un movimiento tectónico de levantamiento lento y sin resaltes importantes. Por el contrario, los macizos estalagmíticos corroídos, sumergidos en el agua de los sifones, el hundimiento permanente de grandes galerías y, un muy débil gradiente de la superficie piezométrica hasta el océano indican una reciente subsidencia.

RESUME

Karst à collines coniques classique (kegelkarst), le Gunung Sewu se présente au sud de Wonosari comme une barrière de calcaires miocènes orientée est-ouest parallèlement à la côte, large d'une dizaine de km et culminant à cet endroit vers 250 m. Le Gunung Sewu est bordé au nord par un plateau à la topographie uniforme de quelques cents mètres d'altitude, élaboré sur les marnes du Miocène supérieur. Un réseau hydrographique dentritique y serpente du nord vers le sud. Les rivières se perdent dès qu'elles s'incisent dans les calcaires par de vastes gouffres-grottes. Leur morphologie est essentiellement commandée par la nature lithologique de la roche encaissante et les très fortes actions fluviatiles. Leur section en canyon témoigne d'un enfoncement continu et régulier de la rivière, conséquence d'un mouvement tectonique de surrection lent et sans à-coup important. Par contre, des massifs stalagmitiques corrodés, ennoyés dans l'eau des siphons, l'ennoyement permanent de grandes galeries, un très faible gradient de la surface piézométrique jusqu'à l'océan indiquent une subsidence récente.

A. Introduction

Gunung Sewu signifie en javanais les «Milles Montagnes». Des calcaires coralliens du Miocène ont subi une importante karstification au centre-sud de Java (Waltham et al., 1983; Quinif, Dupuis, 1984; Willis et al., 1984; Sautereau de Chaffe, 1985). Des milliers de collines en forme de cônes de 40 à 80 m de haut, séparées les unes des autres par des dépressions à fond plat (dolines et ouvalas) ou des vallons secs se succèdent sur plus de 1.200 km^2 (Danes, 1910, 1915; Escher, 1931; Lehmann, 1936; Pannekoek, 1941; Flathe, Pfeffer, 1961; Quinif, Dupuis, 1985). Si le relief de surface est ainsi un «kegelkarst», les formes souterraines sont abondantes et diversifiées: gouffres-grottes au N, avens-méandres et avens d'effondrement au coeur du kegelkarst, grottes-résurgences et grottes de versants. L'expédition franco-belge de juillet 1982 a oeuvré dans la transversale de Wonosari, explorant notamment plusieurs des gouffres-grottes de la bordure N, pertes actives, temporaires ou permanentes (Bestgen, Quinif., 1982). C'est de ces cavités qu'il est question dans cet article.

B. Contexte Geologique

Les faciès concernés par les cavités étudiées appartiennent à la «Wonosari Formation», ensemble de calcaires récifaux du Miocène reposant un substratum volcanique (Sartone, 1964). La formation se termine par une cinquantaine de mètres de calcaires finement stratifiés à bancs métriques et même décimétriques. La sédimentation marine s'achève à la fin du Miocène avec la «Kepek Formation» constituée surtout de marmes. Au début du Pliocène, la région subit un soulèvement d'ensemble accompagné, dans la transversale de Wonosari, par des failles normales orientées N90° E, décrochées suivant des accidents N140° E et N150° E. Ces failles ont provoqué l'enffondrement du compartiment N où la «Kepek Formation» a pu ainsi être conservée en couverture des calcaires de la «Wonosari Formation» tandis que le compartiment S, soulevé, exposait ces derniers à l'érosion qui les a sculptés en kegelkarst.

C. Le contexte Morpho-Hydrogéologique.

Le kegelkarst constitue une barrière de plus de 20-0 m d'altitude dans la transversale étudiée, séparant le bassin de Wonosari au N de l'océan Indien au S (fig. 1). S'étendant à une altitude moyenne de 150 m, la cuvette de Wonosari est sillonnée d'un réseau hydrographique dentritique peu imprimé. Les rivières coulent du N vers le S sur les marnes de la «Kepek Formation» pour se perdre au contact des calcaires. Au sud de cette ligne de pertes, une topographie plane d'environ un kilomètre de large précède la zone des failles où l'altitude s'élève au delà de 200 m avec le kegelkarst. Les résurgences se trouvent sur la côte, notamment celle de Baron qui draine toutes les rivières perdues dans le district étudié.

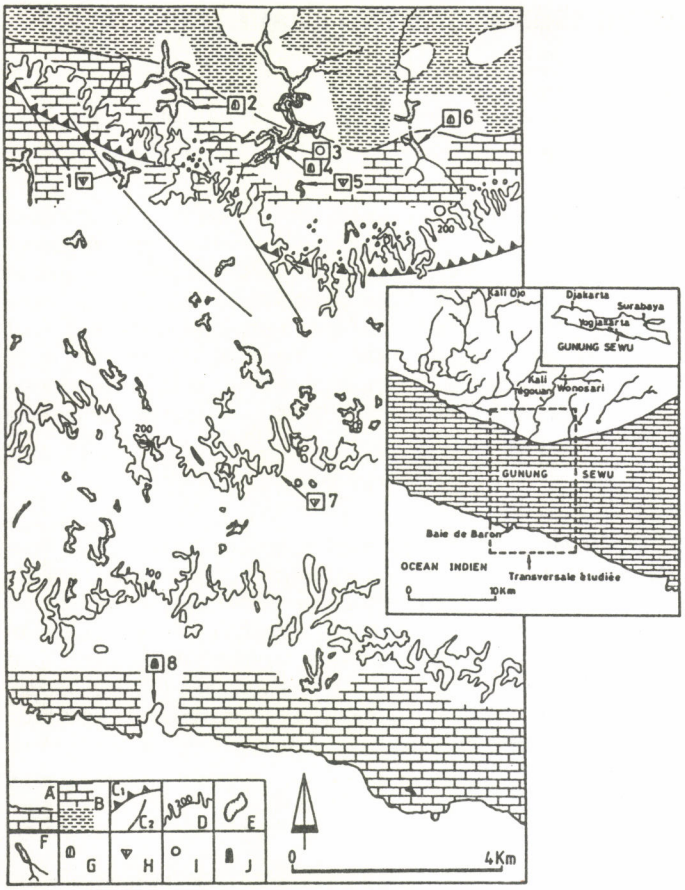

Figure 1. Localisation de la région étudiée. Schéma géologique et morphologique de la transversale de Wonosari. A: calcaires de la «Wonosari Formation»; B: calcaires et marnes de la «Kepek Formation»; C1: faille (le compartiment N est affaissé); C2: décrochement; D: courbe de niveau; E: Dépression fermée; F: rivière et canyon; G: perte temporaire pénétrable débutant par une galerie horizontale; H: perte temporaire pénétrable debutant par un méandre subvertical; I: perte pérenne impénétrable; J: résurgence;, 1: Luweng Bandung Sumuran; 2: Gua Si Karangmiri; 3: Luweng Semurup; 4: Luweng Banteng; 5: Gua Towati; 6: Gua Nging Rong; 7: Luweng Jowa (ou Setra); 8: Résurgence de Baron.

D. Structure et Morphologie des pertes

1. Contrôle lithologique

Au sortir des marnes de la «Kepek Formation», le premier contact des rivières avec la «Wonosari Formation» se fait par l'intermédiaire des calcaires supérieurs finement stratifiés. Les cours d'eau s'y incisent en canyons et se perdent par de vastes galeries faiblement inclinées (de 10 à 15 m de haut, de 5 à 10 m de large à Gua Nging Rong) conformes à la stratification. Les microformes de corrosion et d'abrasion y sont rares: tout au plus se dessinent vaguement quelques marmites de géant peu profondes. Par contre, ce faciès est très favorable aux éboulements: des blocs, du caillou pugilaire à l'éboulis décamétrique encombrent le sol. Une des pertes, Gua Si Karangmiri, se développe essentiellement dans ces calcaires: aucun puits ne l'accidente, elle est constituée d'une galerie unique, de grandes dimensions, descendant régulièrement avec une pente de 6°.

Les calcaires finement stratifiés reposent sur un complexe de calcaires plus massifs par l'intermédiaire d'un niveau conglomératique à éléments centi à décimétriques (fig. 6). Dès que le cours d'eau arrive à ce niveau, il prend rapidement de la profondeur par des crans verticaux de 10 à 30 m. D'une manière générale, les conduits creusés dans ces calcaires montrent des formes et des microformes spectaculaires, dues aux eaux courantes. Nous les examinerons ci-après. Luweng Benteng se développe dès l'entrée dans les calcaires massifs, les calcaires finement stratifiés étant traversés en canyon aérien.

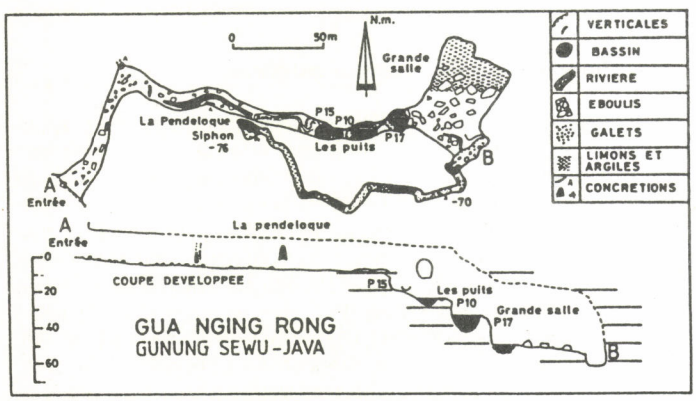

Figure 2. Plan de Gua Nging Rong.

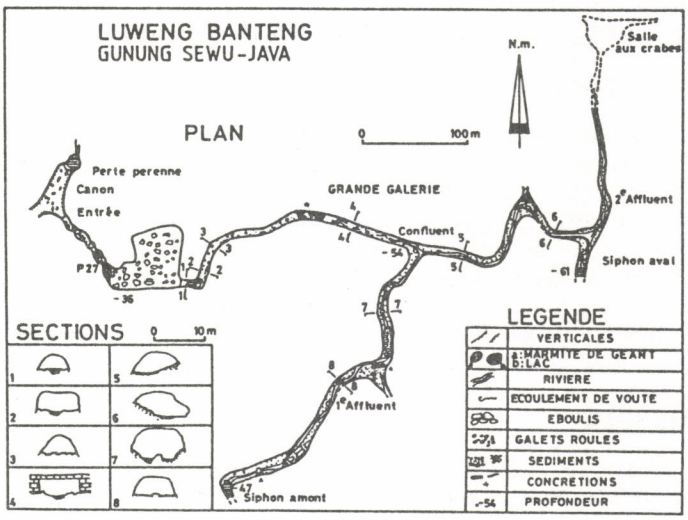

Figure 3. Plan de Luweng Banteng.

2. Dispositifs hydrogéologigues

Nous sommes ici face au dispositif classique d'un réseau de rivières coulant sur un substratum imperméable et buttant contre un ensemble calcaire dans lequel elles se perdent. Les résurgences se situent sur la côte au niveau de l'océan.

Dès que les rivières ont traversé les calcaires supérieurs de la Wonosari Formation, elles gagnent rapidement de la profondeur par des crans verticaux et atteignent la zone de transfert horizontal vadose, très vite suivie par le karst noyé. Les deux gouffres-grottes les plus importants se terminent sur siphon: Luweng Banteng à 15 m d'altitude, Gua Nging Rong à 19 m d'altitude. Gua Towati, perte temporaire située dans le zone de transition en aval de la principale ligne de pertes, permet de rejoindre par un avec-méandre la zone de transfert horizontal, son siphon terminal est à 35 m d'altitude. Le siphon de Gua Si Karangmiri se situe à 65 m d'altitude: la grotte ne perce pas le niveau conglomératique. Aux incertitudes près (la carte topographique donne une équidistance de 25 m, l'altimètre utilisé une erreur de 10 m), la surface piézométrique d'étiage se trouve à 20 m d'altitude.

La résurgence de ces pertes, Gua Sangupati, se trouve dans la baie de Baron à 11 km au S. Un aven, Luweng Jowa, situé à 5 km de la résurgence, permet d'atteindre la surface piézométrique qui se trouve là à quelques mètres d'altitude. Ces données nous indiquent une pente moyenne de 0.3 % entre les pertes et Luweng Jowa, quasiment nulle entre ce dernier et la résurgence. La transmissivité du karst noyé est très forte, les pertes de charge faibles.

3. Morphologie souterraine

Les caractères morphologiques dominants résultent de l'action torrentielle des rivières enfouies et des éboulements principalement liés au faciès finement stratifié des calcaires supérieurs.

a) Les influences torrentielles.

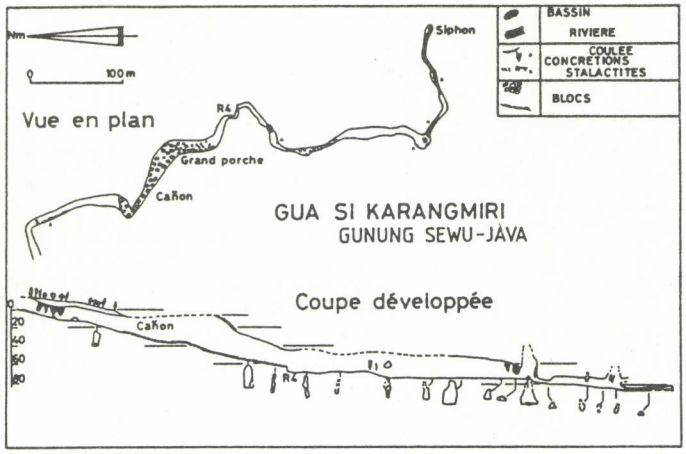

Figure 4. Plan de Gua Si Karangmiri.

Dès que le cours d'eau pénètre dans les calcaires massifs sous le premier banc conglomératique, les formes géantes d'érosion fluviatile sont dominées par les marmites de géant colossales, leur diamètre atteignant parfois 20 m pour une profondeur de 10 m. Le dispositif classique est bien illustré par la zone des puits de Gua Nging Rong où des parois verticales de 10 à 30 m arrondies («gros dos») se terminent par une marmite de géant. Les microformes centi et décimétriques du type coups de gouge sont inexistantes sur ces parois calcaires, complètement oblitérées par la force abrasive du torrent. Des surcreusements méandrants forment des dispositifs en «trou de serrure» au sommet des puits (sommet du P17 à Gua Nging Rong).

Si ces formes prédominent dans la zone de transfert vertical, on en trouve peu plus loin dans la cavité. Les galeries y sont hautes, en canyons, ou bien calibrées avec une section hémicylindrique ou quadrangulaire. Notons par place des microformes d'une toute autre nature, de type coupoles, témoignant d'une corrosion en zone noyée.

b) Les morphologies d'éboulements

Les formes de décolement et d'effondrement sont surtout typiques du faciès finement stratifié des calcaires supérieurs. Il en résulte des galeries vastes, hautes, de forme surtout quadrangulaire (la galerie d'entrée de Gua Nging Rong et Gua Si Karangmiri.)

Gua Nging Rong et Luweng Banteng renferment chacune une grande salle prolongeant la zone des puits. Elle doit son existence aux effondrements résultant de la présence sous-jacente de la base des calcaires supérieurs qui prolongent horizontalement le

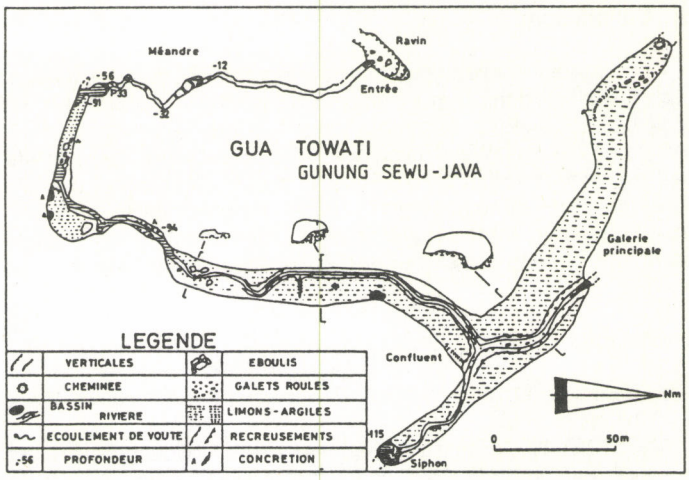

Figure 5. Plan de Gua Towati.

profil de la galerie d'entrée au dessus des vides dûs à l'enfouissement du torrent dans les puits. Enfin, des fractures verticales délimitent certaines parois de ces salles (fig. 6).

4. Les dépôts

Les éboulis se rencontrent dans les galeries creusées au sein des calcaires supérieurs. Les dépôts fluviatiles grossiers (galets roulés ou émoussés) se répartissent à la base des puits. Vers l'aval, ils cèdent progressivement la place aux dépôts plus fins. Ces derniers les recouvrent peut-être mais l'absence de coupe laisse le problème entier. Ces accumulations de sables, limons, argiles sont très importantes dans les collecteurs profonds. Les grandes galeries inférieures de Gua Towati, par exemple, renferment des collines de sédiments recreusées sur plus de 10 m.

Les concrétions stalagmitiques actives sont peu abondantes. Par contre, d'imposants massifs stalagmitiques gisent actuellement écroulés dans les galeries, à tous les niveaux de la cavité,

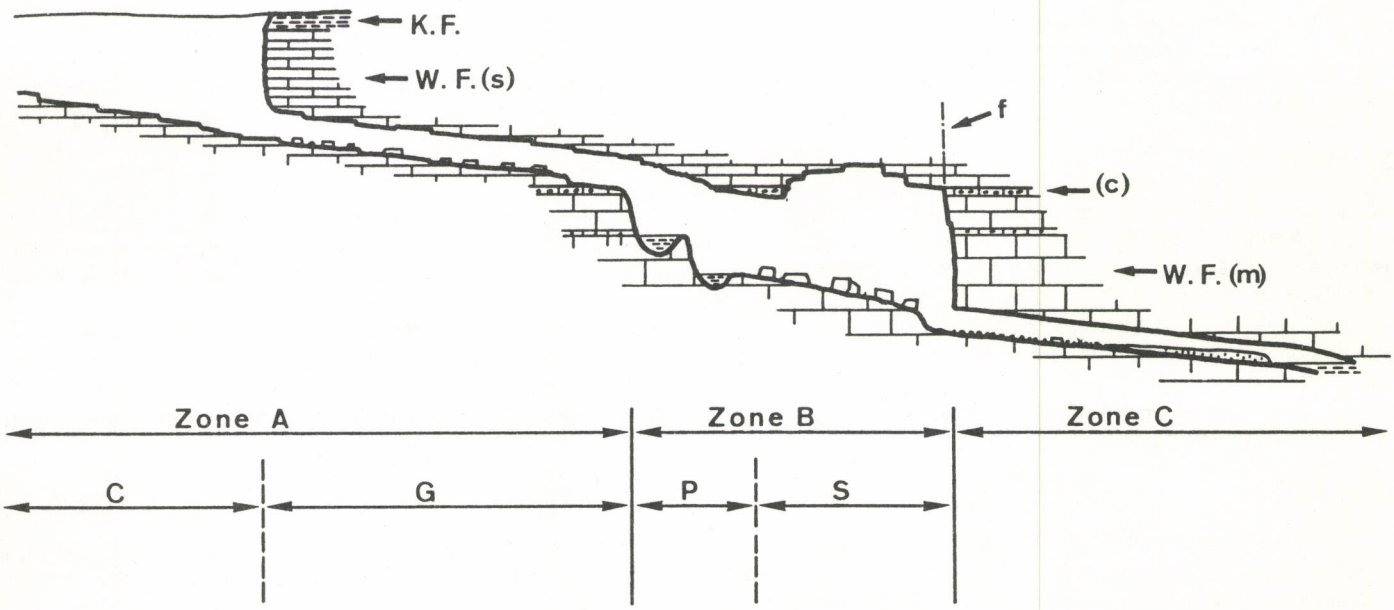

Figure 6. Coupe synthétique type d'un gouffre-grotte.
3 zones se distinguent longitudinalement. La zone A comprenant un canyon (C) et une galerie d'entrée à faible pente (G) traverse le sommet de la «Wonosari Formation» (W.F.(s)) formée de calcaires finement stratifiés. Ceux-ci sont recouverts par les marnes de «Kepek Formation» sur lesquelles coulent les rivières. La morphologie résultante est une galerie sans puits, encombrée d'éboulis et quasi exempte de formes d'érosion fluviatile. La zona B d'enfouissement vertical correspond à la percée du toit des calcaires massifs de la «Wonosari Formation» (W.F.(m)), formé d'un niveau de calcaires conglomératiques (c). Elle est composée d'une zone de puits (P) avec formes d'abrasion prédominantes (marmites de géants) et d'une grande salle (S) à plancher d'éboulis. La salle est limitée en aval par une fracture (f). Enfin, la zone C fait partie de la zone de transfert horizontal. Elle est constituée de galeries parfois en canyon, souvent bien calibrées avec remplissages fluviatiles: galets roulées d'abord puis collines de depôts fins.

corrodés par les eaux courantes. Certains sont en place près des siphons comme à Gua Nging Rong, recouverts par des limons de crue et sculptés de microformes de corrosion.

E. Conclusions

Les pertes étudiées montrent de façon exacerbée les influences fluviatiles dans la morphologie de la cavité, notamment les colossales marmites de géants, dues à la puissance des rivières en crues. Le contrôle lithologique dans la structure de la cavité est également remarquable. Enfin, la présence des gros massifs stalagmitiques périodiquement submergés près des siphons indique une profonde modification de l'environnement morphologique dont l'élucidation passe par la datation des concrétions.

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Caracterización del Karst de Sierra Salvada

Grupo Espeleológico Alavés

RESUM

La Sierra Salvada es troba situada al límit N.O. de la província d'Alaba, llindant amb les veïnes províncies de Burgos i Biscaia (Orduña). Forma part d'una alineació de serralades calcàries de caràcter tabular, que poden seguir-se de forma continuada des de les rodalies de la capital alabesa. El material carstificable està composat d'un paquet calcari del Coniacià Mitjà-Superior, d'uns 150 m. de potència i fortament fissurat.

L'àrea delimitada abarca una extensió aproximada de 20 km². i en ella s'hi han estudiat un total de 150 cavitats, amb un clar predomini de les formes subterrànies verticals. Sis de les cavitats superan el quilòmetre, essent la profunditat màxima aconseguida de 230 m. D'entre elles destaca l'enreixat de l'avenc SI-44, amb més de 27 km. de desenvolupament.

Les característiques de la morfologia subterrània, el traçat i la geometria de les galeries, es troben fortament condicionats per la fracturació de la zona.

RESUMEN

La Sierra Salvada se encuentra situada en el límite NO. de la provincia de Alava, lindando con las vecinas provincias de Burgos y Vizcaya (Orduña). Forma parte de una alineación de sierras calcáreas de carácter tabular, que pueden seguirse de forma continua desde las inmediaciones de la capital alavesa. El material karstificable está compuesto por un paquete calizo de edad Coniaciense Medio-Superior, de unos 150 m. de potencia y fuertemente fisurado.

El área delimitada abarca una extensión aproximada de 20 km²., y en ella han sido estudiadas un total de 150 cavidades, con claro predominio de las formas subterráneas verticales. Seis cavidaes superan el km. de desarrollo, siendo la profundidad máxima alcanzada de 230 m. Entre todas ellas destaca el enrejado de la sima SI-44, con más de 27 km. de desarrollo.

Las características de la morfología subterránea, el trazado y la geometría de las galerías, se encuentran fuertemente condicionados por la fracturación de la zona.

SUMMARY

The Salvada mountain range is located in the North-West limit ot the province of Alava, and borders on with the neighboring produces of Burgos and Vizcaya (Orduña). It belongs to a calcareous range alignements of tabular characteristics, which can be continuously followed from the near bys of vitoria, the capital of the province. The karst is composed by a calcareous zone from the Half-Superior Coniaciens age, which thierness is about 150 meters, and heavily fissured.

The delimitated area has an extension of about 20 km²., in which a total of 150 caves have alrealdy been studied, with clear predominance of subterranean vertical formations. Six caves develop more than one km., being 230 meters the maximun reached depth. Among all them it stands out the network of chasm SI-44, with more than 27 km. in lenth.

The subterranean morphological characteristics, the laid out and the geometry of the galleries, are strongly determined by the fracturing of the area.

Speleological provinces in Brazil

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RESUM

Aquest treball fa una ressenya de les principals àrees carbonatades del Brasil, parant especial esment en aquelles més favorables per al desenvolupament de cavitats. Es descriuen també vàries àrees d'arenisca d'importància espeleològica.

Fins avui s'han definit sis províncies espeleològiques en roques carbonatades i dues en arenisca basant-se en dades geològiques, geomorfològiques i climàtiques.

Les províncies espeleològiques són considerades com a regions amb una certa unitat litostratigràfica, on les roques carbonatades són susceptibles d'ésser sotmeses a procesos càrstics, inclosa la formació de cavitats. A cada província s'han delimitat districtes espelològics a les zones amb una major abundància local o general de cavitats, la qual cosa palesa la discontinuïtat del procesos càrstics al llarg de la formació espeleològica.

A cada districte, els sistemes de cavitats poden definir-se en base al coneixement dels enfonsaments, elevacions i corrents subterranis.

RESUMEN

Este trabajo describe las principales áreas carbonatadas del Brasil, poniendo especial énfasis en aquellas que son más favorables para el desarrollo de cavidades. También se describen varias áreas de arenisca con importancia espeleológica.

Hasta hoy se han definido seis provincias espeleológicas en rocas carbonatadas y dos en areniscas, basándose en datos geológicos, geomorfológicos y climáticos.

Las provincias espeleológicas *están consideradas como regiones con una cierta unidad litostratigráfica, en la que los cuerpos rocosos carbonatados son susceptibles a los procesos kársticos incluyendo la formación de cavidades. En cada provincia se delimitan* distritos espeleológicos *en zonas de mayor presencia local o general de cavidades que reflejan la discontinuidad de los procesos kársticos a lo largo de la formación geológica.*

En cada distrito, los sistemas de cavidades *pueden definirse en base al conocimiento de los hundimientos, levantamientos y corrientes subterráneas.*

SUMMARY

This paper describes the main Brazilian carbonate areas, with emphasis on those that are most favorable for the development of caves. Several sandstone areas which have speleological importance are also discussed.

To date, six speleological provinces have been defined in carbonate rocks and two in sandstones, based on geological, geomorphological and climatic data.

Speleological provinces *are here considered as regions within a certain lithostratigraphic unit in which carbonate rocks bodies are susceptible to karstic processes, including cave formation. Within each province, in sectors of greater local or regional occurences of caves,* speleological districts *are recognized, which reflect the discontinuity of karstic processes along the geological formation.*

Within each district, cave systems *can be defined on the basis of knowledge of sinks, rises and subterranean streams.*

Introduction

Brazil, of approximately 8.500.000 sq.km., possesses extensive carbonate rock formations. However, not all of them are karstified. The Brazilian Speleological Society has identified and surveyed approximately 500 caves, occuring in geographical areas we call speleological provinces. In addition, caves are also present in non-carbonate rock, mainly sandstones and quartzites with karstic features.

Knowledge of Brazilian speleological resources, is to date, despite vast, incomplete. Therefore, any attempt of classifying and sistematizing the distribution and typology of caves is necessarily provisional. New caves are discovered every year, increasing the volume of data and changing the brazilian speleological map.

The basic criteria for classification of areas propitious for cave formation are geologic. This principle criteria, based on the occurence of stratigraphic unities that are favorable to speleogenesis is supplemented by geomorphologic and climatic data.

Conceptual and Methodological Framework

From a survey of carbonate rock occurence in Brazil, those areas more propitious for cave formation were designed as speleological provinces (Karmann and Sánchez, 1979). Later, regions with other lithologies where we have verified cave occurence as a nonisolated phenomenon were also classified as speleological provinces. Therefore, *speleological province* is here defined as a region, belonging to a common lithostratigraphic unit where either carbonate rocks are susceptible to karstic processes, including speleogenesis, or non-carbonate rocks are susceptible to other kinds of speleogenesis, causing cave grouping. Two conditions are necessary to define a speleological province: geological continuity (the same lithostratigraphic unit, even if isn't geographically continuous) and cave grouping. Neither the absolute number of caves is important, nor the surface area of the lithostratigraphic unit, but the radio between the number of caves and the surface area. This criteria is conceptual, non numerical. Within a speleological province one can define *speleological districts* in those sectors with greater local or regional cave incidence. These formations demonstrate the discontinuity of the karst process along the geological province, here designated speleological province for karst studies. Analogously, in the case of non-carbonate rocks, the speleological district demonstrate the concentration of geologic, geomorphologic and climatic factors which, local or regionally, combine to cause speleogenesis.

The concept of speleological district, on a lower level of analysis, is sensitive to local or regional order factors, whereas the concept of speleological province is related to large geological

factors. In the definition and delimitation of different districts into a province, the following factors should be considered: –the continuity of the lithostratigrafic unit and its structural and faciologic variations; –the concentration of caves and karst features in some sectors of the province; –the topographic compartimentation; –cave and karst typology; –topo and microclimatic variations; –vegetal cover variation.

Enlarging the scale further, within each speleological district, we speak of *cave systems* on the basis of the integrated knowledge about water intake areas, their subterranean streams and the kinds of outlets in relation to the karst set. This concept, not restricted to karst cavities, works with local order factors such as the suterranean hydric streams and local geological structures (jointing, faulting, folding and bedding patterns, faciologic variations).

Our usage of this hierarchical classification, province-district-system, has so far proved useful in analysis of brazilian caves. However only further research will be able to definitively confirm its applicability. In this paper, we will be limited to a short description of the already defined provinces, whose distribution can be seen in the map.

Regions which are less favorable to cave development were classified as carbonate regions. While some carbonate regions contain caves as an isolated phenomenon, others, because of the lack of speleological research, may in future be classified as provinces.

Speleological province of the Ribeira Valley

Situated in the Southeastern region of the country, in the South of São Paulo State and Northeast of Paraná State (24-25° S/ 48-49° W), the province is drained by the tributaries of the Ribeira River. This is the best known of the speleological provinces despite the probable existence of many undiscovered caves.

To date, we have surveyed about 170 caves, all exceeding 50 m in length'and 15 m in depth. The caves are developed in metamorphic limestones and dolomites of the Açungui Group (Upper Proterozoic). They are very folded, faulted and metamorphisized on greenshist facies. These carbonatic bodies outcrop in sinforms predominantely producing elongated carbonatic bandes interlayed in metapelitic and metapsamitic rocks. The topography is abrupt and the greatest altitute of approximately 1.100 m is along quartzite crests. The region is covered by tropical rain forest. Climate is hot, humid tropical, with high pluviometric rates. Karst topography is nor very developed, but isolated superficial features like escarpments, towers and dolines are common; Casa de Pedra cave (SP-9) entrance is very remarkable (173 m high). Sinks and rises are frequent, with caves along the subterranean streams, like Santana cave (SP-41), whose development is 5.700 m. Abysses are common, the largest is Juvenal Abyss (SP-146), 250 m deep, the deepest in Brazil. This province has the greatest potential for pothole development.

Speleological province of the Bambuí

Situated in central Brazil (10-20° S/ 41-47° W) and covering parts of Minas Gerais, Bahia and Goiás States, this province is the most extensive carbonate rock unit favorable to cave occurence in Brazil. It covers more than 1.000 km from North to South and about 600 km from East to West, although interlayed by pelitic and psamitic rocks.

Bambuí Group, of Upper Proterozoic age, is a clay-carbonate low metamorphic sedimentary sequence. This group exhibits structures from, on the one hand practically undeformed and without metamorphism cratonic coverings to, on the other hand, basin internal zones with intensive folding and greenshist facies metamorphism.

Geologic, geomorphologic and climatic diversity is high. In Goiás and Western Minas Gerais the climate is tropical with 2 seasons: a dry winter and a wet summer. Typical vegetal cover is «cerrado», a kind of savana with variable arboreous stratum, with «barriguda» *(Chorisia sp),* a tree species indicative of limestone presence. In Northern Minas Gerais and Bahia, along the São Francisco river basin, the climate becomes drier, achieving the semiarid. The vegetation varies from «cerrado» to «caatinga» (vegetal formation with predominance of cactaceous and caducifolious shrubs).

Bambuí province presents vast continous areas of exposed limestones, which conditiones the formation of an exemplar karst topography, the most remarkable in Brazil. Throughout the province we find areas with extensive subterranean drainage, constantly associated with sinks and rises with large cave entrances. Among the highest, we refer to Terra Ronca cave (GO-1) 73 m high, in Goiás, Janelão cave, about 70 m high, in Minas Gerais and Brejões cave (Ba-1), 106 m high, in Bahia. Another frequent feature are the long and continuous limestone escarpments, with many lapiés, dolines and uvalas. Depending upon the maturity of the karst topography one finds extensive karst plains with isolated residual hills strongly dissected and with lapiés presence and caves. An example of this formation is Bom Jesus da Lapa cave, in Bahia, along São Francisco river.

The largest caves are found in São Domingos, Goiás: São Mateus-Imbira (GO-11), approximately 20 km long, and Angélica-Bezerra (GO-3), approximately 10 km long. In this region, a typical cave characteristic are overlayed two-level galeries. Speleological knowledge in Bambuí province is heterogeneous, with very studied regions, like Lagoa Santa, Minas Gerais, and virtually unexplored areas. This province is being subdivided in several speleological districts.

Speleological province of the Bodoquena range

Located in Midwest Brazil, Mato Grosso do Sul state (19-22° S/57-58° W), this speleological province has a main N-S extension of 200 km and is surrounded by the Pantanal basin. It is made up of low metamorphic limestones and dolomites of the Corumbá Group (Upper Proterozoic). They are strongly folded and jointed. The climate is hot and humid with two well defined seasons (dry and humid). The vegetation is typical «cerrado» and natural savannahs. The topography is composed of plains with some lines of crests and great erosion remnants. The same occurs in the carbonatic areas, where we do not observe a typical karst topography, but only isolated karst features, for example, sinkholes, sinks and rises of streams, only rarely associated with caves.

The caves of the Bodoquena show an advanced degree of evolution with large «Inkasion» rooms along diping planes (bedding and joint surfaces) which frequently enter beneath the water table. In such cases, the formation of lakes occur, like the great lake (100 m wide and over 50 m deep) of the «Blue Lake Cave» (Gruta do Lago Azul, MS-02). Vertical caves also are present, for example the Anhumas abyss with a 70 m vertical shaft and a lake 120 m wide, 11 m deep, at the bottom.

Speleological province of the upper Paraguai river

Located in the Central-West of Brazil, in northern Mato Grosso state (14-16° S/54-57° W), this province is made up of greenshist facies dolomites and limestones of the Araras Group (Upper Proterozoic), in the form of large synclines and anticlines, which is reflected in the topography. The climate is hot and semi-humid with «cerrado» vegetation. This province is unexplored to date despite the presence of several as yet unsurveyed caves.

Speleological province of the ibiapaba Plateau

This province is on the East side of the Ceará state (4° S/ 41° W), northeast of Brazil. At present, this is the smallest province of the Country. The Ibiapa province is formed over low grade metamorphic limestones of the Jaibaras Group (Jaibaras basin,

SPELEOLOGICAL PROVINCES IN BRAZIL

Carbonate Provinces

I - Ribeira Valley
II - Bambuí
III - Bodoquena Ridge
IV - Upper Paraguai Valley
V - Ibiapaba Plateau
VI - Lower Pardo River

Arenitic Provinces

VII - Serra Geral
VIII - Upper Urubu River

Upper Proterozoic). The climate is hot and semi-arid, with periodic torrential rains. However, near the escarpment of the Plateau there is a humid microclimate of forests.

This province has a group of large limestone erosional remnants which containes several caverns and exhibits great lapiés like vertical sharp crests. The largest cave is the Ubajara (CE-01), with 1.120 m in lenght. There is not a typical subterranean drainage within the karstic features.

Speleological province of the pardo river

Located in Southeast Bahia state (15° 20' - 15° 20' - 16° 00 S/ 39° 10' - 39° 45' - 39° 10' - 39° 45' W), this province comprises part of the lower Pardo river valley. It is found ever low metamorphic limestones and dolomitic limestones of Rio Pardo Group (Upper Proterozoic). A mature karst topography is found, mainly covered by thick residual soil. There are isolated karst features, like dolines. The region has hot humid climate and exhibits an exhuberant tropical rainforest. This province is virtually unexplored, but several caves are known. The largest is Lapão cave, 480 m long.

Speleological province of the Serra Geral

This arenitic province occupies a narrow strip through São Paulo, Paraná, Santa Catalina and Rio Grande do Sul states. Caves occur just along the base of the escarpment of the «São Bento» Group sandstones (Triassic to Jurassic) and are associated with springs. The best known sector of this province is in northeastern São Paulo, where Martins (1985) defined the main characteristics of the province. The largest known cave is 720 m in total length (Gruta Olho de Cabra, SP-178).

Speleological province of the upper Urubu river

This province is located in Amazonas state, about 200 km north of Manaus (2° 10' S / 60° 00' W). This province is developed over the Trombetas Group sandstones (Upper Ordovician) of the Amazon geologic basin. The morphology is caracterized by tabular forms with horizontal bedding planes and valleys which have subvertical slopes. This sandstones exhibits some karst features, like sinkholes, sinks and rises with caves. The caves are mainly small (between 30-40 m of length), the longest explores to date has 390 m in length (Gruta Refúgio do Maroaga, AM-02).

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The Karst of Colombia

RESUM

Les primeres investigacions efectuades a coves de Colòmbia van començar l'any 1850. Actualment són poques les coves que es coneixen, la majoria d'una extensió limitada i distribuïdes, principalment, al llarg de la serralada dels Andes Orientals i la vall del riu Magdalena. La major part de les coves conegudes es troben desenvolupades en la zona vadosa, superant a bastament les coves freàtiques, tant en importància com en llur freqüència.

La recent elevació dels Andes marca l'inici de la gènesi de les cavitats en la major part del país, fins el Plistocè o el Post-Plistocè. Les dades sobre la història geològica de Colòmbia indiquen que els futurs descobriments càrstics es duran a terme en les mateixes àmplies regions ja conegudes i en les calcàries cretàciques, que constitueixen els materials responsables del desenvolupament del carst de la regió del Caribe i zones del voltant.

RESUMEN

Las primeras investigaciones de cuevas en Colombia empezaron hacia los años 1850. Actualmente son conocidas pocas cuevas la mayoría de extensión límitada y distribuidas principalmente a lo largo de la cordillera de los Andes orientales y en el valle del río Magdalena. La mayoría de las cuevas conocidas están desarrolladas en la zona vadosa, excediendo en mucho las cuevas fréaticas tanto en importancia como en frecuencia.

El reciente levantamiento de los Andes marca el comienzo de la génesis de las cavidades en la mayor parte del país hasta el Pleistoceno o Post-Pleistoceno. Los datos sobre la historia geológica de Colombia indican que los futuros descubrimientos kársticos se efectuarán en las mismas ámplias regiones ya conocidas, y en las calizas cretácicas que son los materiales principales de desarrollo de karst de la región del Caribe y alrededores.

SUMMARY

The first investigations of Colombian caves began in the 1850's. At present, a few score caves are known, mostly of limited extent, and distributed primarily along the length of the eastern Andean cordillera and in the Magdalena River valley. Most of the known caves are of largely vadose development, far exceeding phreatic caves in importance and occurrence.

The recent age of the Andean uplift limits the beginning of cavern genesis in most of the country to the Pleistocene or post-Pleistocene. Considerations of Colombian geologic history indicate that future karst discoveries will still be primarily within the same broad regions as those already known and in the Cretaceous carbonates that are the great karst-formers of the Caribbean and circum-Caribeean region.

Exploration of Colombian caves was initiated by a priest, Romualdo Cuervo, in the 1850's. In 1851, Cuervo had himself lowered by basket 118 meters into the huge shaft of the Hoyo del Aire, at that time the deepest vertical cave descent in the world. Scientific study commenced a century later with the efforts of Dr. Cabrera Ortiz.

Geology

Relatively recent uplift, beginning as late as the Pliocene, resulted in the uplift of the Andean cordilleras. The eastern half of the country is composed either of extremely ancient shield rocks, or covered with clastic debris. Of the three Colombian cordilleras, the Central and Occidente have a veneer of Volcanic debris overlying primarily arenaceous and argillaceous sediments. The Rio Cauca valley between these two ranges is covered with their alluvium. Only in the Cordillera Oriental (a geosyncline in the Cretaceous), and in the neighboring Rio Magdalena valley was sufficient limestone deposited and preserved to allow karstification. A map of the cavern distribution of the country (Figure 1), shows this.

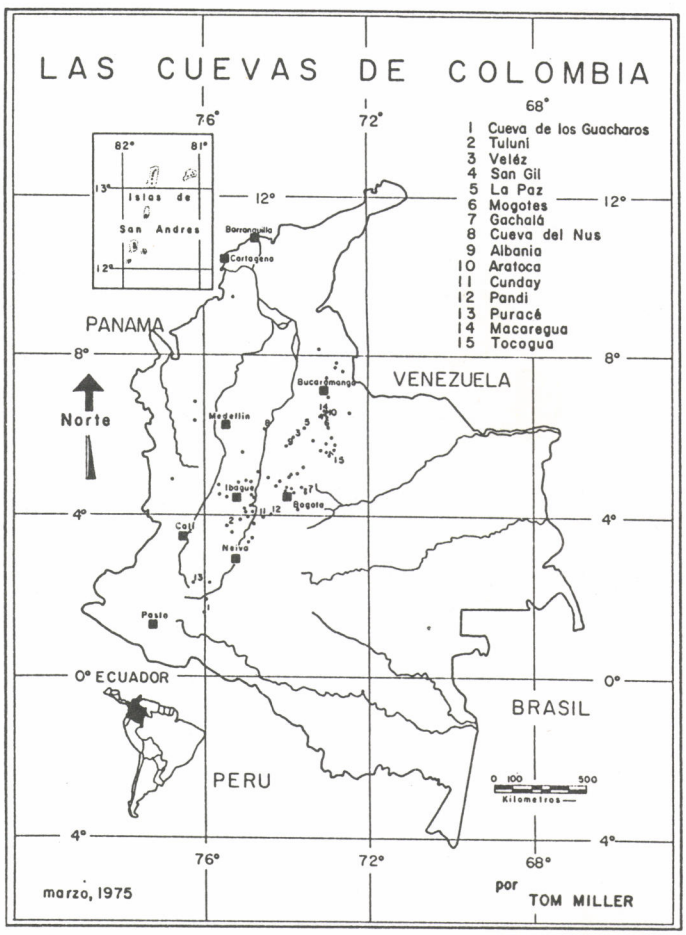
The Caverns

At present, caves group about 1.700-2.000 m elevation, with a range of 400-2.700 meters. Most are in gently dipping (> 15°) Cretaceous limestone, often impure, which as noted has had development only since the Pliocene. This has been counteracted to some extent by the ample rainfall and well-bedded and jointed lithology.

Caves are the most prevalent karst features in the country: dolines and karren are infrequent. A cockpit-like karst is present in one area, and deep shafts in excess of 100 meters are known.

Few caves are known at present in Colombia that exceed a kilometer in length. Notable exceptions are Cueva de Guacharos and Cueva del Indio in the south. Many contain evidence of extensive phreatic phases, and abandoned surface channels. As could be excepted from caves of such recent origin, the vadose sections are still occupied by their original streams. Bedding planes (strike and dip), jointing, and faulting to a lesser extent, have been the primary influences on flow direction.

Two unusual caves are not located in limestone. The Caverna del Nus has formed in Paleozoic or pre-Cretaceous, low grade marble. Geologic evidence indicates it had a phreatic origin in the Pliocene, making it the oldest known cave in the country. The Cueva de Cunday, once the deepest in the country (160 meters) has all of the characteristics of a limestone cave, including some of the largest calcite speleothems, yet is formed entirely in (calcacerous?) sandstone.



Summary

Although its geological development has placed limitations on the cavern development of Colombia, its great size (1.1 × $10^6 km^2$) *and the number and distribution of caves presently known, are already sufficient cause to pursue further investigations.*

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Caves in Southwestern Wisconsin, U.S.A.

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RESUM

A les dolomies ordovicianes de l'àrea Driftless al sud-oest de Wisconsin hi ha més de 200 cavitats. La major part tenen menys de 500 m. de galeries, degut, en part, a la lenta dissolució de les dolomies, però, principalment, a que els sistemes de cavitats han estat disseccionats pel ràpid encaixonament de la vall, abans o durant el Plistocè. La major part de les cavitats l'entrada de les quals es troba al cim o als vessants de la vall, són sistames freàtics preplistocènics abandonats, amb una erosió fluvial limitada i amb un extens procés clàstic.

Les cavitats posseeixen una sèrie uniforme de sediments, fonamentalment argiles rogenques i grises que, en part, s'han format a partir de l'alteració de les dolomies, però que, majoritàriament, provenen del loess superficial. L'absència de dipòsits d'origen directament glaciar ha estat confirmada per la datació de concrecions mitjançant urani i avala l'argument que diu que el sud-oest de Wisconsin no va sofrir glaciacions, si més no, durant les últimes fases del Plistocè.

RESUMEN

Existen más de 200 cavidades desarrolladas en dolomías de Ordovician en el «Area Driftless» en el Sud-Oeste de Wisconsin, la mayoría de las cavidades tienen menos de 500 m. de galerías, debido en parte a la lenta disolución de las dolomías, pero principalmente, a que los sistemas de cavidades han sido diseccionados por el rápido encajonamiento del valle antes o durante el Pleistoceno. La mayoría de las cavidades cuya entrada se encuentra en la cumbre o en las laderas del valle, son sistemas freáticos pre-pleistocenos abandonados con una erosión fluvial limitada con un extenso proceso clástico.

Las cavidades poseen una serie uniforme de sedimentos, esencialmente arcillas rojas y grises, que en parte han sido formadas por la alteración de las dolomías pero que derivan en gran parte de loes superficiales. La ausencia de depósitos de origen directamente glaciar ha sido demostrada por la dotación de concreciones a través del uranio y refuerza el argumento de que el Sud-Oeste de Wisconsin no sufrió glaciaciones, por lo menos durante las últimas fases del Pleistoceno.

SUMMARY

More than 200 caves are developed in the Ordovician dolomites of southwestern Wisconsin's «Driftless Area». Most caves contain less than 500m of passage, partly because of the sluggish dissolution of the dolomites but largely because the cave systems have been truncated by rapid valley incision before or during the Pleistocene. Most of the caves, the entrances to which are located on ridgetops or valley sides, are abandoned pre-Plesticene phreatic systems with limited vadose entrenchment but extensive breakdown.

The caves contain a characteristic and uniform suite of sediments, essentially red and grey clays, which are in part formed by weathering of the dolomites but which are largely derived from surface loess. The absence of any deposits of direct glacial origin, in combination with Uranium series dating of calcite deposits, strengthens the argument that southwestern Wisconsin was not glaciated at least during the latter phases of the Pleistocene.

Introduction

The «Driftless Area» of southwestern Wisconsin is an upland dissected by dendritic drainage (Figure 1). Interfluves are capped by Ordovician carbonates of the Prairie du Chien and Sinnipee Groups. Ridge tops are gently sloping buy valley side slopes are steep and cliffs are developed in many of the carbonates. The valleys are deep, broad and alluviated. Local relief is about 140m. Much valley widening and deepening occurred during the Pleistocene either as a result of glacial meltwater discharge or by fluvial erosion during periods of high rainfall discharge. The karst is a disjunct and covered fluviokarst containing caves, sinkholes and valleys with sinking streams and ephemeral flow.

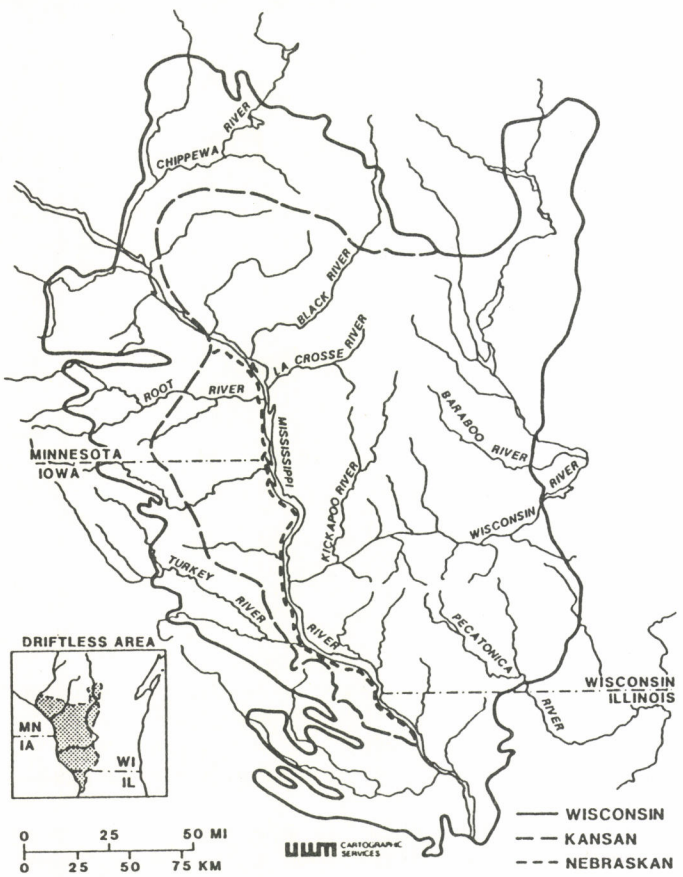

Figure 1. Southwestern Wisconsin, showing proposed glacial boundaries of the Driftless Area.

Regional Geology

The Paleozoic rocks of southwestern Wisconsin are approximately 400m of sandstones and dolomites which dip at less than 1.° to the south and southwest. The major cavernous formations are the Ordovician carbonates: the dolomitic Oneonta Formation of the Prairie du Chien Group and the Platteville and Galena dolomites of the Sinnipee Group.

The Oneonta Dolomite reaches a thickness of about 60m. Barden (1980, p.5) describes it as «...a thick or poorly bedded, medium crystalline, saccharoidal dolostone with minor amounts of chert and shale, cavernous zones of poorly preserved algal stromatolites and, in many areas, large secondary calcite crystals.» Day (1979, 1984) describes the Prairie du Chien as a medium-textured impure sandy dolomite. Quartz content often exceeds 10 % (Day, 1979) and clay contents average 2.1 % (Frolking, 1982). Mean insoluble residue is 12.17 % by weight (Day, 1979) with a range between 1.37 % and 26.26 % (Black, 1970). Porosity is about 10 % and recrystallisation is evident, often with silica replacing carbonate.

The Platteville carbonates reach 25m in thickness and consist of fine to medium crystalline, buff to blue-grey, fossiliferous, variably bedded dolomites and limestones (Barden, 1980). The Galena Formation is composed of thin to thick bedded, buff, shaley dolomites locally with chert and shale bands. Total thickness of the Galena is nearly 80m (Barden, 1980). The Platteville and Galena dolomites are the dominant cave and karst forming rocks south of the Wisconsin River (Figure 1). North of the Wisconsin River most caves are in the Oneonta Formation of the Prairie du Chien Group.

The Caves

Although there are more than 200 caves in southwestern Wisconsin, all are small. None exceeds 1000m in total length and most contain under 500m of passage (see Alexander, 1980). In part this results from the sluggish dissolution of the dolomites (Day, 1984) which are also thin-bedded and of variable compressive strengths (Day, 1979, 1984).

Most of the caves are located on hilltops or hillsides and represent remmants of formerly more extensive systems which were dismembered by rapid valley incision. The caves, which now occupy the ridges, are essentially abandoned phreatic tubes and mazes with little vadose entrenchment or with vadose trenches infilled with sediment. Present hilltop catchment areas do not promote contemporary entrenchment and many of the caves are partially blocked by breakdown. Most of the caves are shallow, rarely exceeding 25m deep.

The speleogenesis of southwest Wisconsin caves has received little attention but one can construct a general model based on other geomorphological studies. The age of the caves has been disputed although Martin (1965) felt that they were preglacial and, by analogy with caves in other areas adjacent to Pleistocene glaciers, they are clearly pre-Pleistocene. Milske et al (1983), on the basis of studies in Mystery Cave, Minnesota, proposed that initial cave system development, which pre-dates surface valley entrenchment, was in the shallow phreatic zone close to the level of saturation. Draining and erosion of sediment fills, resulting from surface valley entrenchment, commenced at about 160,000B.P.

A similar sequence was proposed by Olmstead and Borman (1968) for Pop's Cave in Wisconsin. They suggested that the cave originated through bi-level, joint-controlled phreatic dissolution contemporaneous with the commencement of valley incision. As valley downcutting progressed a major phase of formation in the upper part of the phreatic zone occurred as increasingly aggressive water came through the cave. Near the end of this stage clay infilling occurred. Further valley incision then stranded the bi-level caves in the vadose zone and loss of buoyancy caused ceiling breakdown, through which the lower passage eventually intercepted the upper to produce the present configuration.

Although there are problems with this scheme, notably in the method and timing of sediment input, and it is clearly not applicable to all the caves of southwestern Wisconsin, it serves as a useful general model. Several of the larger caves have the bi-level phreatic development and most have phreatic spongework. In addition many passage orientations are joint-controlled and breakdown is very common.

Present day cave passages are small, usually requiring stooping or crawling, but this is in part a function of the breakdown which all but fills many passages. Active breakdown occurs in many caves and large chambers, notably those in Boscobel Bear Cave, Pop's Cave and Star Valley Cave are partially filled with breakdown slabs.

The relationship of the caves to regional drainage patterns at their time of formation is unclear, especially since the caves are fragmentary. Pre-incision they were presumably draining toward the proto-Mississippi or its tributary, the proto-Wisconsin. The caves are poorly integrated into contemporary hydrological patterns. Most passages receive little percolation and are dry except after heavy rain or during spring snow melt. However a meandering vadose trench leads into Star Valley Cave and there are vadose sections in other caves such as Cave of the Mounds and Pokerville Cave.

The normal array of calcite formations has developed in the caves and several of them, including Cave of the Mounds and Eagle Cave, are operated commercially. In most of the non-commercial caves many of the formations have been damaged by breakdown or vandalism and the remaining intact examples are small and accessible only with difficulty.

Many of the caves have their entrances in the sides or bases of collapse dolines or sinkholes and several are developed adjacent to the unconformable contact with the overlying rock. Star Valley Cave, for example, has good exposures of the overlying St. Peter Sandstone, especially in breakout domes. Elsewhere overlying sandstones have collapsed into cavities in the Prairie du Chien producing sinkholes and caves such as Bridgeport Cave and Cobb Cave. Nineteenth Century lead miners investigated several of the caves and Bogus Bluff Cave was excavated in part, although the date of this is unknown. More recent quarrying has revealed other caves.

A red, or locally grey clay is characteristic of the caves of southwestern Wisconsin. Most authors have assumed that the clay is the weathering residue of the carbonates and has developed *in situ* but Ehr (1976) suggested that a conical clay mound in Bear Creek Cave was due to infiltration through a ceiling joint. Olmstead and Borman (1968) suggested that the primary time of clay infilling of Pop's Cave was during the last stages of phreatic development and that the increase in the volume of clay toward the adjacent valley indicated «...a downward movement of phreatic water and an increase in solution...» (1968, p. 123).

The cave clay is similar to red clays which mantle dolomite ridges. These clays are «...almost invariably red to dark red-brown with minor yellow mottlings; grays have been produced by very local reducing conditions. Small amounts of silt and sand also are characteristic. The clay is fissile in the lower part of thick deposits and blocky in the upper part...» (Black, 1970, p.I-6). Although the mineralogy of the clays is similar to that of Woodfordian loess, they were produced neither solely by weathering of dolomite nor of loess. Their texture suggests clay illuviation in the zone of dolomite dissolution (Frolking, 1982).

Cave sediments in southwestern Wisconsin have been examined in some detail by Bull and Day (in press). Sedimentary sequences are uniform both within and between caves. Many of the sediments are of silt size and have been derived from windblown loess, deposited initially in ice-marginal loess sheets and in many ways similar to present surface loess deposits. The sediments, which in many ways resemble the surface red clays, have entered the caves by downward movement through cracks and fissures which links the cave passages to the surface. The infiltration has been partly gravitational and partly the result of downward wash. The remainder of the cave sediments are the result of dolomite weathering; these are readily distinguishable from the allochtonous silts because of their diagenetic alteration (Bull, pers. comm.). There is no evidence of any materials of direct glacial origin and this, together with Uranium series dates of interbedded calcite deposits (Bull and Day, in press), supports arguments that southwestern Wisconsin was not glaciated during the Pleistocene (see Mickelson et al, 1982).

Acknowledgments

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Le systeme karstique de Han-sur-Lesse (Belgique)

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RESUM

Un recent estudi topogràfic de les coves de Han ens permet de sintetitzar les principals dades recollides fins el moment actual d'aquesta important xarxa. Això ha estat possible gràcies a un tall subterrani del meandre del Lesse, des del seu pas a través de les calcàries givetianes. La geometria de la xarxa i la morfologia dels conductes estan, en gran part, determinades per la litologia –les calcàries de Charlemont (Gvb) de 350 m. d'espessor estan separades de les de Fromelennes (Gvb) de 140 m. d'espessor, per un horitzont esquistós d'uns 20 m.– i per la tectònica –estructura en cúpula anticlinal del massís carstificat i presència d'una falla cavalcant. Dos nivells principals superposats d'excavació estan caracteritzats per les seves seqüències sedimentàries: la més antiga data del Saalià i la més recent del Weichselià.

RESUMEN

Un reciente estudio topográfico de las cuevas de Han nos permite sintetizar los principales datos adquiridos hasta el momento sobre esta importante red. Ello es debido a un corte subterráneo del meandro del Lesse desde su paso a través de las calizas givetienses. La geometría de la red y la morfología de los conductos, son en gran parte determinados por la litología –las calizas de Charlemont (Gvb) de 350 m. de espesor están separadas de las calizas de Fromelennes (Gvb) de 140 m. de espesor, por un horizonte esquistoso de unos veinte metros –y por la tectónica– estructura en cúpula anticlinal del macizo karstificado y presencia de una falla cabalgante. Dos niveles principales superpuestos de encavación son caracterizados por sus secuencias sedimentarias: la más antigua data del Saaliense, la más reciente del Weichseliense.

RESUME

Une récente étude topographique des Grottes de Han nous a permis de synthétiser les principales données acquises jusqu'à présent sur cet important réseau. Il est dû à un recoupement souterrain de méandre de la Lesse lors de son passage au travers de la barre del calcaires givétiens. La géométrie du réseau et la morphologie des conduits sont en grande partie déterminées d'une part par la lithologie: les calcaires de Charlemont (Gva) épais de 350 m sont séparés des calcaires de Fromelennes (Gvb) épais de 140 m par un horizon schisteux d'une vingtaine de mètres, d'autre part par la tectonique: le massif karstifié présente une structure en dôme anticlinal et est affecté par une faille chevauchante. Deux principaux niveaux de creusement sont caractérisés par leur séquence sédimentaire: la plus ancienne, mise en place au niveau supérieur, date du Saalien, la plus récente, mise en place au niveau inférieur, date du Weichselien.

I. Introduction: contexte morpho-structural

Descendant de la Haute Ardenne essentiellement constituée de roches quartzo-pélitiques du Dévonien inférieur, la Lesse aborde les premières roches calcaires du Dévonien moyen dans la région de Belvaux – Han-sur-Lesse (Delvaux de Fenffe, 1985). S'étant établie d'abord durant le Tertiaire sur un relief aplani et recouvert de sables et argiles, la Lesse, comme les autres rivières de l'Ardenne, s'est surimposée dans le socle plissé, recoupant systématiquement les différents étages du Dévonien plissés par la tectonique hercynienne et aplanis durant le Mésozoïque (Quinif, 1977).

Le massif calcaire de Boine, dans lequel sont creusées les grottes appartenant au réseau de Han-sur-Lesse, se présente comme un anticlinal dont l'axe est orienté E-W avec un plongement vers l'W (fig. 1). Cette structure relativement simple est accidentée de nombreuses fractures dont plusieurs failles. L'une d'entre elles est en fait un pli-faille (N170°E) faisant chevaucher le compartiment E sur le compartiment W (Sorotchinsky, 1939).

Quant à la stratigraphie, les calcaires concernés appartiennent au Givétien. Succédant aux schistes et grès du Couvinien, le Givétien est constitué des calcaires de Charlemont puissants de 350 m. Une série de couches de passage formées de schistes et calcschistes sépare les calcaires du Givétien inférieur de ceux du Givétien supérieur (assise de Fromelennes) (Coen et Coen-Aubert, 1971). Ces derniers, épais de 140 m, précèdent les schistes frasniens et marquent ainsi la fin des assises karstifiables de la colline de Boine.

Le relief local se caractérise par une mise en dépression des roches schisteuses s'opposant à une mise en relief des calcaires. C'est ainsi que l'anticlinal de Han-sur-Lesse occupe une position dominante, fortement soulignée par la profonde vallée de la Lesse qui s'élargit considérablement lors de la traversée des schistes.

II. Le dispositif hydrogéologique

Actuellement, après s'être encaissée dans les calcaires à la sortie du village de Belvaux, la Lesse se perd dans le Gouffre de Belvaux, vaste porche au flanc de la colline de Boine. La rivière réapparaît au Trou de Han aprés avoir parcouru 1.800 m de galeries et siphons presque complètement explorés (fig. 2) (Van den Broeck, Martel et Rahir, 1910; Kaisin et de Pierpont, 1939).

En aval du Gouffre de Belvaux, la vallée sèche en étiage contourne le massif de Boine; elle porte le nom «Chavée». Le Trou d'Enfaule, niché au creux du versant gauche de la Chavée 450 m en aval du Gouffre de Belvaux, absorbe la Lesse lorsque, lors des crues, la perte permanente ne peut plus engloutir la totalité du débit. Elle parcourt à ce moment un second ensemble de galeries avant de confluer souterrainement avec le courant principal. Cent mètres en aval du Trou d'Enfaule mais 7 m plus haut, le Trou du Salpêtre, entrée actuelle du circuit touristique, constitue une perte de plus haut niveau à présent abandonnée. Cette entrée donne accès au réseau supérieur qui, lui aussi, conflue avec le réseau inférieur temporaire venant du Trou d'Enfaule et les galeries à circulation permanente venant du gouffre de Belvaux. Mentionnons une petite galerie obstruée après quelques dizaines de mètres occupant une position analogue au Trou du Salpêtre: les Pertes Follettes, ancienne perte de la Lesse et, enfin, une perte temporaire nichée dans le creux de la Chavée

Figure 1. Carte géologique du site(d'après Delvaux de Fenffe, 1985).
1) Couvinien: schistes.
2) Couvinien: calcaires et calcschistes à calcéoles.
3) Givetien: calcaires de Charlemont.
4) Givetien: calcaires de Fromelennes.
5) Frasnien: schistes et calcaires.
6) Frasnien: schistes noirs et schistes à nodules.
7) Dépôts alluviaux quaternaires.
8) Faille.
9) Chevauchement.
10) Axe anticlinal.
11) Axe synclinal.
12) Pendage faible et fort.

à la limite des schistes frasniens qui absorbe la rivière lors des grandes crues.

Enfin, deux autres cavités importantes: le Trou des Crevés et la Grotte du Père Noël se développent dans l'assise de Fromelennes. Leur rôle hydrogéologique reste obscur.

III. Morphologie et dépôts

1. Relations avec la structure

Le massif de Boine est très fracturé; les strates calcaires sont d'épaisseur métrique et sont bien individulisées par des joints apparents. La fracturation tectonique est également serrée: les diaclases sont nombreuses et il y a plusieurs failles avec rejet. La faille de Sorotchinsky est même chevauchante.

La karstification a exploité largement cet ensemble de fractures. Plusieurs diaclases subverticales appartenant à différentes familles on été transformées en galeries importantes, par exemple la Galerie des Verviétois suivant la direction N140°E. Plusieurs autres galeries montrent une forme dépendant de la stratification, comme la Galerie des Petites Fontaines ou la sortie de la Lesse en aval de la Salle du Dôme.

L'existence de plusieurs grandes salles pose le problème de leur genèse, qui fait souvent intervenir les facteurs structuraux et hydrogéologiques. La Salle du Dôme en est le plus bel exemple. Elle se localise à l'E du pli-faille de Sorotchinsky ainsi que le montre la coupe de la figure 3. La stratification métrique favorise les multiples éboulements successifs. De plus, la partie N-E se développe dans les couches de passage schisto-calcaires éminemment favorables aux éboulements. Enfin, la Lesse souterraine baigne la base de l'énorme cône d'eboulis qu'elle dissout continuellement. La Salle d'Armes se trouve à un croisement de nombreuses galeries et connaît aussi ce processus d'éboulements-dissolution. La Salle Vigneron résulte de la jonction par éboulements des deux étages de galeries. La Salle de la Pentecôte se trouve sur l'axe anticlinal, perce les couches de passage et voit également l'éboulis dissout dans sa partie inférieure.

2. Les étapes de creusements

D'un point de vue strictement topographique et morphologique, nous pouvons distinguer trois écoulements successifs. Le premier est le plus ancien et le plus élevé; il empruntait le Trou du Salpêtre et la Galerie dans Verviétois. Le second partait du Trou d'Enfaule et passait par la Galerie des Mamelons. Le troisième est actuel: c'est celui de la «Lesse souterraine». Remarquons que ces trois voies d'eau ont toujours eu la même résurgence: le Trou de Han.

3. Les séquences sédimentaires

L'étage supérieur est caractérisé, depuis le Trou du Salpêtre jusque pratiquement le débouché W de la Galerie des Mamelons par une séquence sédimentaire, bien développée surtout dans la Galerie des Verviétois (fig. 3), comprenant un ensemble détritique essentiellement sableux surmonté d'un massif plancher stalagmitique épais parfois de plus d'un métre. Les sables sont fluviatiles, avec des niveaux limoneux de circulations hydrologiques plus paresseuses. Ces dépôts, nettement postgénétiques, témoignent sans ambigüité de l'ancien passage de la rivière.

L'étage moyen, temporairement noyé, est recouvert de limons de crues. Néanmoins, à certains endroits, des dépôts anciens

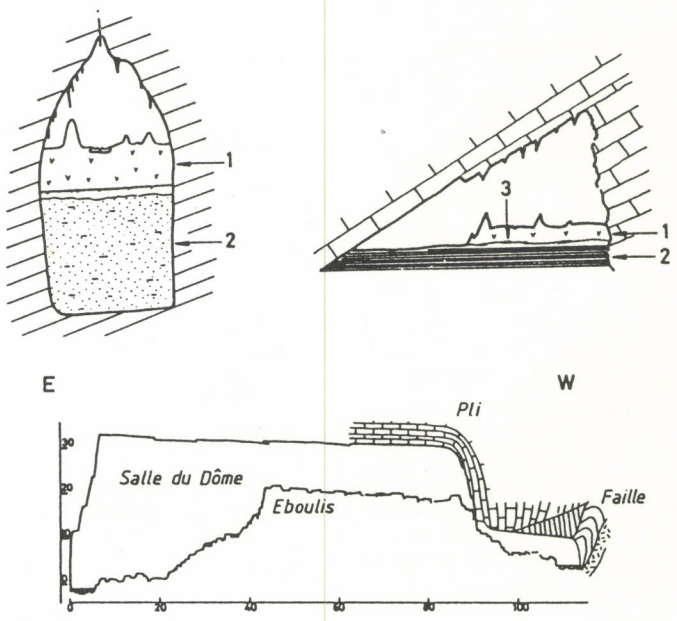

Figure 2. Localisation du site et esquisse topographique du réseau (d'après Coen, tiré de Quinif, 1984). On y voit la Lesse se perdre dans le gouffre de Belvaux, parcourir le réseau de la «Lesse souterraine», s'enfoncer en galerie noyée, ressotir à la Salle d'Armes et résurger au Trou de Han. Le Réseau Sud peut être considéré actuellement comme une dérivation surtout active en crues. Le Trou d'Enfaule et les conduits jusqu'à la Galerie des Mamelons constitue un ancien trajet à présent utilisé en crues tandis que le Trou du Salpêtre et la Galerie des Verviétois constituent le trajet fossile.

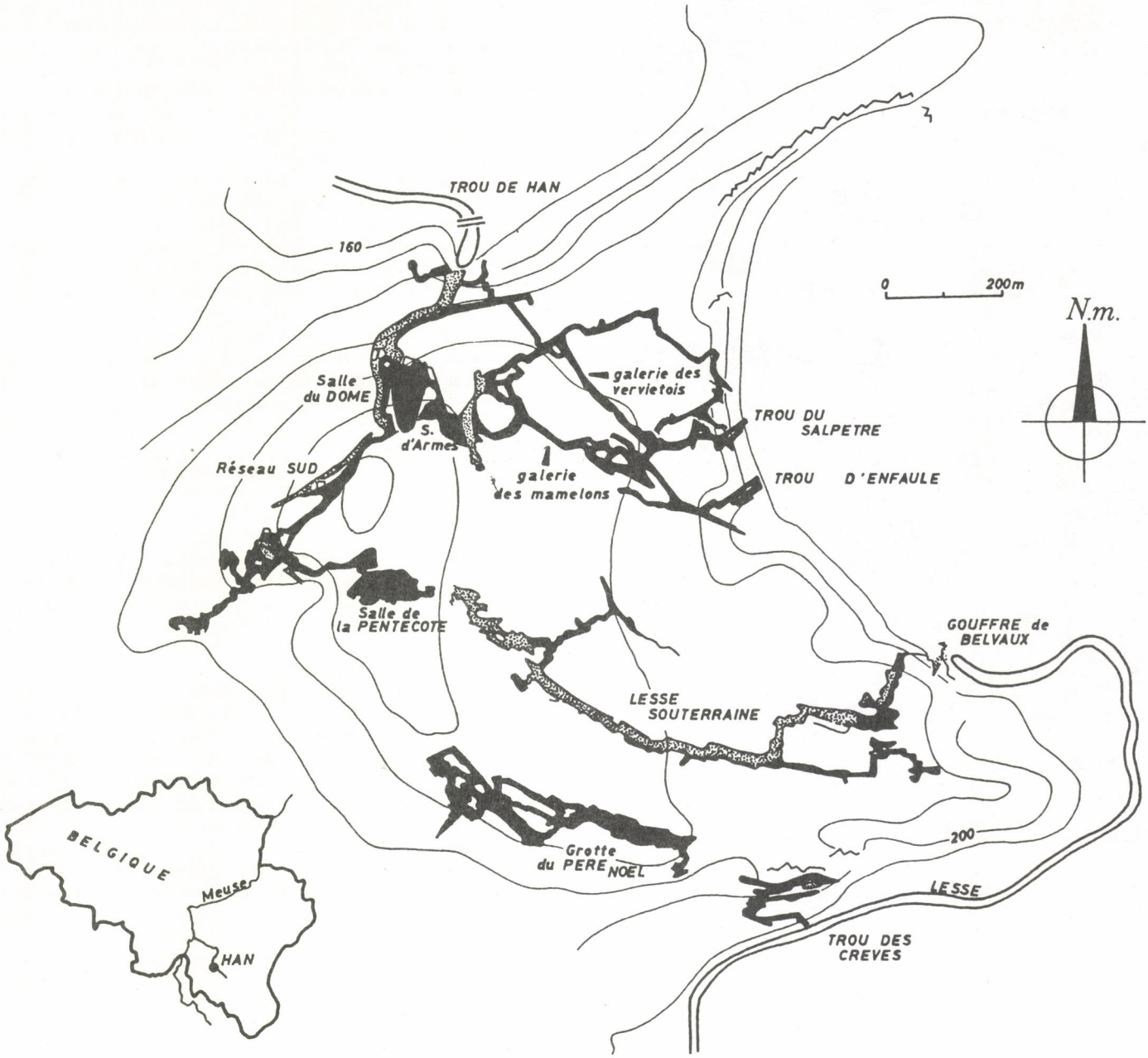

Figura 3. Exemples d'ensembles morpho-sédimentaires:
a) Section de la Galerie des Verviétois. 1: plancher stalagmitique, 2: sables.
b) Section de la Galerie des Petites Fontaines. 1: plancher stalagmitique, 2: argiles et limons, 3: charbons de bois.
c) Coupe E-W de la Salle du Dôme montrant les relations entre la morphologie et le pli-faille de Sorotchinsky (d'après Quinif et Bastin, 1984).

apparaissent. Le premier est une terrasse de galets, visibles sur le sol de la galerie principale, depuis le Trou d'Enfaule jusqu'à a la Galerie des Mamelons où ils ont été retrouvés par sondage à deux mètres de profondeur sous les limons de crues. Eux aussi témoignent à l'évidence de l'ancienne perte de la Lesse. La présence des galets implique que la rivière coulait de façon permanente devant l'orifice. Actuellement, seuls les débordements accompagnés seulement d'une sédimentation fine ou organique (bois flottés) envahissent encore la cavité. Un deuxième type de dépôt ancien colmate en partie des galeries secondaires, comme la Galerie des Petites Fontaines. Il s'agit d'un ensemble ici surtout argilo-limoneux surmonté d'un complexe stalagmitique: plancher et stalagmites. Ce plancher a été retrouvé par place dans la galerie de sortie de la Lesse, près de la voûte, prouvant ainsi un colmatage quasi-total du réseau et un arrêt des circulations lors de certaines périodes.

4. Donnés chronologiques

Ces résultats sont encore très fragmentaires. Une série de datations U/Th du grand plancher de la Galerie des Verviétois situe une partie importante de sa croissance durant le stade isotopique 5 (Shackleton, 1969). Il est possible que le début de sa croissance soit plus ancien. Les sables inférieurs sont donc au moins saaliens. L'absence de témoin détritique supérieur tend à prouver que cette galerie est restée exempte de circulations fluviatiles aprés cette période.

Le plancher stalagmitique de la Galerie des Petites Fontaines est holocène. D'après la palynologie, son âge est atlantique ou plus récent. Les sédiments détritiques sous-jacents sont weichséliens et témoignent du colmatage de la grotte à la fin de la dernière glaciation. Le recreusement est donc fort tardif: probablement post-atlantique.

IV. Conclusions

Le réseau de Han-sur-Lesse, par l'ampleur de ses galeries et de ses salles, constitue un terrain privilégié d'études dans le domaine karstologique (relation morphologie-structure, problèmes spéléogénétiques, hydrodynamique souterraine). De plus, ces études débordent largement du cadre strict du karst pour déboucher sur des problèmes structuraux, morphologiques et paléoclimatiques à l'échelle régionale.

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Cave Development in the Tropical Marble Karst of the Central Cordillera, Colombia

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Geologist.

RESUM

L'article resumeix els estudis que es varen dur a terme prop de les coves i la carstificació del cinturó marmori proper a la ciutat de Medellín. El marbre forma part de la seqüència paleozoica matamòrfica de la regió. Hi ha varis cons tropicals erosionats i s'ha format un carst de torres. Els nivells de base de l'erosió són tributaris del riu Magdalena. A la zona on el riu s'endinsa en els marbres s'han desenvolupat profunds «cañons». La carstificació va esdevenir durant els darrers 6 milions d'anys, en els quals es van succeir vàries fases del desenvolupament de les coves. Planures de carst dissecat s'originaren entre els cons, i l'aigua va anar penetrat en el marbre format-se les coves. Hom pot observar vàries generacions de desenvolupament de coves formades paral·lelament el «cañó» i al con.

RESUMEN

El artículo resume los estudios que se llevaron a cabo cerca de la cuevas y karstificación del cinturón marmóreo cerca de la ciudad de Medellín. El mármol forma parte de la secuencia Paleozoica metamórfica de la región. Existen varios conos tropicales erosionados y se han formado un kant en torres. Los niveles de la base de erosión son los tributarios del Río Magdalena. Allí donde el rio ha penetrado los mármoles se han formado cañones profundos. La karstificación ocurrió durante los últimos 6 millones de años en los que hubo varias fases en el desarrollo de las cuevas. Llanuras de karst disecado se formaron entre los conos y el agua profundizó en el mármol y se formaron las cuevas. Se puede observar varias generaciones de desarrollo de cuevas formadas al parecer a la vez que el cañón y cono.

SUMMARY

The article summarizes the studies, which have been carried out about the caves and karstification of the marble belt near Medellin city. The marble is member of the Paleozoic metamorphic sequence of the region. There a severly eroded tropical cone and tower karst has been developed. The local erosion base levels are the tributaries of the Magdalena River. Where rivers have broken through the marble zone deep canyons have formed. The karstification occured over the last 6 million years with various phases of cave development. Dissected karst plateaus formed between the cones and here water sunk into the marble and developed caves. Several generations of cave development, formed concurrently with the canyon and cone formation, can be observed.

The investigated caves are situated in a karst area at a 100 kilometres distance to the East of Medellín in the foothills of the Central Cordillera not far from the Magdalena valley /fig. 1/ The outcrop forms a 1-4 km wide and a 100 km long NNE-SSW trending belt between the N 5° 46'22'' W 74° 55'06'' and the N 6° 38'11'', W 74° 38'27''. The highest elevation of the marble is 600 m above the sea level while the elevation of the local base level falls between 200 and 350 m.

The climatic conditions are favourable for the development of tropical cone karst, however it is strongly modified by geological and tectonic factors. The karst range belongs to the hot region of the Cordillera, to the so called «tierra caliente». The average temperature is 28° centigrade with 4000 mm of precipitation. The 160-200 rainy days are almost evenly distributed in the year, less rainfall can be expected only from January to March. Dense tropical rain-forest covers the area.

Karstification in the area occures in the lower Paleozoic low metamorphic grade marble. The marble is grey to white, chemically seems to be pure, subordinately quartzose schist interbeddings can be found. In these interbeddings graptholitic beds appear which were determined as lower Paleozoic. The marble is composed of 0,5 to 1,0 m thick partially folded series of banks. It can be considered as interstratification of the surrounding metamorphic rocks such as quartz-feldspar gneiss, green and black achists, quartz, feldspar, chlorite, actinolite and graphitic shists. The whole sequence is Eastward from the huge instrusion of the Antioquian batholite which is composed of quartzodiorite and granodiorite. The NNE-SSW trending marble belt wedges out at several places which causes 1 to 10 km long interrumptions in its continuity. The Eastern margin of the range is limited by the NNE-SSW trending Palestine Fault and the NNW-SSE trending Otu fault. The range itself is dissected by numerous

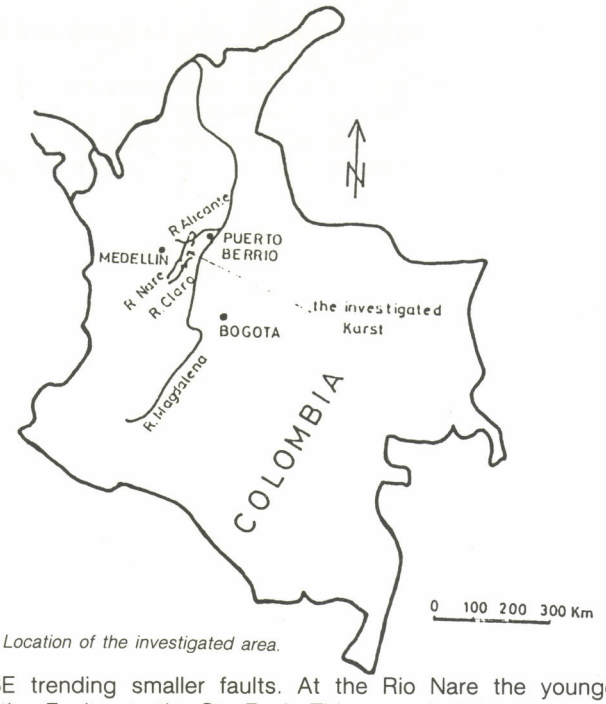

Fig. 1 Location of the investigated area.

NW-SE trending smaller faults. At the Rio Nare the younger Palestine Fault cuts the Otu Fault. This tectonical situation of the marble and its association with the metamorphic schist strongly determines the extension of the karstification and –of course– cave development

Karstification happened during the last 6 million years parallel with the Cordillera erosion. The metamorphic series of the Central Cordillera has been eroded since the late Tertiary period. The Magdalene Basin was filled up with detritus forming thick Tertiary and Quaternary deposits. At the same time the marble underwent karstification. Due to the climatic conditions a strongly eroded tropical cone and tower karst has been formed. Several generations of the caves formed concurrently with the karst where marble canyons and cone-hills can be observed. Three main rivers broke through the marble zone where large, deep canyons were formed as local base levels. These rivers are the tributaries of the Magdalena River in the South the Río Claro, in the middle the Río Nare and in the North the Río Alicante.

Cave development can be classified into two groups. One is cave development at right angles to the major rivers –«transversal development», while cave development along the river bank is «lateral development». Dissected karst plateaus formed between the cones and here water sunk into the marble and developed significant caves of the hydrologically less dynamic «tributary zones». The resurgences of these active stream caves are at the base level. /fig. 3/ The caves of lateral origin are of minor importance. They correspond to the cliff-foot caves which were described by several authors on other tropical karst regions. There is an interaction between the different groups of caves. Due to the long period of time karstification developed and destroyed countless generations of caves of both origin. Today it is imposible to recognize all these generations but at least five different phases can be observed. The rejuvenation of the oldest remains of the stream caves, the active stream caves and their different levels mark the development of the «transversal» caves while from the base to the top of the marble walls of the canyons and cone hills the cliff foot caves and their fossil remains represent the respective «lateral» development stages.

STAGE	CAVE DEVELOPMENT	
	A TRANSVERSAL DEVELOPMENT Stream caves	B LATERAL DEVELOPMENT cliff foot caves
1.	Cave rejuvenation, reactivation of fossil caves through collapse dolines. (e.g. collapse dolines to the W from the Rio Claro Canyon)	Initial development of the Cliff foot caves in the river beds and at the banks of the rivers in the form of flooded holes along the river banks. (e.g. They appear mostly in the larger rivers as the Rio Claro, Rio Nare and Rio Alicante)
2.	Active stream caves (e.g. Caverna del Condor)	
3.	Upper passages of active stream caves (e.g. Caverna de las Dantas)	Cliff foot caves (e.g. Boca del Caiman, Caverna de los Titis, Cueva Dona Augustina etc)
4.	Uplifted phreatic chambers (e.g. Caverna del Nus) Fossil stream caves (e.g. Cavena de Frances)	Fossil cliff foot caves (The canyon walls contain many of these cavities at various elevation)
5.	Callapse dolines (e.g. to the W from Rio Claro)	

Fig. 2 Tabular summary of the cave development of the marble karst region.

It was mostly erosion that formed the caves. As the catchment area of the sinkholes lays mostly on non-kartic- surfaces a large amount of quartz pebbles is transported by the streams into the caves from the metamorphic regions. Water, seeping through the karstic marble rock forms some spectacular adjoining passages and chambers but its influence concerning the development of the whole of the caves is secondary. Certainly solution plays a more important role at cave rejuvenation. The initial development of the diff-ffot caves is phreatic. The bedding plain and joint oriented solution that occures mainly below the water level of the rivers forms these caves enlarged later by the lateral erosion of the river. The origin of the Caverna del Nus near the Río Nare is beleived to be phreatic.

Figure 2 gives more information on an idealized sketchy section which is not exactly a new theory on tropical karsts just a classification of caves based on morphology an development.

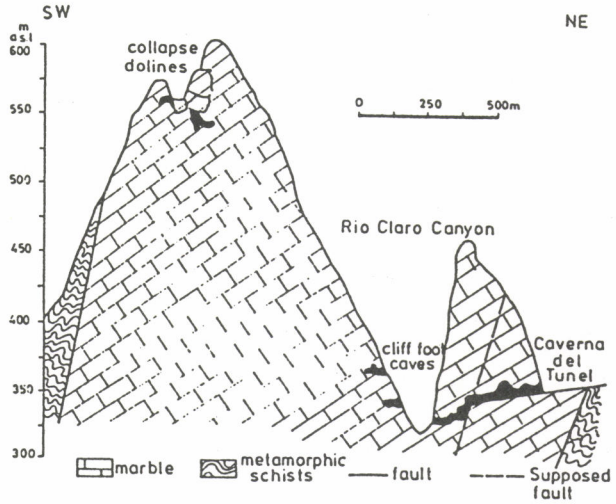

Fig. 3 Geological section through the Tunnel Cave and the Río Claro canyon.

I would like to give an overview in the followings about the most important caves of the area. These caves were studied mostly in the Southern part of the area where the most spectacular surface and subsurface karstic phenomena formed.

The Caverna del Tunel is a 442 m long stream cave. To the East of the Río Claro the water sinks at the foot of the largest cone hill and emerges directly at the river. /fig. 3/ the cave consists of 2-3 m wide and 10-15 m high joint oriented passages with spectacular forms of erosion accompanied by nice stalactite and flowstone decorations.

To the South of the Caverna del túnel opens the Caverna de Vicky, a 370 m long swallet cave. The underground stream flows to a large breakdown and behind it emerges in the side of one of the cone hills high above base level. The surface continuation of the stream is a steep canyon that falls to a tributary of the Río Claro. It seems that a young fault zone had bisected the karst here and forced the strean to the surface.

Downstream of the resurgence of the Caverna de Vicky emerges a large karst spring, the Manantial de las Dantas. A water filled passage is stopped after 10 m by a breakdown, but 30 m above the spring a 150 m long dry passage was discovered, the so called Caverna del Indio, which is very rich in brilliant flowstone formations. The Manantial de las Dantas is part of a hydrological system that drains the waters to the East from the above mentioned fault zone and the Caverna del Indio is a upper level of the hitherto undiscovered stream cave which belongs to this system.

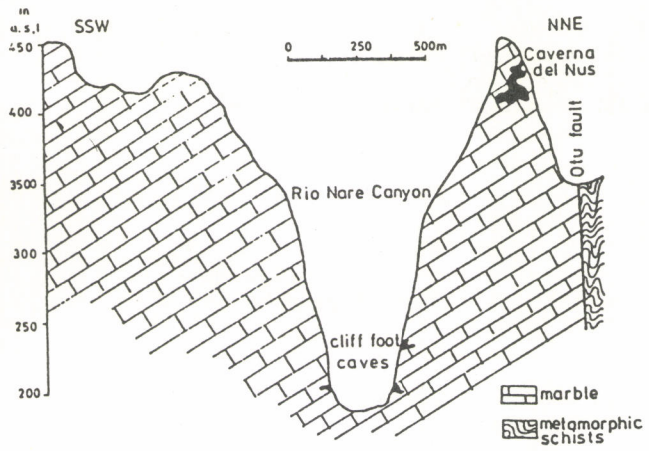

Fig. 4 Geological section through the Caverna del Nus and the Río Nare canyon.

The Caverna de la Águila is a 30 m long dry passage to the West of the Rio Claro at about 500 m above the sea level. This inactive passage marks an early phase of cave development. Above this cave at about 600 m of elevation on the cone hill surfaces four large collapsed dolines formed. They have diameters of about 100-300 m and they are 40-100 m deep. They formed as the results of collapses of fossile caves in view of the fact that there are several small fossile caves in their marble walls. The water of the surrounding area sinks into these collapse dolines as a reactivation of the fossile caves.

The Caverna del Condór is an extremely large stream cave in an Eastern tributary canyon of the Rio Claro /fig. 6/ The water sinks through a 30 m by 15 m entrance and emerges after 488 m of subsurface route. The cave consist of a series of large chambers some more than 30 m high and more than 20 m wide. The canyon itself probably marks a destroyed, collapsed cave system as also suggested by the natural bridge downstream in the canyon.

The longest cave of the area is 873 m long Caverna de las Dantas to the South of the Rio Claro canyon /fig. 5/ A large amount of water flows through the impressive main passage. Nicely decorated big chambers and a collapsed labyrinth form the upper levels.

The Caverna del Francez is located on the very rugged karst to the West of the Río Claro. The area resembles a «cockpit» karst high above the river level. The cave is the longest /60 m/ example of a fossile stream cave high above base level. At about 220 m to the South of this cave the large entrance of the Caverna del Tigre is located. This is a 30 m long fossile remnant of a former stream cave with definite signs of the reactivation.

The Caverna de los Titis ia a 15 m deep cliff foot cave in the upper tributary of the Río Claro. Behind it a 60 m long keyhole sectioned inner passage was found which conducts water from the non karstic surface. The cave is an interesting combination of the two kinds of cave development, the phreatic «lateral» cliff-foot cave and the vadose «transversal» stream cave.

The most spectacular foot caves of the Río Claro canyon are the «Templo del Tiempo» and the «Boca del Caimán.».

The Caverna del Nus is the most significant cave of the Río Nare region /fig. 4/ the cave entrance is elevated at 435 m above the sea level and 300 m above the Rio Nare. The cave is a series of large solution chambers in several levels. The arrangement of the «salones» does not reflect any drainage pattern of fault oriented maze structure and do not show any trace of a stream. The cave represents a very old stage of phreatic cave development which occured before the formation of the Rio Nare canyon. Due to the relatively fast uplift by the Otu and Palestine faults the remains of the ancient cave was preserved from the strong erosion effect.

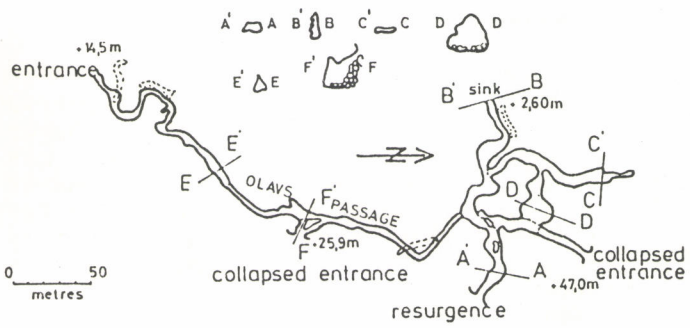

Fig. 5 Map of the Caverna de las Dantas. /a multilevel stream cave/.

1 km to the North of the Caverna del Nus formed the Caverna de los Guacharos, a 200 m long stream cave. As a witness of the erosion the former upper level of the cave appears as a natural bridge on the cone slope.

Several levels of the foot caves can be found in the Río Nare canyon too.

In the Northern part of the karst in the Rio Alicante canyon the marble is less favourable for karstification, only the Cueva de Doña Augustina a large size cliff foot cave with nice tuff curtains is worth of mentioning.

The present paper is a summary of a long period of investigations but it is important to notice that there are much more possibilities to explore and to study the caves of this region.

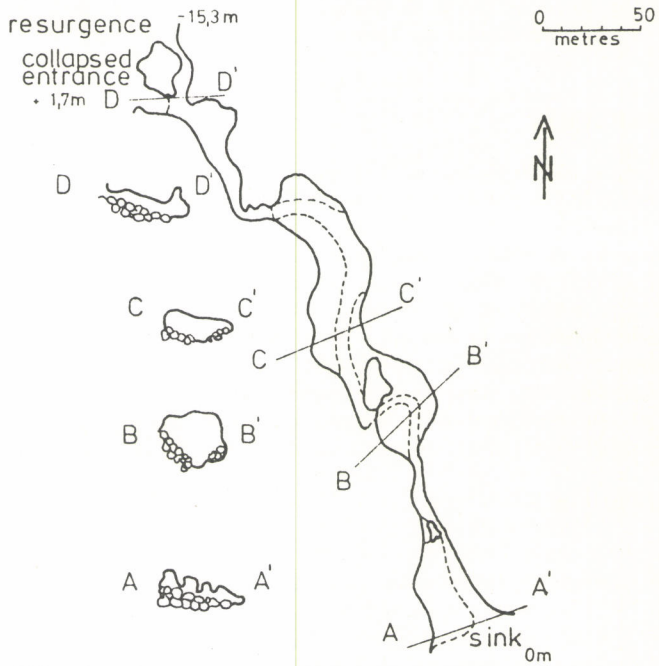

Fig. 6 Map of the Caverna del Condór /An extremely large stream cave/.

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Caractere des karsts artiques du Yukon septentrional

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RESUM

La regió d'Old Crow està situada al nord del Cercle Polar, a la Beríngia oriental, en una zona on el sòl es troba permanentment gelat. La temperatura mitja anual és de −10° C, amb precipitacions de 215 mm/any (el 50 % en forma de neu).

Allí hom pot observar dos tipus de manifestacions càrstiques:

1. Al fons de les valls, un drenatge càrstic actiu amb algunes pèrdues en medi boscós.

2. En els vessants de massissos residuals, de 200 a 500 m. per sota de les valls, nombrosos vestigis de cavitats exhumades per l'erosió. Aquestes darreres conclouen segments de conductes càrstics (fins a 200 m de longitud) amb un contingut complex, ric en materials alòctons, amb concrecions sorprenentment abundants i massives (algunes de 2 m de gruix). Aquest materrial es troba sovint en forma de material detrític al pendent dels vessants.

Es constata, doncs, alhora, la presència d'una carstificació actual i indicis d'una altra molt més antiga que va precedir l'excavació de les valls.

RESUMEN

La región de Old Crow se encuentra al norte del Círculo Polar, en Beringia oriental, en zona de suelo permanentemente helado (pergelisol) y no ha sido deshelada jamás. La temperatura media anual es de −10° C, con precipitaciones de 215 mm/año (50 % de nieve).

Allí se observan dos tipos de manifestaciones kársticas:

1. En el fondo de los valles, un drenaje kárstico activo con unas pérdidas en medio boscoso.

2. En las vertientes de macizos residuales, de 200 a 500 m. por debajo de los valles, numerosos vestigios de cavidades exhumadas por la erosión. Estas últimas concluyen segmentos de conductos kársticos (hasta 200 m. de longitud) conteniendo un relleno complejo, rico en materiales alóctonos, con concrecionamiento sorprendentemente abundante y masivo (hasta 2 m. de espesor). Este material se encuentra frecuentemente bajo forma de derrubios de pendiente en las vertientes.

Se constata pues al mismo tiempo la presencia de una karstificación actual y las indicaciones de otro muy antigua que ha precedido la excavación de los valles.

RESUME

La région d'Old Crow se trouve au nord du cercle polaire, en Béringie orientale, en zone de pergélisol continu et n'a jamais été englaciée. La température moyenne annuelle y est de −10° C avec des précipitations de 215 mm/an (50 % en neige).

On y observe deux types de manifestations karstiques:

1. au fond des vallées, un drainage karstique actif avec des pertes en milieu boisé.

2. sur les versants de massifs résiduels, de 200 à 500 m au-dessus des vallées, de nombreux vestiges de cavités éventrées par l'érosion. Ces derniers incluent des segments de conduits karstiques (jusqu'à 200 m de longueur) contenant un remplissage complexe, riche en matériaux allochtones, avec un concrétionnement étonnament abondant et massif (jusqu'à 2 m d'épaisseur). Ce matériel se retrouve fréquemment sous forme d'épandages sur les versants.

On constate donc, à la fois, la présence d'une karstification actuelle et les indications d'une autre très ancienne ayant précédé le creusement des vallées.

Introduction

On considère généralement que dans les régions arctiques, la karstogenèse est considérablement limitée (Balázs, 1977) sinon tout à fait inhibée, ou oblitérée par les morphogenèses glaciaire et périglaciaire. Corbel (1957) disingue deux types de karsts arctiques: ceux des régions à pergélisol continu et ceux des régions à pergélisol discontinu. Dans le premier cas, que l'on rencontre dans les îles de l'arctique canadien, au Groënland septentrional, au Spitzberg et en Sibérie, il y a absence de circulations souterraines et de cavernes. La dissolution affecte surtout la surface des gélifracts où elle creuse de micro-lapiazs (Bird, 1953). Le second type se retrouve au Groënland méridional, en Islande ainsi qu'au nord de la Norvège et en Laponie. On y observe des écoulements souterrains et quelques grottes. Dans les régions humides du nord de la Scandinavie, les grottes sont particulièrement abondantes (Engh, 1977; Lauritzen, 1981 et 1983). Elles sont généralement intégrées à la morphologie glaciaire locale et plusieurs sont antérieures au Weichsel (Lauritzen, 1984 A et B).

Les karsts arctiques observés au Yukon septentrional différent sensiblement de ceux mentionnés ci-dessus. Ils ont été étudiés durant l'été 1985, à la suite des observations préliminaires de Cinq-Mars et Lauriol (1985).

La région d'Old Crow

La région étudiée se situe dans le nord-est du Yukon entre le village d'Old Crow et le cercle polaire (Figure 1). Elle appartient à la Béringie orientale (Hopkins et al., 1982). Elle a pour particularité de n'avoir subi aucune glaciation au cours du Quaternaire (Prest, 1970). La sécheresse du climat n'a pas été favorable à la formation de glaciers locaux alors que l'inlandsis laurentidien n'a jamais réussi à franchir la barrière formée par les monts Richardson. Des observations récentes ont permis de constater que la région se trouve dans la zone de pergélisol continu (C. Tornacai, comm, pers.). A Old Crow, le pergélisol atteint une centaine de mètres de profondeur (J. Pilon, comm. pers.).

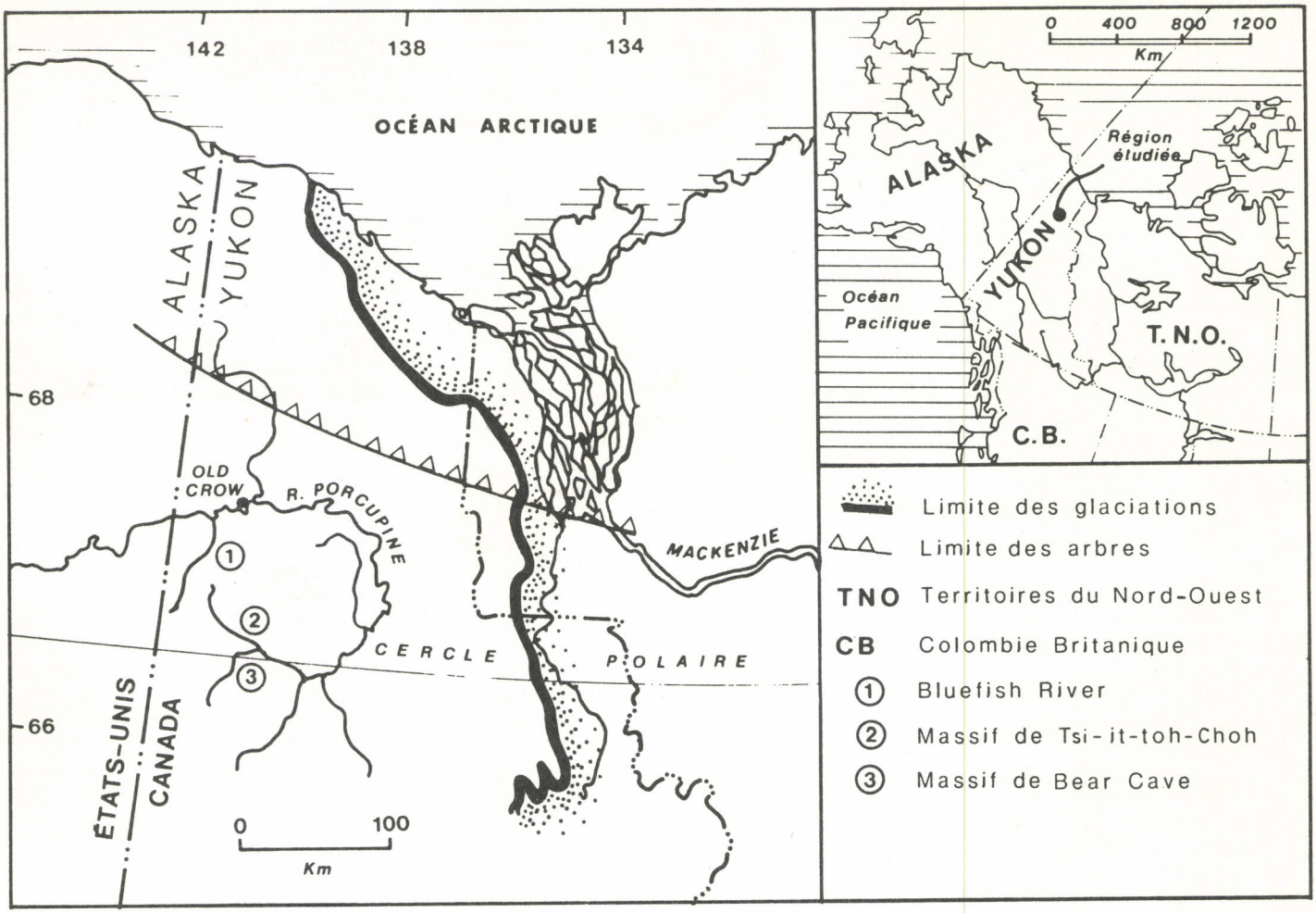

Figure 1: Localisation de la région d'Old Crow et des sites mentionnés.

Old Crow est soumis à un climat arctique continental (Figure 2) avec une température moyenne annuelle de −10° C, un hiver très froid et un été doux. Les précipitations ne sont que de 215 mm/an (dont 50 % en neige) (Environnement Canada, 1982). L'eau reste immobilisée à l'état solide d'octobre à mai, soit près des deux tiers de l'année. On retrouve la forêt boréale partout jusqu'à une altitude d'environ 800 m. Au-dessus, c'est la toundra qui domine.

Les karsts arctiques de la région d'Old Crow

Les karsts rencontrés sont de deux types: des fluviokarsts actifs en milieu boisé dans les vallées et des karsts reliques perchés sur les versants.

Les fluviokarsts actifs.

Ils se trouvent en milieu forestier, dans les vallées ou sur des bas plateaux, à la tête des vallées. Il y a présence de pertes, de résurgences et d'écoulements souterrains karstiques dans les secteurs de la rivière Blue Fish et du massif de Tsi-it-toh-Choh (Cinq-Mars et Lauriol, 1985). Une attention particulière a été accordée à deux pertes voisines situées à 2 km au nord du massif de Tsi-it-toh-Choh. Elles drainent approximativement 0.5 et 1.0 km^2 de terrain plat situé au centre d'un bas plateau boisé et entaillé au nord et au sud par des vallées d'une centaine de mètres de profondeur. Elles capturent ainsi des écoulements qui alimentaient la vallée du côté sud. La résurgence n'a pas encore été localisée mais les sites potentiels les plus proches sont distants d'au moins 1.5 km sous des gradients hydrauliques de 4 à 5 %. Ces pertes se font dans une doline d'effondrement et une doline de dissolution morphologiquement «fraîches» et dont le volume respectif dépasse 5.000 m^3.

Un échantillonnage hydrochimique préliminaire a permis de constater que dans les deux secteurs, les eaux des pertes et des petits cours d'eau voisins possèdent des teneurs en CO_2 dissous (PCO_2 calculées entre 0.4 et 1.2 %) et un potentiel de dissolution du calcaire tout à fait comparables à ceux de leurs équivalents des milieux forestiers du Canada méridional. Ainsi l'existence d'une karstification active ne pose pas de problème sur le plan de le capacité de dissoudre. Ce qui étonne c'est plutôt la présence de circulations karstiques au sein du pergélisol continu. Présentement, l'hypothèse la plus vraisemblable est celle de l'installation de conduits karstiques à une époque sans pergélisol continu, puis le maintien ultérieur au sein du pergélisol, d'une envoloppe rocheuse dégelée autour de ceux-ci, dû aux apports thermiques des circulations d'eau estivales.

Les karst reliques perchés

Ceux-ci ont été observés dans les massifs de Tsi-it-toh-Choh et de Bear Cave (Figure 1). Ces massifs résiduels appartiennent tous deux à la structure anticlinale de Bear Cave orientée N-S et sont formés des calcaires dévoniens des formations de Ogilvie et de Gossage (Norris, 1978). Ce sont les vestiges de plateaux disséqués toute part par un intense ravinement. Ils dominent de 500 à 600 m les vallées environnantes. Le massif de Tsi-it-toh-Choh large de 6 km et long de 14 km culmine à 1.280 m. Celui de Bear Cave, large de 5 km et long de 6 km, culmine à 990 m et se situe exactement à la latitude du cercle polaire.

A l'exception d'une doline d'effondrement au sommet du massif de Tsi-it-toh-Choh (Cinq-mars et Lauriol, 1985) on n'a encore observé aucune trace de karstification à la surface des plateaux. Par contre, dans les ravins et versants abrupts, les porches abondent sur les affleurements subverticaux. Presque tous donnent accés à des segments de conduits karstiques rarement explorables sur plus d'une dizaine de mètres. Ce sont les vestiges de réseaux souterrains vraisemblablement complexes et extensifs, tronqués et presqu'entièrement démantelés par le recul des versants. On les retrouve perchés à presque toutes les altitudes avec une concentration entre 800 et 1.000 m. La plus importante cavité explorée est Bear Cave sur le massif du même nom, où 220 m de passages ont été cartographiés.

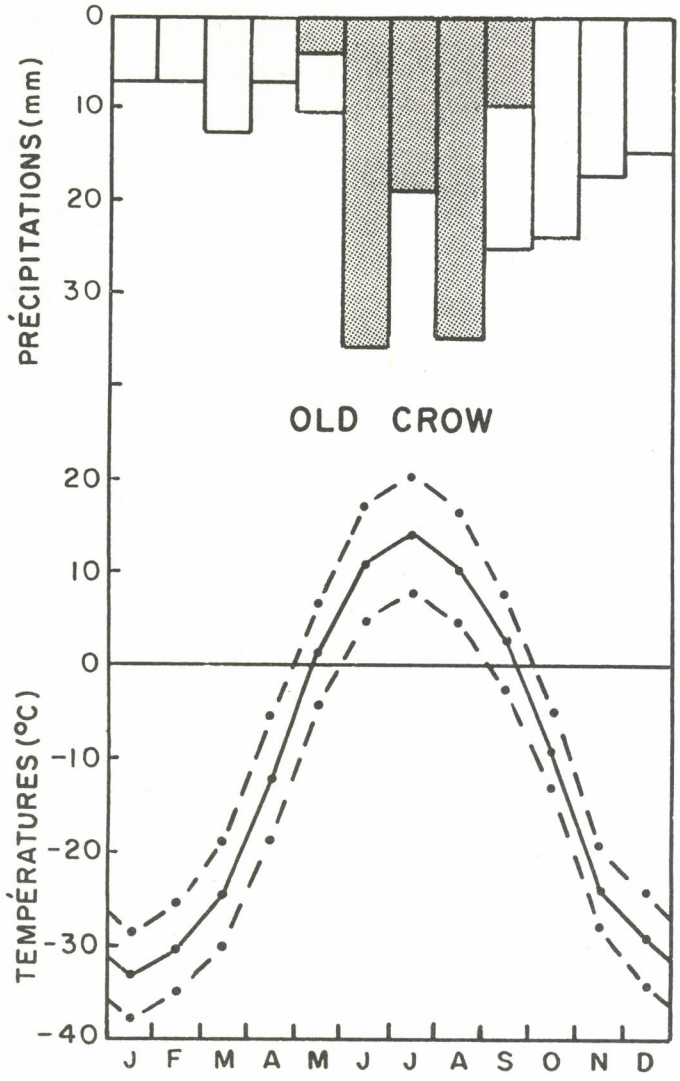

Figure 2: Précipitations et températures mensuelles moyennes à la station d'Old Crow. Les barres pleines représentent la pluie et les barres creuses, la neige. Les trois courbes correspondent à la normale des températures mensuelles minimales, moyennes et maximales.

Presque toutes les galeries visitées présentent la morphologie caractéristique des conduits creusés en régime noyé. Elles se développent le long de plans horizontaux indépendamment du pendage ou du gradient topographique local. Ce sont des vestiges de cavités de type «watertable cave» témoignant de la position d'anciens niveaux de base du drainage karstique local..

Les matériaux de remplissage y sont variés. Aux matériaux autochtones (gélifracts, éboulis) s'ajoutent d'abondants sédiments allochtones allant des limons fins aux conglomérats grossiers. Le concrétionnement est fréquent et abondant. Cette abondance surprenante en milieu arctique, est inusitée, même au sud du Canada. Dans Bear Cavel des coulées et des planchers stalagmitiques ont plus de 1 m d'épaisseur et plusieurs mètres cubes de volume. Dans certaines cavités, les remplissages se combinent de façon complexe, suggèrant plusieurs phases de remplissage et d'érosion. On rencontre souvent de la glace sous forme d'accumulations de cristaux de givre ou de glace massive transparente. Ces cavitées installées au sein du pergélisol ne reçoivent pas d'eau d'infiltration et la présence de glace est liée aux influx de vapeur d'eau.

Les matériaux de remplissage observés dans les grottes se retrouvent fréquemment sous forme d'épandages sur les talus de débris, sur les versants dont le recul a causé la destruction de grottes. Ces épendages contiennent fréquemment des fragments de concrétions de quelques décimètres cubes, exceptionnellement de plus de 1 m^3. Parmi le matériel clastique d'un de ces épandages, presqu'au sommet du massif de Bear Cave, on a compté plus d'une centaine de galets fluviatiles gréseux dont certains cimentés dans des fragments de concrétions. Il s'agit vraisemblablement de galets allochtones entrainés dans une cavité par des pertes en aval de terrains gréseux. Actuellement, les affleurements de grès les plus rapprochés sont séparés du massif de Bear Cave par une vallée profonde de 500 m et large de 9 km (figure 3). Ceci constitue un indice supplémentaire de l'accienneté des cavités perchées, à tout le moins sur le massif de Bear Cave.

Le concrétionnement des cavités deux implique donc l'absence du pergélisol continu et suggère la présence sur les plateaux d'un couvert végétal à même d'enrichir substantiellement les eaux d'infiltration en CO_2. Au cours du Quaternaire, ce processus n'aurait donc été possible qu'à la faveur de climats plus chauds que l'actuel. L'abondance des concrétions serait attribuable à de longues périodes de déposition permises par l'âge élevé des cavités et peut-être à un éventuel paléoclimat nettement plus chaud et plus humide, favorable à des taux de déposition élevés.

Conclusion

Nous avons observé dans un milieu arctique à pergélisol continu, à la fois la présence de circulations souterraines karstiques actives et de nombreuses cavités. Les processus karstiques continuent à affecter le milieu souterrain même au sein du pergélisol. Toutefois, pour expliquer la genése de ces conduits de même que le concrétionnement dans les cavités anciennes, il faut invoquer l'absence du pergélisol continu.

Le contexte physiographique des cavités perchées sur le flanc des massifs suggère que'lles sont très anciennes. Elles seraient donc susceptibles d'avoir été des milieux propices à la conservation de données sédimentologiques, polliniques et isotopiques précieuses à la connaissance de la paléoécologie quaternaire de la région. Une étude détaillée de leur remplissage tente présentement d'explorer ces possibilités.

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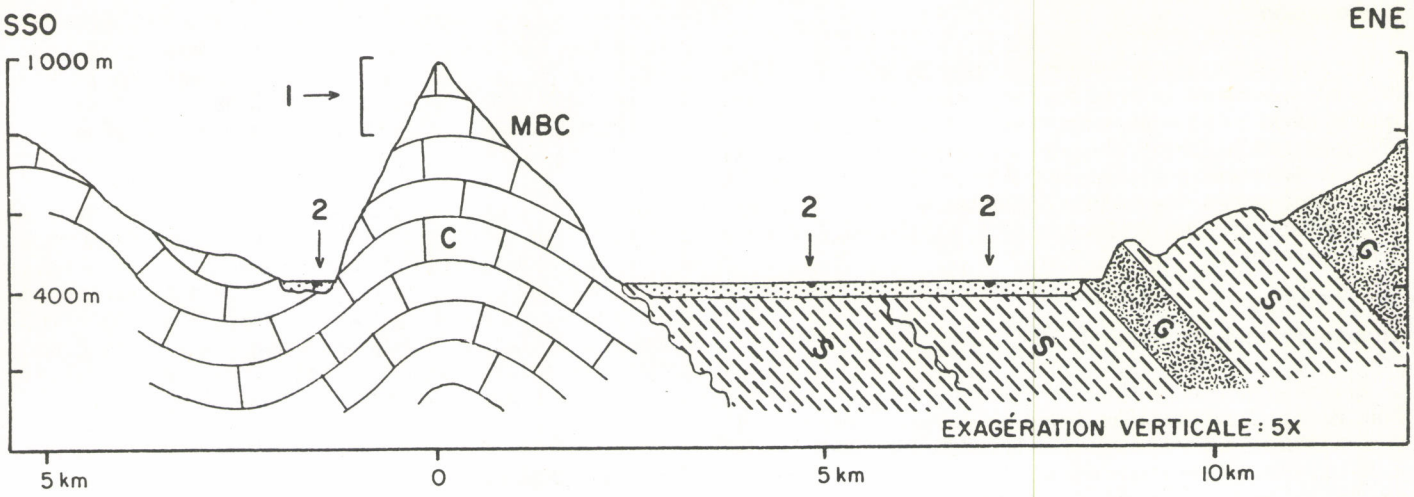

Figure 3: Coupe géologique simplifiée du massif de Bear Cave et des environs, perpendiculaire à la vallée de la Fishing Branch.

1: zone de concentration de cavités perchées;
2: rivière Fishing Branch et sa plaine alluviale;
C: calcaires dévoniens;
G: grès du Crétacé;
S: schistes argileux du Crétacé;
MBC: massif de Bear Cave.

Contribución al conocimiento de las cavidades submarinas del sureste peninsular (Cartagena)

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RESUM

Els fenòmens càrstics costaners del S. E. de la península Ibèrica són molt poc coneguts. Una part de la costa de Múrcia és molt abrupta com a conseqüència de la tectònica intensa a la que aquesta zona ha estat sotmesa i que es traduí en una gran complicació de plecs, abundància de falles i l'aparició de nombrosos penya-segats. Recentment, el descobriment de noves cavitats a la costa brinda noves expectatives als espeleòlegs.

En aquest treball s'estudien cinc cavitats, una part de les quals es troba submergida dins el mar. En elles s'hi han trobat restes que han aportat dades molt valuoses de cara a un millor coneixement de les oscil·lacions de la Mediterrània (per exemple, formes axials submergides, estalagtites, localitats prehistòriques en contacte amb el mar, dipòsits clàstics, etc.).

RESUMEN

Los fenómenos kársticos costeros del sudeste de la Península Ibérica son poco conocidos. Una parte de la costa de Murcia es muy abrupta, consecuencia de la tectónica intensa a la que esta zona ha estado sometida y que tuvo como resultado una gran complicación de pliegues, fallas y aparición de numerosos acantilados. Recientemente el descubrimiento de nuevas cavidades en la costa ofrece nuevas expectativas para los espeleólogos.

En este trabajo se estudian cinco cavidades, una parte de las cuales se encuentran sumergidas en el mar. En éstas se han encontrado restos que aportan datos preciosos para el conocimiento de las oscilaciones del Mediterráneo, por ej.: formas axiales sumergidas (estalagtitas,...), localidades prehistóricas en contacto con el mar, grandes rellenos clásticos, etc.

RESUME

Les phénomènes carstique-côtiers du Sud-est de la péninsule ibérique sont peu connus. Une portion de la côte de Murcie est trés abrupte, c'est une conséquence de la tectonique bien forte à laquelle cette zone s'est vue soumise et qui a eu comme résultat une grande complication de plis, des failles et l'apparition de nombreuses falaises. Récemment la découverte des neuves cavités dans la côte offrent des neuves spectatives pour les spéléologues.

Dans ce travail-ci on étudie cinq cavités, une partie se trouvant submergées dans la mer. Dans celles-ci ont été trouvés des restes qui apportent des dates précieuses pour la connaissance des oscillations de la Méditerranée, por exemple; des formes axiales submergées (des stalactites,...), des placements préhistoriques en contact avec la mer, des grandes remplissages clastiques, etc..

Introducción

La zona de estudio se sitúa en el litoral Oeste de Cartagena (Murcia), «ver mapa 1», entre las longitudes 00º 59' y 01º 15', localizándose en las hojas topográficas n.º 977 de Cartagena y 976 de Mazarrón, del Inst. Geográfico y Catastral de España «ver mapa 2». En el presente trabajo se dan a conocer cinco cavidades que se encuentran relacionadas con el Mediterráneo, éstas han sido afectadas por una tectónica reciente, que ha llegado a hundir parte de la costa.

Encuadre geológico general

El área estudiada se sitúa geológicamente en las cordilleras Béticas, y está comprendida dentro del sector suroccidental de la zona Bética. En dicha zona se pueden diferenciar varios complejos tectónicos y el tramo que nos ocupa se asienta sobre materiales del complejo Alpujárride, constituido por filitas, cuarcitas y calizas que se le atribuyen un edad triásica, ésta se extiende por toda la línea de costa. La potencia de las calizas es de 100 a 150 m.

La tectónica es muy visible, se caracteriza por diferentes sistemas de fracturas que rompen la continuidad de las estructuras, tanto de Este a Oeste como de Norte a Sur, afectando considerablemente la génesis y el desarrollo de las cavidades existentes. Por otro lado los mantos de corrimiento, típicos de la tectónica de la Bética, acumulan diferentes materiales.

Durante la Orogenia Alpina, los materiales son corridos hacia el Norte, produciéndose un tectónica de mantos de corrimiento, desplegándose en muchos casos de su basamento prealpino. Simultáneamente a estos fenómenos se produce una tectónica de fallas de tensión, que rompe la continuidad de las estructuras en dirección Este-Oeste.

Posteriormente a estas fases orogénicas importantes, se produce una serie de fallas de distensión, que ha provocado el hundimiento de los bloques hacia el mar, esta es la razón por la que el litoral es tan abrupto en el sector y por la que existen tan pocos afloramientos cuaternarios. Esta neotectónica se puede apreciar en estas cavidades, salas y galerías sumergidas, con formaciones litogénicas, son claros exponentes de estos hundimientos.

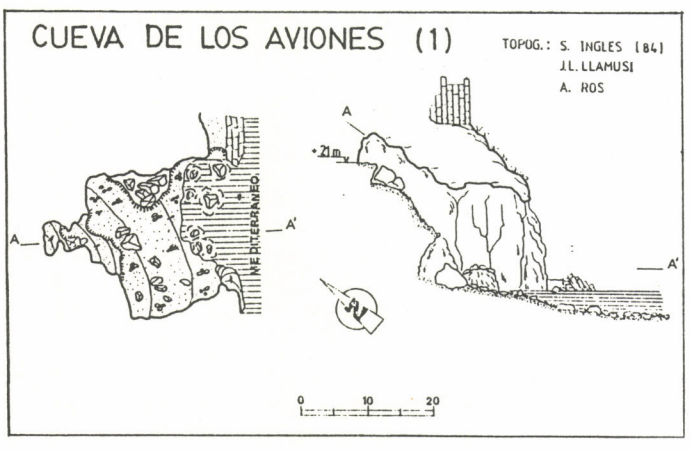
Las cavidades

Cueva de los aviones

Esta situada en las proximidades de la ciudad de Cartagena, concretamente en el dique de Navidad, sus coordenadas son: Long. 37º 35'05'', Lat. 1º 27'20'' m.s.n.m.O. En realidad se trata de un abrigo de escasos metros, pero su importancia viene dada por la existencia de un yacimiento paleolítico, que tiene claras relaciones con la neotectónica en esta zona.

El abrigo es consecuencia de una serie de fallas que se sitúan pricipalmente en dirección NE. y NW., dirección que toma la cavidad y en donde se ha intensificado la carstificación. Posee una amplia boca de acceso, 12m. por 15m. de ancho, es en esta primera sala donde se desarrolla casi la totalidad de la cueva, en dirección NE. se encuentra una pequeña galeria muy erosionada, como la totalidad del abrigo, a causa de los fuertes vientos y la acción del oleaje. En la primera sala se puede ver un pequeño relleno litológico efecto del desarrollo de un pequeño aparato cárstico.

En el extremo Oeste de la boca se encuentra un asentamiento prehistórico que se sitúa cronológicamente en el paleolítico medio, éste se encuentra parcialmente sumergido en el mar, a causa de los movimientos tectónicos recientes. Prospecciones submarinas nos indican que el antiguo nivel de playa se situaba posiblemente a unos 50m. de la línea de costa actual y a unos 7 m. de profundidad, dato que parece confirmar la neotectónica de distensión reciente a que se ha visto sometido este litoral.



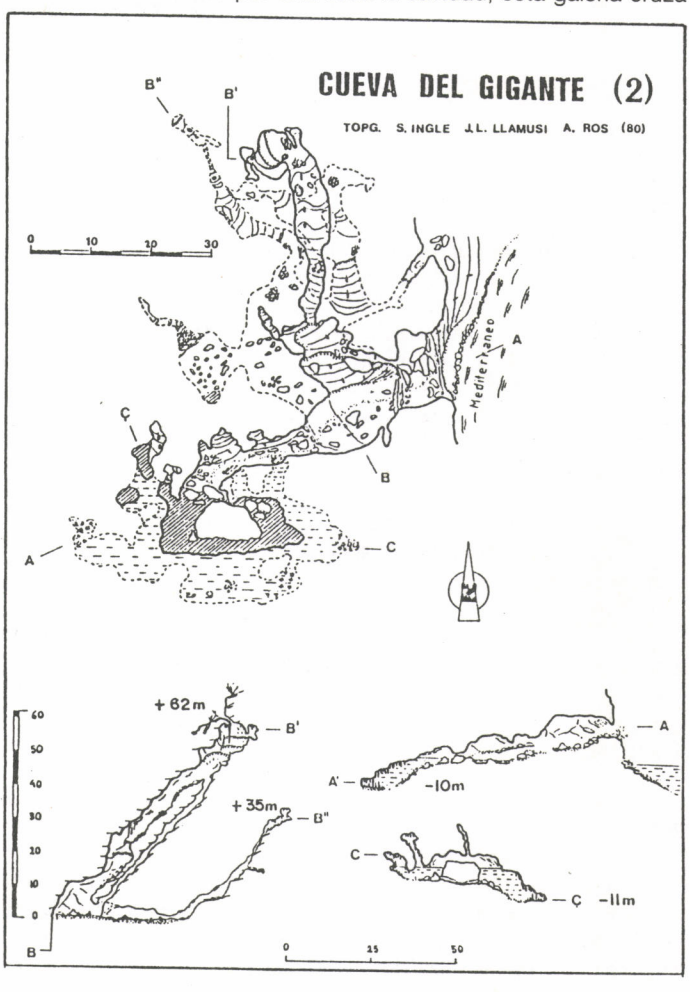
Cueva del Gigante

Está situada a unos 10 Km. de Cartagena al Oeste de ésta, llegando a ella a través de la playa de Portús, sus coordenadas son: Long. 01º 04'34'', Lat. 37º 35'06'', m.s.n.m. 5.

La cueva del Gigante es una cavidad de origen tectónico, aunque en su interior se pueden observar procesos cársticos.

Tiene tres entradas, la mayor de 11 m. por 2,5 m. de altura y es consecuencia del hundimiento de uno de los laterales de la galería principal de la cavidad, que tiene una longitud de 25 m. y recorre la cueva en dirección W 35º S., existen algunas galerias más que recorren la cavidad en la misma dirección, coincidiendo con una supuesta falla exterior, configurando la fisonomía principal de la cueva.

La neotectónica de distensión también está presente, a través de varias galerías que se desarrollan en distintas direcciones. Cerca de la entrada se encuentra una galeria horizontal con dirección N. 30º W en donde se pueden apreciar prospecciones mineras, para la extracción de mineralizaciones de hierro, que se encuentran aflorando por casi toda la cavidad, esta galería cruza

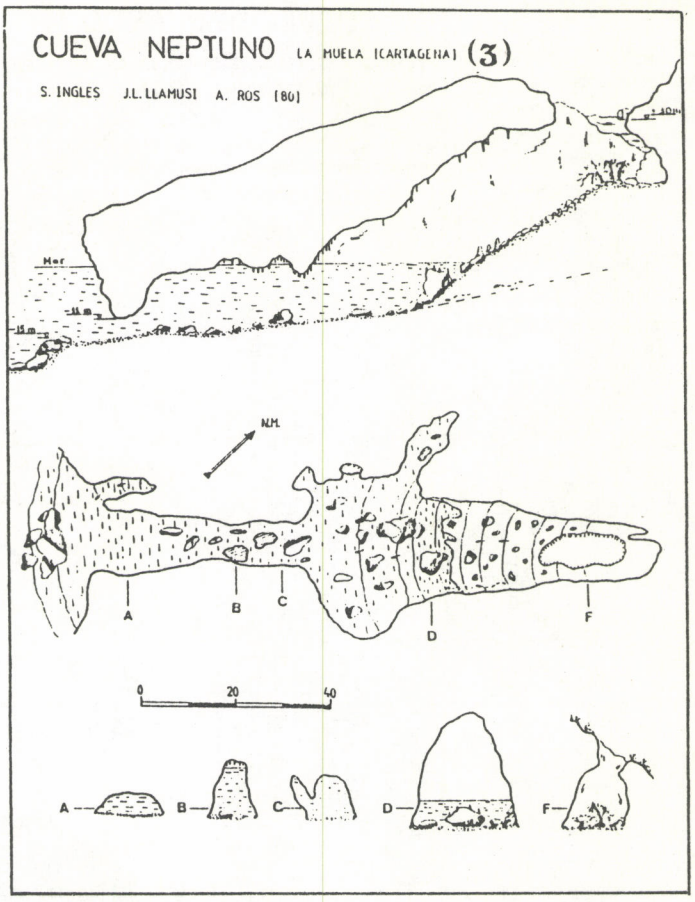


con otras de pequeño recorrido en dirección Oeste y en ellas se observan procesos cársticos, en forma de tubos de presión con rellenos litógenos, fruto de un antiguo aparato cárstico que llegó a estar en funcionamiento, hoy fósil.

Muy próxima a la entrada se encuentra una galeria con dirección N. 25° W. con una fuerte inclinación de 55° que se desarrolla en dirección ascendente junto a otra paralela, separada por una pequeña lamina de caliza, los estratos de esta zona se encuentran muy inclinados, éstas estan comunicadas en la parte superior, a través de una pequeña bóveda que comunica al exterior a más de 62 m.s.n.m., en esta galeria así como en casi toda la cueva se aprecia una fuerte corrosión, producto de la acción de los vientos que azotan la zona, las fuertes temperaturas y la salinidad que satura la atmósfera.

Al Oeste de la entrada y a unos 40 m. se encuentra una pequeña bóveda de 25 por 10 m. como consecuencia de varias fracturas tanto en dirección N.-S. como de E.-W. que se cruzan en ésta, ella se encuentra inundada por el agua del mar, llegando a alcanzar una profundidad de 11 m., bajo el agua existen varias galerias en las que se puede apreciar un relleno litogénico en forma de estalagtitas y estalagmitas, destacando al norte de la sala una gran columna de 4 m. de altura y 1'30 m. de diámetro, encontrándose su tercio superior partido, producto de la acción de la fuerte tectónica a que se ha visto sometida esta zona, al SW-W. de la sala encontramos estalagmitas bajo el agua de hasta 2 m. de altura, a una profundidad de 9 m. Destacan las grandes diferencias de temperatura del agua de esta sala, estando la superficie a 26° y el fondo a 31°.

En varios puntos de la cavidad aparecen pequeños charcos de agua salobre, que oscilan según las variaciones de las mareas barométricas del Mediterráneo.



Conclusiones

La cueva del Gigante viene condicionada por una supuesta falla en dirección Oeste, que cruza con otras fracturas en distintas direcciones, como consecuencia de una fuerte tectónica y después una neotectónica de distensión, parte de la costa se ha hundido y junto a ella parte de la cavidad, que actualmente se encuentra bajo el mar. Indicios como son las diferentes fracturas y el relleno litológico bajo el mar, lo hacen suponer.

Cueva Neptuno

Está situada al Oeste de Cartagena en la denominada cala Aguilar a unos 14 Km. de esta ciudad, sus coordenadas son: Long. 01° 06'04'' Lat. 37° 34'47'' m.s.n.m. 30 y -15.

Esta cavidad viene condicionada por un fuerte cabalgamiento en dirección NS., entre materiales de calizas tableadas azules y dolomías negras con caliza.

Una única galería se encuentra en la cavidad, en dirección NE-SO. con una inclinación de 35° y una longitud de 130 m.

Posee dos accesos, el primero por tierra a través del hundimiento de la galería principal en su parte más alta con una boca de 16 por 7 m. de ancho y 14 m. de profundidad, la segunda entrada se encuentra bajo el mar en el extremo SE. de la cavidad, la entrada tiene unas dimensiones de 5 m. de diámetro y se encuentra a unos 12 m. de profundidad, a través de esta galería sumergida de 40 m. de longitud, se llega a un lago en donde se encuentra la sala principal, ésta tiene 33 m. por 30 m. de ancho y 10 m. de profundidad. En el fondo se encuentran algunas formaciones litógenas.

Toda la galería principal o sala, se encuentra rellena en parte por una gran cantidad de bloques procedentes de la misma y en menor parte por el arrastre producido a causa de la fuerte erosión y las precipitaciones que afectan la ladera del cabezo que rodea la cavidad. En ésta no se puede apreciar ningún proceso cárstico importante excepto el producido por un pequeño relleno litogénico.

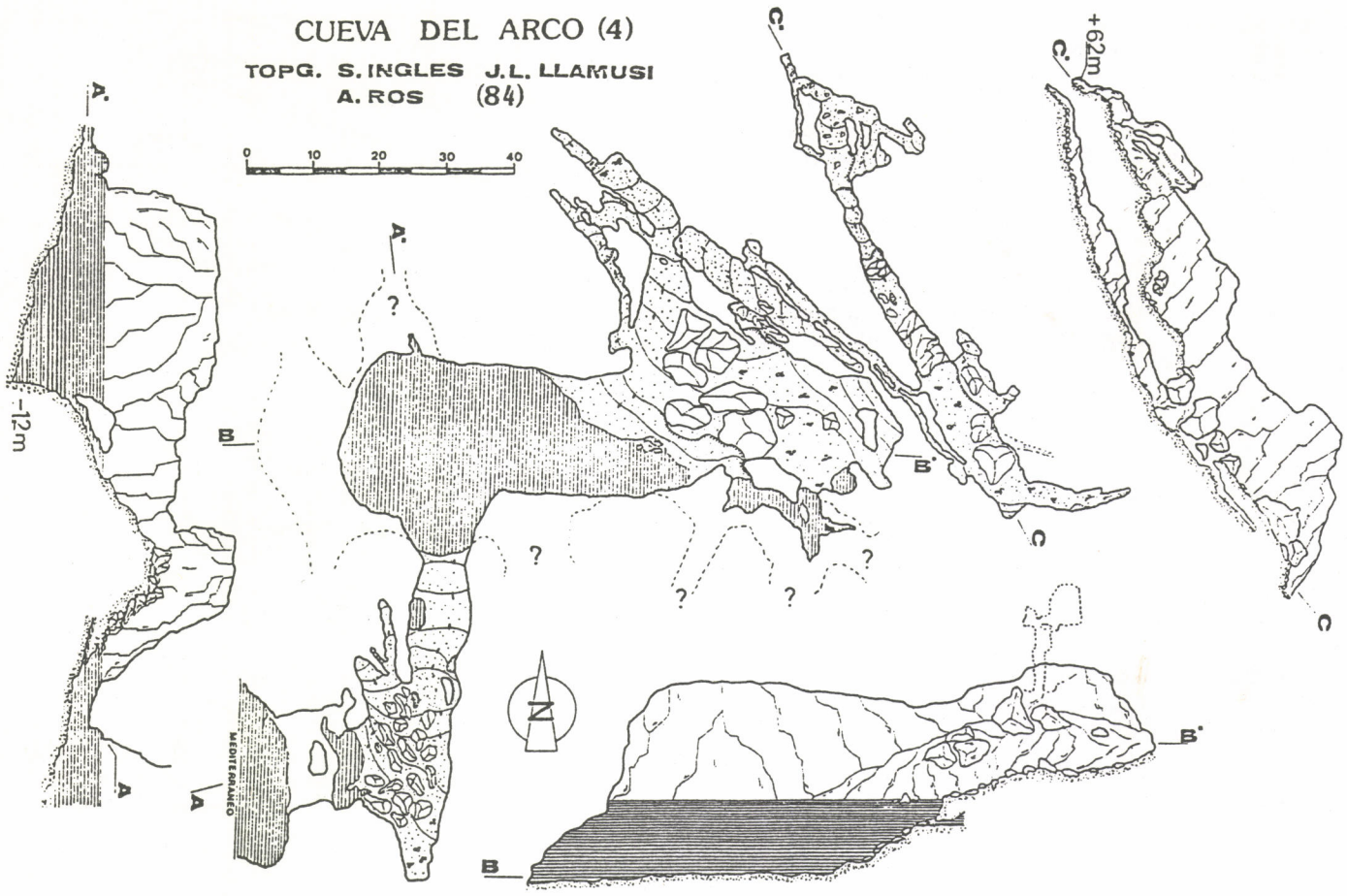
Cueva del Arco

Situada en las proximidades de Cabo Tiñoso a unos 20 Km. de Cartagena, de difícil acceso, siendo necesario el uso de embarcaciones, sus coordenadas son: Long. 01 °7'54'', Lat. 37° 33'30'' m.s.n.m. -2.

La cueva del Arco se encuentra bastante relacionada con la tectónica de la zona, desarrollándose en materiales del Manto Alpujárride Inferior, en calizas tableadas azules, y en contacto con otro tipo de calizas que fracturan esta zona considerablemente. El resultado es una red de galerías de origen tectónico, acentuada por una fuerte corrosión como viene siendo habitual en este litoral.

La entrada se sitúa al pie de un acantilado, a unos 2 m. de profundidad, con unas dimensiones de 11 m. por 3 m. de altura, tras sifonar unos 5 m. se llega a la primera sala, donde unas fracturas que la atraviesan en dirección WE. configuran la fisonomía de ésta, un gran relleno de bloques junto a una fuerte corrosión, crean una fuerte pendiente de 45°, que comunica con una fractura de dirección NS, de unos 50 m. de longitud, conduciéndonos a una gran bóveda de 30 m. por 19 m. por 80 m. de largo, con un lago de una profundidad de 12 m., ésta parece estar condicionada por una fractura en dirección NE. En el extremo de esta sala se encuentra un relleno de grandes bloques empotrados y en dirección NW., se desarrollan algunas galerías de 70 m. de longitud. En el lugar más alto de esta sala en dirección NW. se encuentran varias diaclasas que se comunican entre sí, creando una red de galerías de más de 100 m. de recorrido, en dirección SE. comunicando por varios pasos angostos con una falla de dirección NNW. de 100 m. de longitud y 7 m. de ancho por 10 m. de altura, a lo largo de éstas se puede observar un abundante relleno de bloques.

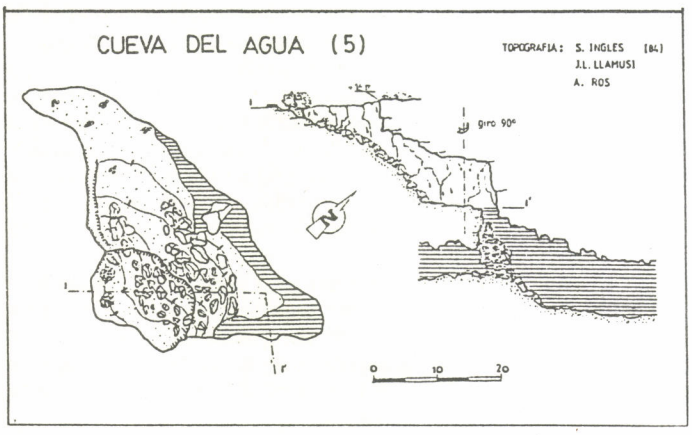
En la sala del lago y en su extremo oriental se encuentran una serie de galerias sumergidas de dirección NE. de más de 50 m. de longitud y de 15 a 20 m. de profundidad. Al Oeste del lago se encuentran otras pequeñas galerías sumergidas, algunas de ellas contienen un pequeño relleno litogénico en forma de estalagtitas a 4 m. de profundidad.



Cueva del Agua

Se encuentra situada a 23 Km. de Cartagena, en la localidad costera de Isla Plana, se accede por la carretera Azohia-Mazarrón, sus coordenadas son: Long. 01° 13'00'', Lat. 37° 34'40'' m.s.n.m. 16 m.

El hundimiento del techo de la única bóveda abre el acceso a la cavidad, un caos de bloques nos conduce a una plataforma rodeada por un lago, que cubre una gran parte de la sala. Una falla en dirección EW. y otra fractura, han dado origen a la única sala de esta cavidad, bajo el agua existen varias galerías en dirección NE. y SW, que se encuentran en período de exploración. El fondo del lago contiene un relleno de materiales procedentes de la corrosión de dicha cueva, con una potencia de varios metros. El lago llega a alcanzar una profundidad de 15 m. y las galerías sumergidas se ha llegado a explorar unos 30 m de longitud.



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Agradecimientos

Numerosas han sido las personas que nos han ayudado a realizar este trabajo, desde estas líneas agradecemos su colaboración a Concepción Perez Ros y a María Angeles Rodríguez Rincón, por su participación en las exploraciones y trabajos, también agradecemos la colaboración de la Concejalía de Cultura, Juventud y Deportes del Exmo. Ayuntamiento de Cartagena.

A study on the karst features of Sagada Luzon Island, Philippines

Gruppo Speleologico C.A.I. Verona; Società Speleologica Italiana

RESUM

El carts de Sagada (província de Montaña, illa de Luzón, Filipines) ocupa una superfície de 20 Km².

Aquest treball analitza les dades recollides durant l'última expedició italiana organitzada per la Federazione Speleologica Veneta. Facilitem el seu perfil geològic, hidrogeològic i morfològic i detbatim la possible evolució del carst.

RESUMEN

El karst de Sagada (provincia de Montaña, Isla de Luzón, Filipinas) cubre una superficie de 20 kms².

Este trabajo trata de los datos recogidos durante la última expedición italiana organizada por la Federazione Speleologica Veneta. El perfil geológico, hidrogeológico y morfológico están indicados y se debate la posible evolución del karst.

SUMARY

The Sagada karst (Mountain Province, Luzon island, Philippines), covers a surface of 20 sq. kms.

In this paper deals with the data collected during the last italian expedition organized by the Federazione Speleologica Veneta, the geologic, hydrogeologic and morphologic outline are given and a possible evolution of the karst is debated.

Introduction

This paper contains the data collected in the course of the recent caving expedition Sagada 85 organized by the Federazione Speleologica Veneta in the Philippines.

In the course of the expedition the system of cavities draining the extreme western part of the karst area has been explored; a test by means of tracers aiming at defining the hydrogeology of the area has been effected as well as a geologic survey of the tectonic structures which might interest the cavities.

The karst of the area had already been the object of research by Deharveng (1980) and a few years later by C. Mouret.

A very deserved note of thanks to M. Cotza and Valentina Reyes whose help has been determinant to the success of the expedition.

Geographic features

The karst area of Sagada (Mountain Province, Luzon) is situated in the Cordillera Central, a huge rocky chain longitudinally intersecting the northern part of the island of Luzon. (Fig. IA).

The karst area lies at about 17° north of the equator. The climate is tropical, wet, but mitigated by altitude, with heavy rainfall concentrated in the summer months. For Baguio (1,500 metres above sea-level) which is less than a hundred kilometres far, we have the following data concerning rainfall and temperature:

annual rainfall	Average annual temperature	average temperature minimum	average temp. maximum
4,597 mm	I7.9 °C	8.8°C	26.6°C

(from Dickerson 1920 in Deharveng 1980).

When typhoons occur, rainfall may be very heavy: at Baguio in 24 hs: 1,168 mm (see Dickerson).

The karst area of Sagada can be defined as a gentle sloping plateau which extends from north to south with heights ranging approximately between 1,600 and 1,100 metres above sea-level.

The carbonate outcrop, which has a surface of about 20 sq km, is delimited by the valley of the Amlusong creek in the north, by the Chico river in the west (fig. 1B) and by the steep valley of the Malitep creek. The Malitep partly receives water from the karst springs of Rolanagan and Ambasing whose waters flow in a large valley bordering on the western part of the karst area.

Contact between karst landforms and non, along the western side, is caused by an extensive tectonic fold that results in various hydrologic exchanges between the surrounding non-karst ridges and the karst area. The Bokon creek is the main water course whose waters are swallowed into the ground; it flows for about 3 km in parallel direction with the valley of the Amlusong (drained basin: about 6 sq km) and it runs into the Karst area north of Sagada. Other phenomena of this kind, i. e. waters sinking into the ground, occur in the so called Sagada amphitheatre, which is divided into several closed basins: in the south of this the first spring is to be found (Ambasing).

The karst plateau is longitudinally cut into two parts by the valley of the Tataya-an, the main element of the autochthonous hydrographic network. The valley is particularly rich in karst landforms in the southern part where huge layers of red earth can be seen together with dolines and swallow holes which continue in a linear regular pattern of remarkable karst forms. This pattern, which develops in the NW-SE direction first between the valley of Ambasing and that of Tataya and then along its bottom, is characterized at one end by Bokon swallow hole and at the other one by Balanagan springs 6 km far in the south.

The plateau section of Tataya valley has barely been explored; nevertheless it shows an interesting development of the surface hydrographic network together with a relative «lack» of surficial karstification.

Geologic Features

The outcropping carbonate rocks of the area have an extension of about 150-200 metres, as it results from an examination of the sections exposed on the plateau peripheric escarpment.

The prevailing lithotypes, probably dating back to the Miocene-Pliocene era, are sandstone, mudstone and limestone. The rock is divided into layers 2-3 metres thick. The limestone is followed by earthy lithotypes: first a seam of conglomerate about 15 metres thick and then marl beddings. They are certainly more than 50 metres thick but owing to the particular condition of their exposition, their thickness cannot be exactly determined.

The main stratigraphic problem emerging from the survey is the relation between the already mentioned formations and the soils of the surrounding relief, of earthy type, which are lacking in the karst area. Their thickness axceeds the 250-300 metres: the rock is arranged in strata, medium to coarse-grained, of more than a few cubic metres.

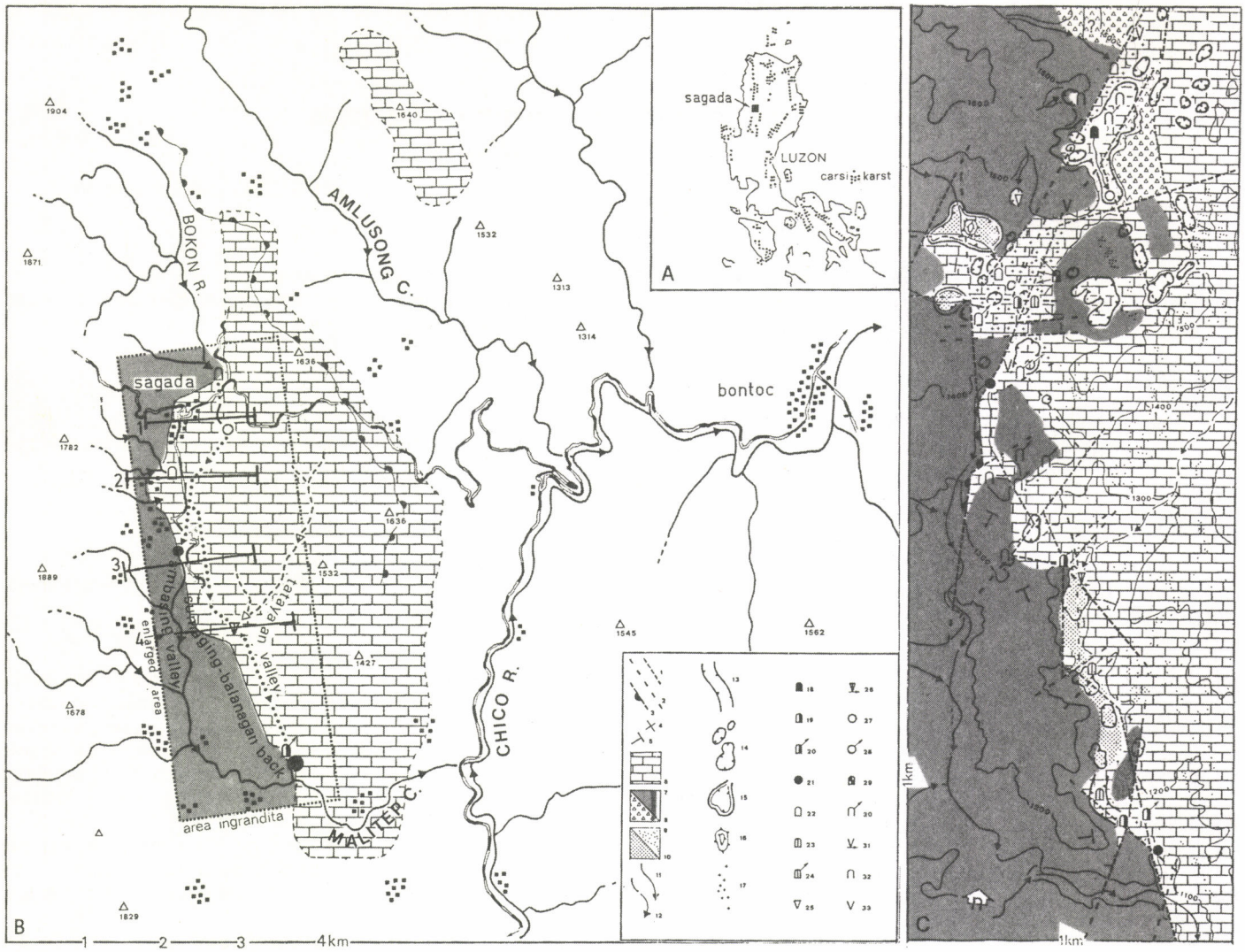


Fig. 1.

1) Fault
2) presumed fault
3) large escarpments and fault escarpments
4) Sub-horizzontal stratta (0-5)
5) inclined strata (6-25)
6) calcareous rocks
7) non calcareous rocks
8) Volcanic rocks
9) red earths
10) red earths in thick deposits
11) perennial stream
12) temporary stream
13) small canyon in calcareous rock
14) small dolines, dolines and uvala
15) karst plain
16) hum
17) karst pinnacles
18) perennial resurgence cave
19) temporary resurgence cave
20) idem connected to a perennial water-system
21) impenetrable perennial spring
22) perennial swallow hole
23) temporary swallow hole
24) idem connected to a perennial water-system
25) perennial steep-sided sink hole
26) temporary steep-sided sink hole connected to a perennial water-system
27) impnetrable perennial swallow hole
28) idem connected with perennial water-system
29) both resurgence and swallow hole cave
30) inactive cave connected with perennial water-system
31) inactive shaft connected with perennial water-system
32) cave with no water-circulation
33) shaft with no water-circulation

Unfortunately owing to the limited surface surveyed, to the problems resulting and the lack of bibliography, a detailed reconstruction of the tectonic features of the whole area has not been possible; therefore the exam of the structures directly interesting the karst system explored has been considered preferable.

The tectonic structure of the area is determined by important faults directed towards NNW-SSE.

The upright displacements, as far as the main faults are concerned, may range within a few hundred metres; nevertheless the exam of some fault plans points out the existence of remarkable shifting movements. The alteration pattern of the carbonate block is essentially plain: there seems to be no relevant folding structures as suggested by Deharveng 1980, but only local and modest undulations in the upper marl formations.

The carbonate outcrop is delimited, in the west, by a system of folds which directly affect the karst genesis of this part of the plateau, causing the limestone to come into contact with the surrounding impermeable formations. The latter define the karst area with the exception of short segments where the karst surface stands out from the surrounding grounds.

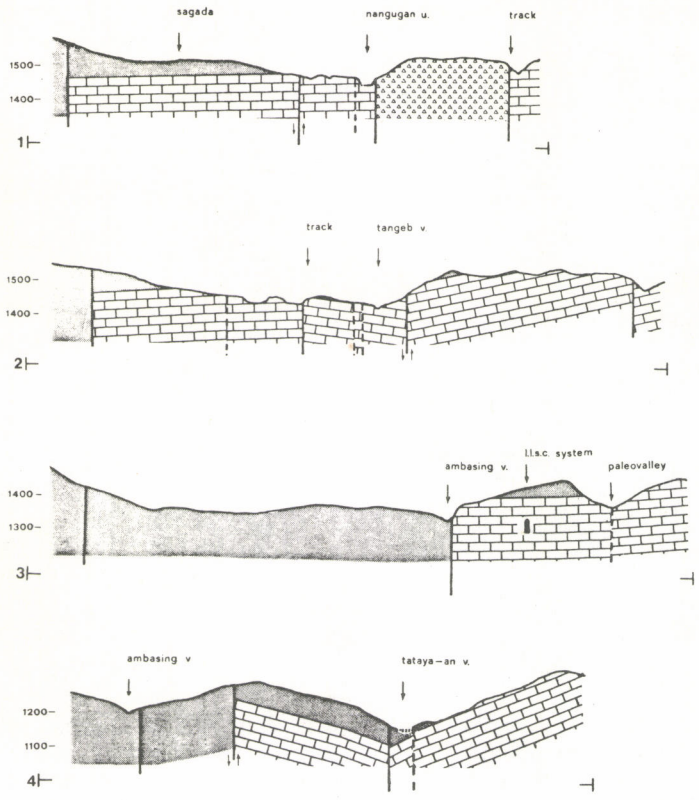
In the area of Sagada the main tectonic contacts are the result of fractures oriented towards NNW-SSW but the structure of the area is made more complex by the presence of faults joining to the previous ones. (Fig. 2, section I and 2). Some lines converge towards the spring of Ambasing south of which a faulted calcareous escarpment develops (fig. 2, section 3) which tends to decrease as one proceeds towards south.

A second important system of fractures joins to the already mentioned one at about 0.5 km south of Ambasing: it runs SE with frequent variations in direction, following for a while the river-bed of the valley of Tataya.

The region included between this system of fractures and the previous one is called ridge-line of Sumaging-Balanagan.

The pattern of the tectonic structure is various: for the area of Sagada sub-horizontal bedding planes prevail but a clear increase of dipping values occur in the area of Tataya and of the ridgeline of Sumaging-Balanagan. The two areas are divided by a sort of faulted escarpment which is made evident by the monoclinal pattern of the Tectonic units dips towards SW-SE in the direction of the bottom of Tataya valley (fig. 2, section 4).

East of the line of Tataya an, the Tectonic units plunge towards



west, with the consequence that the valley of Tataya an is included, at least in the southern part, in a sort of tectonic depression stretching away in the meridian direction.

Geomorphology and hydrology

The greatest density of karst landforms has been noticed in the section of the karst area situated in the north west. In this zone, as a matter of fact, lithological and structural conditions (such as frequent stratigraphical and tectonic contacts between lithotypes with different permeabilities and sub-horizontal bedding planes) have taken place which are particularly favourable to the development of surface landforms.

In the rest of the plateau the karst features connected with normal erosion stand out greatly from the point of view of morphology, but the surficial hydrographical network is inactive

In this context the epigeous karst formsare, as far as the north west area is concerned, poorer and more isolated: the factor that is the most unfavourable for their development is likely to be the monoclinal bedding having as result a series of sloping surfaces.

The karst area explored may be defined as divided into three sections each of them being characterized by a particular association of forms and whose limits coincide with meaningful Hydrographical or structural phenomena.

A) Area of Sagada

The area of Sagada is included between the blind valley of Bokong and the spring of Ambasing.

Hydrogeology:

The area is characterized by massive percolation phenomena (Bokon and «polje» of Denang): the drainage occurs along the fracture of the valley of Tangeb.

The spring of Ambasing provides water discharge out of the karst system, but the system of caves of Lomiang-Latipan-Sumaging-Crystal permanently receives the waters of a minor stream which is presumably situated in the valley of Tangeb.

Cavities:

The cavities of the area have generally a sub-horizontal development. Among these the furthest away in the north, Latan cave (Bokon swallow hole), consists of a vadose conduit about 35 metres deep and 10 metres wide that cuts up its way through the calcareous barrier situated between the valley of Bokon and the «uvala» of Nangugan. The highest level of massively concretioned galleries extends at about 20 metres under the karst surface. Along the valley of Tangeb numerous entrances of cavities open up: they are conected with the karst system of Bokon.

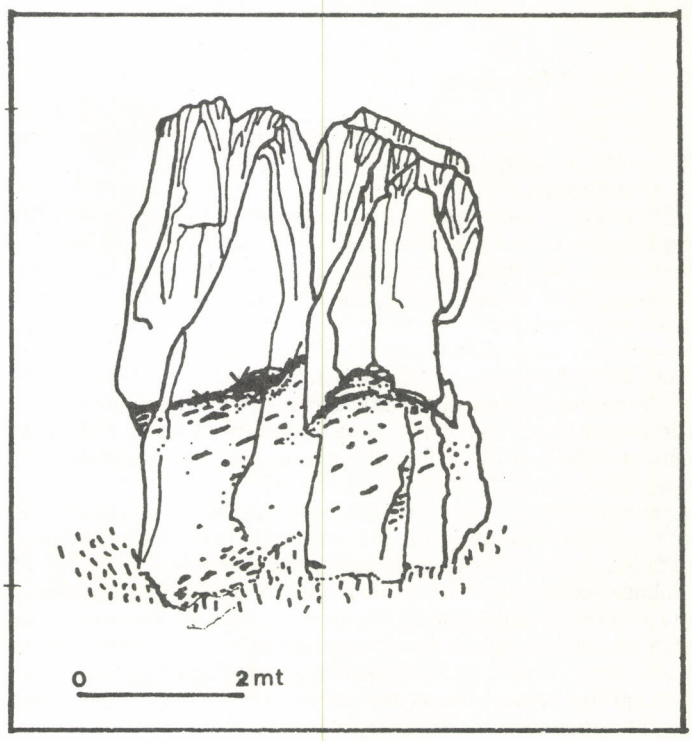
Proceeding from north to south the first opening is Lake cave (easily comparable to an estavelle), a «valcluse» spring sumping; then Tangeb cave II and a long segment of Tangeb cave collector. The caves developing a few metres under the bottom of the valley show elliptic sections or flat roof ones. Occasionally (Tangeb) the tunnels have collapsed. The seasonal fluctuation of the aquifer, which we may presume remarkable, would cause the cavity to have a phreatic development and, at the same time, would promote the formation on the surface of short flooding river beds joining together the entrances. In the southern part of the valley the flooding waters flowing out of an entrance of Tangeb are diverted from the cave of Sugong to the LLSC system.

Surficial landforms

The area of Sagada is characterized by numerous and various karstforms extending both on the surface and beneath the soil mantle. A major role is played by the karren fields (fig. 3) with isolated pinnacles and peaks or at the top of massive monoliths (fig. 1). They may be more than 10 metres high.

Among the frequent dolines of various size and shape some elements stand out as particularly important. The closed depression of Nangugan, immediately south of the valley of Bokon, is a form of fluviokarst origin. Its major axis, about 700 metres long, is constituted by a deep ravine through which the Bokon flows after passing through Latan cave. The widest point can be found in the north where a few dolines have coalesced. The depression is set in the middle of a network of fractures determining the contact, along the whole eastern side, between calcareous rocks and volcanic ones.

The basin of Sagada, where the village has been built, is a huge depression of structural origin, divided into four main basins with no outlets: the «poljes» of Demang in the west, the blind valley of Tangeb surrounding it in the east, and the doline of Lomyang southwards of Tangeb.



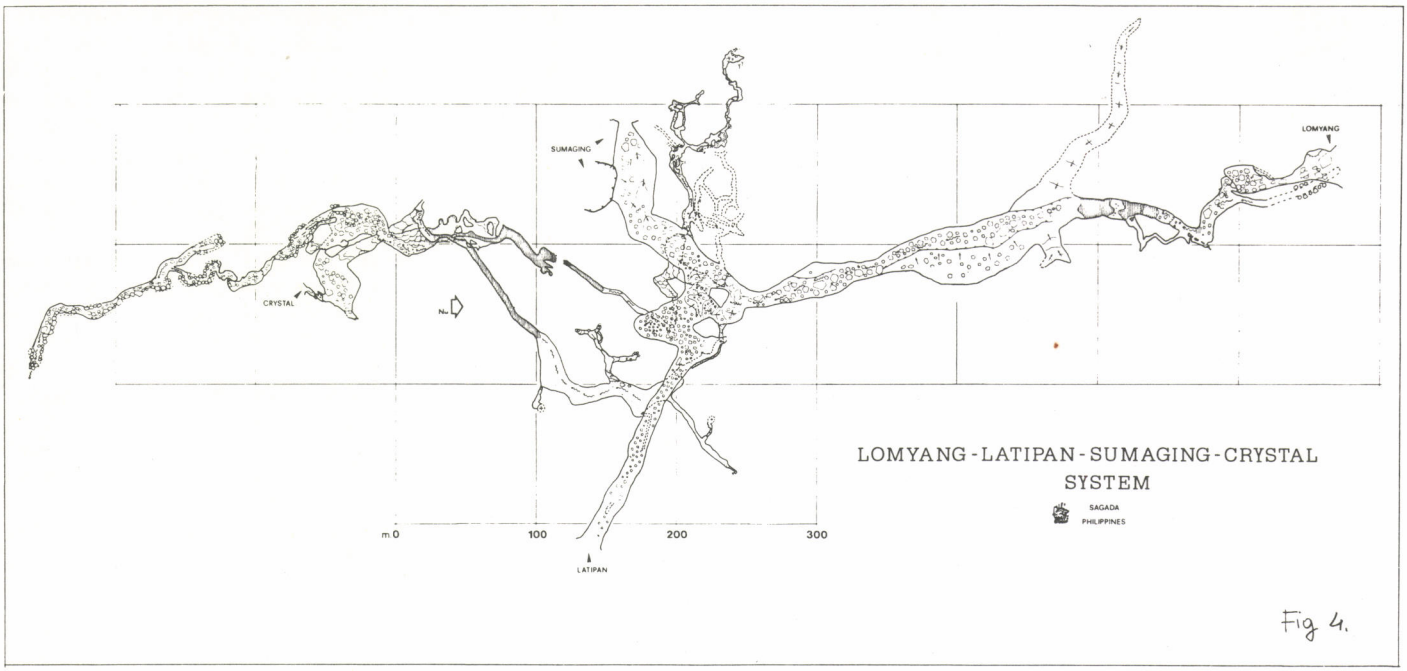


Fig 4.

The 85 % of the valley is delimited by impermeable rocks. The closed basins of Demang (more simply defined as «poljes») are two limited basins separated by a calcareous ridge with large dolines; the northern «polje», which is larger, is also the most irregular and is characterized by a small hum. A modest ridge separates the «poljes» from the valley of Tangeb which develops in a network of fractures between the depressions of Nangugan northwards and the dolines of Lomyang southwards.

The topography of the valley, extremely uneven, is characterized by rocky walls, boulders and many karst landforms such as peaks, small natural bridges, swallow holes and the entrances of the mentioned cavities.

The doline of Lomyang is the most southwards among the depressions of the valley of Sagada. The shape is elliptical, with rocky valls forming an amphitheatre with no outlet in the south, while the side northwards is less steep. Its major axis, which is not practicable, extends for about 300 metres while its depth below the swallow hole draining it, is of more than 70 metres. Beyond the western side of the doline the spring of Ambasing flows out of an impressive mass of collapsed rocks.

B) Area of Sumaging

It extends between the doline of Lomyang in the north and the valley of Tataya an.

Hydrogeology:

In this area water circulation occurs within the system of LLSC caves. The remarkable dilution of the tracer which, differently from the strong colouring obtained in the spring of Ambasing, could not be detected with the naked eye, points out an increase in the hydrogeologic basin. The LLSC system, necessarily set towards the east, represents without any doubt the deepest and most diversifield hypogean system in the karst area (development 3.700 metres, depth about 200-205 metres). The main axis is constituted by a Cyclopean gallery that are never less than 20 metres wide and 30-40 metres high, in which the underground river flows among huge boulders (fig. 4).

Northwards the gallery bifurcates: an active passageway runs in the direction of the doline of Lomyang, a concretioned inactive passageway with a steep slope goes towards the spring of Ambasing. In the extreme south the gallery divides into four levels: the nearest to the surface (Sumaging, Latipan) lead up to as many entrances, while the others link up to the farthest cavity (in the south direction) of the system: Crystal which is practicable through the upper level as the active gallery sumps after a few hundred metres.

Morphologically speaking, Crystal can be divided into two sections: two large chambers present a prevailing clastic morphology, the clastic debris often consisting of more than a thousand cubic metres in the lower chamber at the extremities of which, northwards and southwards, the active galleries start.

The northern gallery out of which the water is discharged presents phreatic conduits in good conditions, while the gallery opening southwards is blocked by collapsed boulders.

The most interesting lithogenic phenomena in the LLSC system are the big gours and the stalactites in Crystal.

Surficial landforms

South of the doline of Lomyang, affected by the same, a paleovalley develops (1,410 metres above sea-level) in the SW direction and it is delimited westwards by a marl ridge: there, immediately below, lies the LLSC system. A large collapse doline dominates the southern part of crystal cave. The doline, the paleovalley and the entrance of Lapitan lie on the escarpment that structurally delimits the karst area with sub-horizontal bedding planes. Instead the entrance of Sumanging opens up on the valley of Ambasing.

C) Area of Tataya an valley

Hydrogeology:

From a lithologic and hydrogeologic point of view, the karst area up to the valley of the Malitep is bordered by the ridge line of Sumaging-Balanagan, where a marl cover is still present. The water circulation occurs along the faults of the valley of Tatayan, inside the important system of cavities formed by Dialeò an Balanagan cave. The latter is the southern spring of the karst area and its main entrance discharges only during the rainy season. In low water periods the water outflows through nearby impenetrable springs.

Cavities:

At the base of the escarpment a few small cavities with stagnant water are probably the result of an overflowing of the waters from the LLSC system. The most important cavities are Dilaeò Cave and Balanagan both fed by the LLSC system.

The main entrance of Dileò consists of a 40 metres shaft in the middle of which there is a small hanging lake embedded in a pot-hole. Below the shaft, which takes in a temporarily active stream, two subhorizontal galleries open up, perennially active: the northern gallery out of which the water comes, is of a small

size and it gets narrower and narrower when proceeding towards the terminal sump. Instead the southern branch is characterized by impressive galleries and large chambers with long sumping lakes. Here three affluents innest: they are rather small if compared to the main gallery and they receive the waters of the streams coming from the ridge line of Sumaging-Balanagan. A fourth gallery, labyrinth-shaped, develops eastwards near the terminal sump of Dilaeò presenting large clay deposits.

The main entrance of Balanagan Cave (other minor ones open on a wide rock wall) is situated at about 1,100 metres above sea-level. The cave can be defined as consisting of two well separate areas: a first inactive section formed by numerous galleries leading to the secondary entrances which are higher than the main one, and a second section formed by a large gallery morphologically similar to the collector of Dilaeò towards which it proceeds and of which it is a southern development. Said gallery has large sandbeds lying among long lakes. The gallery develops for a long section which is opposite to that of water circulation.

In the low-water season the underground river is drained, in the lower levels, by small conduits.

The whole system of Dialeò an Balanagan show forms and developments which are mainly phreatic.

The area of Tataya an valley taken into account is divided into four main depressions sinking down into consistent deposits of red earth which have undergone a deep erosion in proximity to the most northern and southern dolines. The dolines situated in the north are drained by the two known entrances of Dialeò Cave and are divided by a rocky surface situated in proximity to an evident narrowing of the valley. The usually flat bottom of the valley is enclosed in the south by a modest mountain ridge beyond which a short canyon starts and flows into the Malitep creek. On the left side in a large rocky walls there are the entrances of Balanagan Cave.

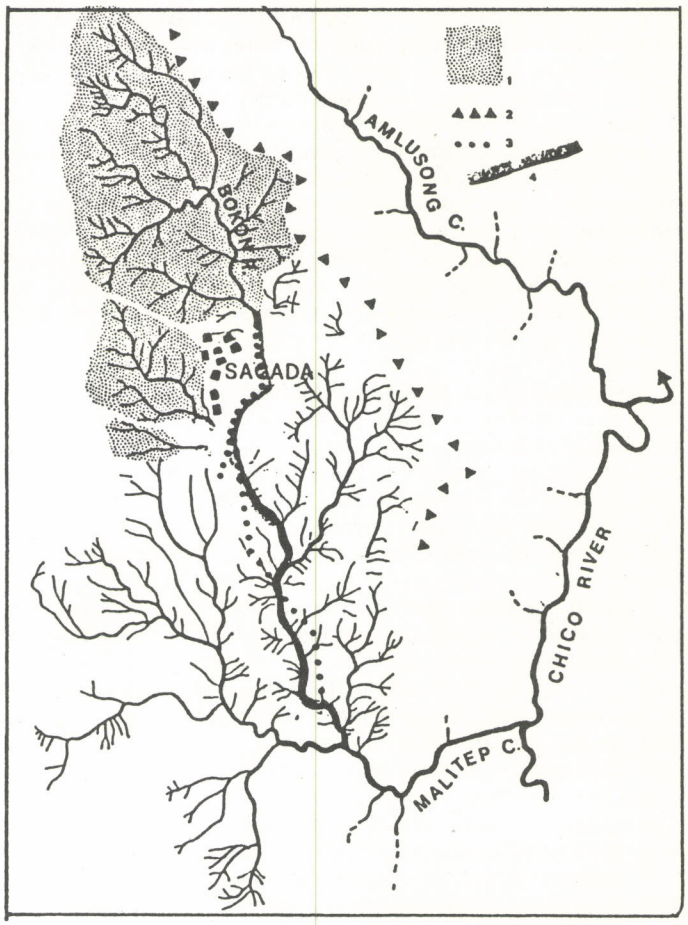


Fig. 5.

1) hydrographic basin of allogenic streams swallowed
2) outer escarpment of plateau
3) course of underground river
4) surficial paleo-course of the Bokon

Considerations on the karst development.

The actual environment of the karst area insofar described has been largely determined by the evolution of the surficial hydrographical network under a strong lithological and structural control. As far as the karst area is concerned, the impermeable marl mantel has been determinant to the development of the hydrographic network and to the location of the first swallowing points.

The removal of the impermeable surfaces has implied a gradual functional reduction of the hydrographic network; in the same way new calcareous surfaces have been exposed determining a consequential rearrangement karst network.

In the karst area a dispersion of the sinkholes has generally taken place with the exception of the western section steadily water-supplied by allogenic streams.

In this area, as a matter of facts, the most important karst forms are found and they are evidently in relation with the rivers which have been swallowed up and, in particular, with the Bokon.

There is good evidence for the Hypothesis of a paleokarst extending on the karst surface out of which the various forms might have developed by leakage during the removal of the marl cover (fig. 5). The most convincing evidence is provided by the paleovalley of «Lomyang» which has no relation with the present topographic environment. Further in the north, the depression of Nangugan is separated from the valley of Tangeb by a clearcut steep ridge very difficult to reach from the surrounding uplands but very likely to correspond to an old and very damaged section of the valley.

Another interesting datum is constituted by the upper planes of Latan which, owing to the fact that they are situated at about 15 metres from the calcareous surface, give evidence of a lowering of the circulation level of about 40 metres. The altitudes referring to the mountain ridge of Laten and of the upper planes (1490 and 14), to the ridge between Nangugan and Tangeb (about 1490) and of the paleovalley (1410) are compatible if the possible mi stakes due the cartographic base used, are taken into account.

According to this hypothesis, the paleo Bokon would flow through the area where presently Nangugan is set, running down along the eastern side of the valley of Sagada later joining the valley of Tataya an.

A detailed and reliable reconstruction of the speleogenetic stages following to the karstification of the paleoriver seems to be rather difficult; nevertheless it is possible to define at least the evolution of the area. (fig. 6).

Fig. 7 represents a N-S cross section explaining the main structural, functional and morphological elements connected with the Bokon network.

After an exam of the figure, the following points may be observed:

a) the poor gradient of the underground collector of the Bokon in the section between the swallow hole and Ambasing: it is interesting to note how high the flowing level is as regards to the doline of Lomyang and how the doline itself seems to «swallow» it up;

b) the lowering undergone by the collector in proximity to the escarpment of «Tataya» which is determinant to the development of deep vadose galleries and various levels of conduits among which the paleo-resurgences of Sumanging and Latipan;

c) the poor gradient in the southern section of the karst area. If these elements are taken into account, it is possible to assume the following course of karstgenetic stages which will have to be carefully checked in the future:

1) Development of a network of channels due to leakage in the section Nangugang-Tangeb which supplied water to the LLSC system through the northwest branch and probably through Lomyang Cave. The waters would flow down out of the Karst system through Sumaging Cave, which might have been a paleo-resurgence of the «vaucluse» type.

2) Opening of Latipan resurgence, due to the water attraction exerted by the morphological and structural depression of Tataya in proximity to the escarpment. Vadose deepening of the LLSC system and development of Lomyang doline.

The southern part of the karst area, whose development partly depends on the autochthonous hydrographic network, shows little relation with the previous one. Desintegration through ages and fossilization under thick layers of soils make the southern part of Tataya an valley determinant to understand the development of the Dilaeó-Balanagan system. The steep-sided sinkhole of Dialeò is likely to have been the main water swallowing point of the system up to the removal of the impermeable cover of the karst area and up to the complete karstification of the Bokon system.

The rather simple structure of the system points out on one hand an uninterrupted water circulation inside the presently active conduits of phreatic type, on the other hand the setting up of a recent vadose circulation subsequent to the opening of passageways which cut off the long upward branch of the system.

So far there has been no reference to the spring of Ambasing because it implies particular problems which will be analyzed as follow:

in what has been said up to now, it has been assumed that the development of the first cavities took place by leakage of the paleoriver in the section Nangugan-Tangeb.

Apart from the numerous morphological and hydrogeological complications the area presents, which, yet, do not seem to change the interpretation as regards essentials, the water circulation is likely to have already settled down, in this phase, inside the cavities active at the present time (Tangeb and partly Agoyo Ige): said cavities would supply water to the LLSC system through the north west branch and, maybe, Lomyang.

The altimetrical position of the cave excludes all possibility of a karst capture in the paleo-valley section of Lomyang as it is situated well below the highest points of the conduits; yet, as the spring of Ambasing is located between the cave of Agoyo Ige and the north west branch of LLSC at a slightly inferior altitude, a hydrological connection between the two caves is not consistent with the present environment.

The most probable solution to the problem is likely to be a relatively recent origin of the spring, subsequent to the already mentioned cavity.

The spring lies in a tectonic unit at which numerous faulting lines converge: some of them are associated with strongly disturbed points and extraordinarily developed rock-collapse (Tangeb Cave, Ambasing spring, Crystal Cave) which may be justified assuming a neo-tectonic origin of the phenomenon.

The neo-tectonioc activity is, moreover, supported by the geodynamical outline of the region and, locally, by other

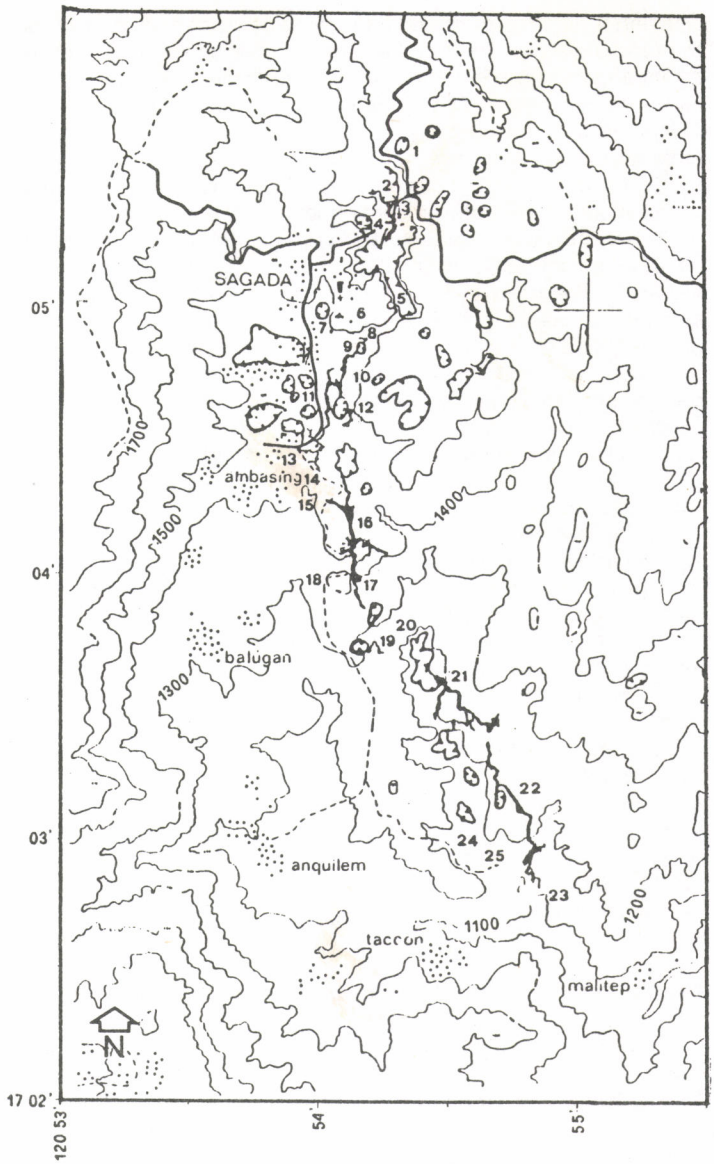
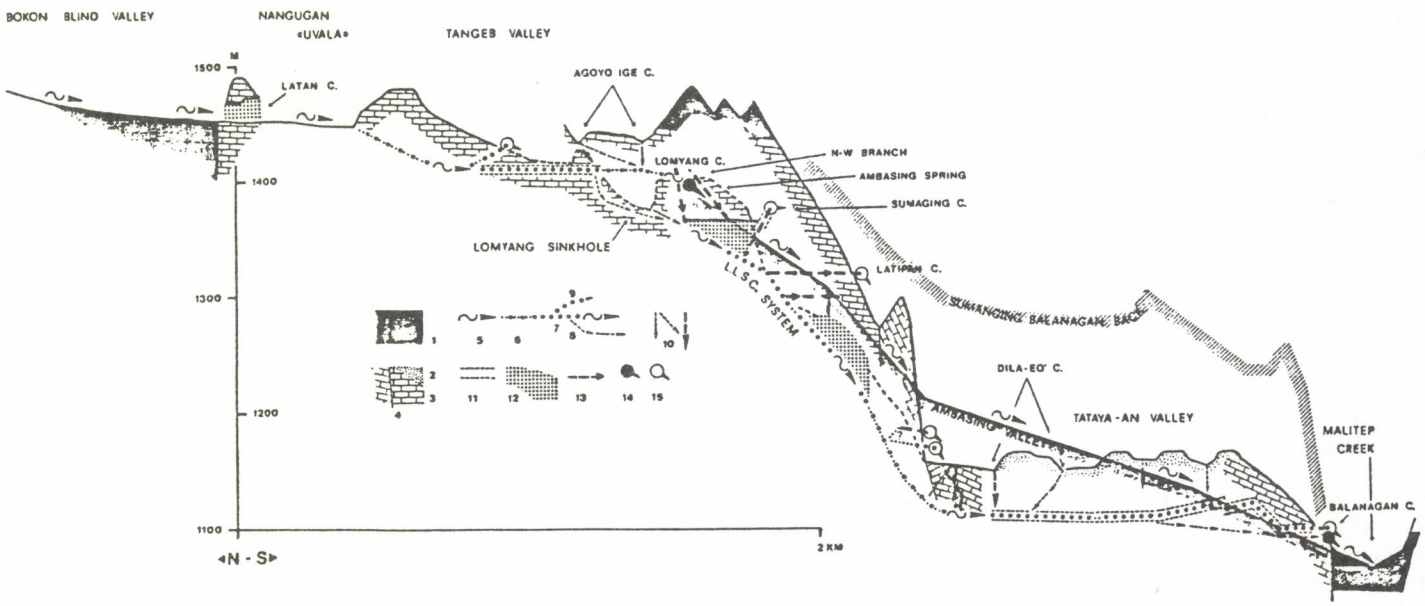


Fig. 6.

Topography of karst area and cavities explored
2) Latan Cave, 8) Lake Cave, 9) Tangeb IIº Cave, 10) Tangeb Cave, 12) Sogong Cave, 16-17) Lomyang-Latipan- Sumaging-Crystal (LLSC) system, 21) Dila-eò Cave, 22) Balanagan Cave, 23) Balanagan Springs



indications such as, for example, the isodeflection of stalactites in Crystal Cave.

Further observations will, anyway, be needed.

Conclusions

As agreed by Deharveng (1980), it is rather difficult to describe the karst of Sagada as a unitary system.

As a matter of fact, only the section of plateau situated N-W shows a tropical morphology, characterized by large dolines and now and then chaotic development: instead the remnant of the karst area has much in common with some Mediterranean karst landscapes.

Inactivity and partial fossilization seem to be hereditary characteristics of the surficial landforms in this area; on the contrary in the N-W area and in the cavity systems there is a remarkable morphologic dynamism together with a general renewal of erosion, as supported by new erosion of surface deposits (the coastal plaines of Nangugan depression, the dolines in the valley of Tangeb and of Tataya an) and of underground deposits (Latan Cave, LLSC system, Balanagan Cave, etc...)

The lack of climatological and paleo-climatic data accounts for the difficulty in deciding to what extent the karst morphogenesis may be affected by climatic, lithologic and structural factors, even if they have certainly played a very essential role.

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Styles of karst landform development in limestones and domolites of the northern Mackenzie Mountains, Northwest Territories of Canada.

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RESUM

Podem trobar un carst perfectament desenvolupat a 64º–66º N, a les Muntanyes de Franklin i Mackenzie. Les temperatures mitjanes anuals són de l'ordre dels 6º als 12º C i la mitjana de precipitacions anuals se situa entre els 250 i 500 mm. Aquesta zona presenta un permafrost discontinu. Les roques càrstiques són:

1) Dolomies massives de plataforma (Ordovícic–Silúric), seguides de

2) megabretxes de dolomies cimentades amb anhidrita (Devonià)

Els estils del paisatge càrstic varien segons la litologia, l'estructura, la topografia i el caràcter recent de l'última glaciació severa. Comprenen dolines càrstiques, «dallage» i gorges càrstiques, un carst genuí amb formes de dissolució, interestrats i un polje format per una morrena de contenció.

RESUMEN

El Karst se ha desarrolado bien a 64º–66º N en las Montañas Franklin y Mackenzie. Las temperaturas medias anuales son de – –6º a – 12º C, y las precipitaciones medias anuales se sitúan entre los 250 y 500 mm. En esta zona existe un permafrost discontínuo. Las rocas kársticas son:

1) las dolomías masivas de plataforma (Ordovicico–silúrico) seguidas por

2) megabrechas de dolomías cementadas por anhidrita (Devónico).

Los estilos del paisaje kárstico varían según la litología, la estructura, la topografía y el carácter reciente de glaciación severa. Incluyen dolinas kársticas, dallage y desfiladeros kársticos, un notable karst con disoluciones, interestratos y un poljé creado por una morrena de contención.

RÉSUMÉ

Le Karst s'est bien développé à 64 – 66º N dans les montagnes du Franklin et Mackenzie. Les températures moyennes annuelles sont de – 6º a –12ºC. Et les précipitations moyennes annuelles se situent entre 250 et 500 mm. Il y existe un permafrost discontinu. Les roches karstiques sont:

1) des dolomites massives de plateforme (ordovicien – silurien) suivies par

2) des mégabrèches de dolomites cimentées, par de l'anhydrite (Dévonien).

Les styles du paysage karstique varient suivant la lithologie, la structure, la topographie et le caractère récent de glaciation sévére. Ils incluent des dolines karstiques, des dallages et couloirs karstiques, un remarquable karst drapé de dissolutions intrastrates et un poljé créé par une moraine endigante.

Karst landforms are well developed in ranges of the Franklin Mountains and Mackenzie Mountains between 64° and 65° 1/2 N and at altitudes of 300 to 2000 m. The most important host rocks are 1) Ronning Group, > 1000 m of thick–massive, well bedded dolomites of Ordovician–middle Silurian age, disconformably overlain by 2) the Bear Rock Formation, 100-300 m of poorly cemented dolomite mega–breccia with anhydrite. This is of middle Devonian age and is succeeded by 3) 60–100 m of well bedded limestones (Hume Formation).

Very different suites of karst landforms have developed on these strata, reflecting effects of lithology, mountain topography and the recency and intensity of glaciation. Bear Rock and Mackay Range are isolated massifs in the mega breccia that were fully glacierised during the Late Wisconsin (main Wurm) Glaciation. They display big, ice–moulded, sinkholes. Bonus Lake Karst is a partly drowned, corridor or giant bogaz terrain in Hume and Bear Rock strata. Adaptation by Wisconsin ice margin rivers is suggested.

Carcajou Karst is a draped topography resulting from intrastratal solution of the Bear Rock where it is in a hydrogeologically perched situation above canyons cut in Ronning Group strata. Four successive stages of draping are represented by systematic zonal change in the landforms. Dodo Pavement is very massive solutional pavament on the Ronning dolomites that is probably older than the Wisconsin Glaciation. It is very extensive. Finally, at Keele River a terminal moraine has dammed a large valley in a syncline formed in all these rocks, creating a glacial polje. This displays classical polje hydrologic features (seasonal inundation, estavelles, sub–polje caves, etc.) and marginal corrosion that has created a few karst hums.

All of these features have developed in a mountainous region of discontinuous permafrost where mean annual temperatures range -6 to -12° C and precipitation is between 250 and 500 mm.

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Karst of the Karhantau Ridge (Western Tchien-Shan USSR)

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RESUM

La Serra de Karzhantau, una part marginal de les muntanyes del Tchien-Shan occidental, al sud de Kazakhstan, està construïda per una seqüència carbonatada fortament tectonitzada del Carbonífer Inferior. El seu relleu és morfològicament diversificat, entre els 2.600 m. i els 2.900 m. sobre el nivell del mar, amb nombrosos engolidors, depresions càrstiques, serralades i amb una formació de tipus polje disseccionada per un profund «cañó». Les cavitats horitzontals són rares, els avencs, en canvi, són freqüents (Uluchurskaya, -350 m.). Les característiques del carst són el resultat de, com a mínin, tres fases en el procés de carstificació: 1) Cretaci, amb l'origen dels relleus de tipus cúpula. 2) Miocè i Pliocè, amb una lenta i contínua elevació de la zona. Origen del polje, del sistema de cavitats horitzontals, etc. 3) Quaternari, amb ràpides elevacions del terreny, moviments neotectònics, glaciacions i inici de la circulació vertical de carst profund. Les fases de carstificació estan íntimament relacionades amb el desenvolupament geotectònic i geomorfològic de la zona.

RESUMEN

La Sierra de Karzhantau, una parte marginal de las montañas de Tchien-Shan occidental en el Sur de Kazakhstan está constituida por una secuencia carbonatada fuertemente tectonizada del carbonífero inferior. Su relieve es morfológicamente diversificado 2.600 a 2.900 m. sobre el nivel del mar, con numerososo sumideros, depresiones kársticas, cordilleras y una formación de tipo polje diseccionada por un profundo cañón. Las cavidades horizontales son raras, las simas frecuentes (Uluchurskaya-350 m.). Las características del Karst resultan por lo menos de tres fases de karstificación: 1) Cretácico con el origen de los relieves de tipo cúpula, 2) del Mioceno al Plioceno con el lento y contínuo levantamiento de la zona y el origen del polje, sistema de cavidades horizontales, etc. y 3) Cuaternario durante el rápido levantamiento, movimientos neotectónicos y glaciaciones con el origen de la circulación vertical de karst profundo. Las fases de karstificación están estrechamente relacionadas con el desarrollo geotectónico y geomorfológico del área.

SUMMARY

The Karzhantau Ridge, a marginal part of the Western Tchien-Shan Mountains in the southern Kazakhstan is built of highly faulted Lower Carboniferous carbonate sequence. Its relief is morphologically diversified, 2,600 to 2,900 m asl. with numerous sinkholes, karst depressions, ridges and a polje-like form dissected by deep canyon. Horizontal caves are rare, chasms are common /Uluchurskaya-–350 m/. The karst features are results of at least three karstification phases: /1/ Cretaceous with the origin of cuppola-shaped relief, /2/ Miocene to Pliocene with the slow and continuous uplift of the area and the origin of polje, horizontal cave system, etc. and /3/ Quaternary during the quick uplift, neotectonic movements and glaciations with the origin of vertical deep karst circulation. The karstification phases are closely connected with geotectonic and geomorphological development of the area.

Speleogenesis of the Rio Grande karst of Belize

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RESUM

Una nova cavitat principal i una regió càrstica es troba actualment en estudi, als vessants meridionals de les muntanyes Maia de Belize. Es tracta de sediments no carbonatats i metasediments que contenen intrusions porfíriques i granítiques. Un excedent de 500 cm. de precipitació cau sobre les vessants recobertes de selva, la qual és drenada per rius alòctons agressius, el més gran dels quals és el Río Grande, de Colúmbia, que posseeix vàries seccions amb corrents subsuperficials. En aconseguir la plataforma de calcàries cretàciques que formen la regió càrstica de Río Grande, l'aigua és engolida ràpidament per a sorgir de nou en la zona de contacte amb els sediments costaners. S'han format extensos sistemes de cavitats amb conductes enormes degut a aquest paisatge particular, sobretot a las calcàries terciàries del veí Yucatan. S'han topografiat conductes que superen els 20 m. d'amplada i els 30 m. d'altura durant vàries milles. Una gran cavitat que supera els 30 m. d'altura i els 70 m. d'amplada i amb 200 m. de longitud ha estat descoberta a Tulz (cova del Tigre). S'estan duent a terme, normalment, diferents estudis hidrològics per a conèixer les taxes del model d'erosió del carst.

RESUMEN

Una nueva cavitad principal y una región kárstica está siendo estudiada en las vertientes meridionales de las montañas Maya de Belize. Se trata de sedimentos no carbonatados y metasedimentos conteniendo intrusiones porfiríticas y graníticas. Un excedente de 500 cm de precipitación cae sobre las laderas recubiertas de selva y es drenada por ríos alóctonos agresivos, el mayor de los cuales es el Río Grande de Columbia que posee varias secciones con corriente subsuperficial. Al alcanzar la plataforma de calizas cretácicas que forman la región kárstica del Río Grande, el agua se sume inmediatamente y reemerge en el contacto con los sedimentos costeros. Se han formado extensos sistemas de cavidades con conductos enormes debido a este paisaje particular, la gran mayoría de lo cual se da en las calizas terciarias del vecino Yucatán. Conductos que superan los 20 m. de anchura y 30 m. de altura se han topografiado durante varias millas y una gran cavidad que supera los 30 m. de altura, 70 m. de anchura y 200 m. de longitud ha sido encontrada en Tulz (= Cueva del Tigre). Se están llevando a cabo normalmente estudios hidrológicos para conocer las tasas del modelo de erosión del karst.

SUMMARY

A major new cave and karst region is being studied on the southern slopes of the Maya Mountains in Belize. The mountains are noncarbonate sediments and metasediments containing porphyritic and granitic intrusions. In excess of 500 cm of precipitation falls on the jungle clad slopes and runs off in aggressive allogenic rivers, the largest of which is the Rio Grande de Columbia which has several sections with subsurface flow. Upon reaching the Cretaceous limestone platform forming the Rio Grande Karst Region, the water immediately sinks and re-emerges at the contact with coastal plain sediments. Extensive cave systems with enormous conduits have formed because of the particular landform assemblage; far in excess of what has occurred in the Tertiary limestones of neighbouring Yucatan. Conduits in excess of 20 m wide and 30 m high have been mapped for several miles and one large cavity in excess of 30 m high, 70 m wide, and 200 m long has been found in Hich Tulz (= Tiger Cave). Hidrologic studies are currently underway in order to model the karst erosional rates.

Introduction

Much cave and karst research activity has been ocurring in the Central American country of Belize. Recent expeditions have been organized by Tom Miller to the Chiquibul River area of the Vaca Plateau on the north side of the Maya Mountains (Miller, 1981; Miller, 1983; Weintraub, 1984), and by the author of this paper to the Rio Grande area on the souther slopes of the Maya Mountains (Dougherty, 1985; Szukalski and Dougherty, 1985). Fieldwork in 1984-85 in the Rio Grande Karst shows this area to be a world-class cave and karst region, both physically because of the immense dimensions of the conduits and culturally because of the Mayan artifacts and human remains found there. This paper concentrates on the physical aspects of the landscape and why there has been such and extraordinary development of karstification.

Location

Belize, an independent country about the size of New Jersey, is located on the eastern coast of Central America in the southeastern portion of the Yucatan Peninsula (Figure 1). To the north is Mexico with Guatemala to the west and south. To make matters more interesting, Guatemala claims Belize as part of its national territory and has threatened to invade it several times. This territorial claim stems from Belize being a former British

FIGURE 1. Location of Belize in Central America

colony which was maintained by a military presence. Although Belize became an independent country in 1981, there are still British troops stationed there to avoid and imminent invasion by Guatemala.

Physical geography of southern Belize

The most interesting aspect about the physical environment is the development of caves and karst. This is caused by a combination of factors including the tropical rainforest climate, large areas of limestone, relief caused by deformation along two crustal plates, and large amounts of water running off noncarbonate rocks into limestone. Passages of up to 18 m wide and 30 m high are not uncommon, and gigantic rooms form at passage intersections or where wide meanders have undercut the walls.

The subject of this study is the Rio Grande Karst which is located in the southern part of Belize on the southern slopes of the Maya Mountains, the highest landform assemblage in the country with elevations of up to 1300 m (Bateson and Hall, 1976). The climate is classified as Af, tropical rainforest, which means that every month has an average temperature above 18° C and a monthly rainfall above 6 cm. In reality most of the area receives over 381 cm of rain per year because of its location in the intertropical convergence zone during the high sun period of June to October. The resulting trade winds blow from the Caribbean Sea onto the land and are orographically uplifted by the Maya Mountains. Rainfall totals at the Toledo weather station for these months are: 55.6 cm, 76.6 cm, 61.3 cm, 46,8 cm, and 29.2 cm (Wernsted, 1972). The dryer period of the year and the best for cave exploration is from February to April for which the precipitation totals are respectively: 6.9 cm, 10.8 cm, and 7.2 cm. The dyer period occurs during the low sun period when the intertropical convergence moves south and is replaced by the savanna conditions which are caused by the subtropical high moving into the area. Even with the great yearly total of precipitation, the area has the characteristics of a much direr area because of the thin, rocky soils and the rapid disappearance of the runoff into the karst conduits. Although the vegetation is jungle and selva, there is an abundance of thorny species indicative of a drier climatic condition.

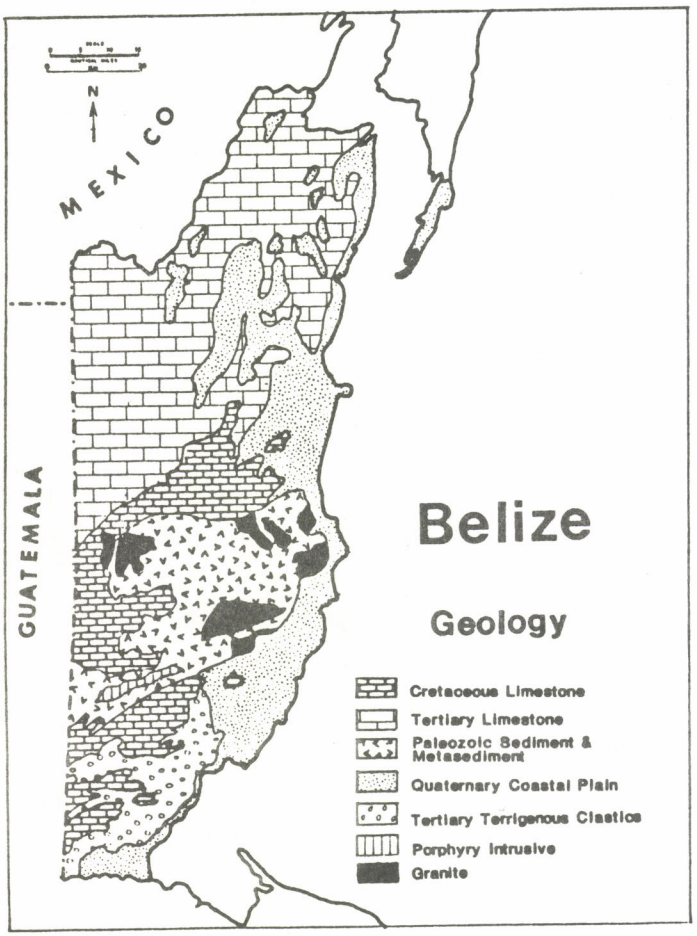

FIGURE 2. Geology map of Belize

Geologically, the area has an ideal environment for the formation of caves. On figure 2, the geologic map of Belize (after Wantland and Pusey, 1975), note that the southern interior of the country is composed of old metamorphosed sediments with granite and porphyry intrusions collectively forming the backbone of the Maya Mountains. These old Paleozoic rocks are fringed by younger Cretaceous limestones, the same condition existing in both the Rio Grande and Chiquibul River karst areas. Further from the highlands one finds a belt of Tertiary limestones that compose the bulk of the Yucatan Peninsula, except south of the Rio Grande Karst where one encounters younger Tertiary terrigeneous sediments and the coastal plain (Bateson and Hall, 1976).

Speleogenesis and karstification

Recent reports have shown that the areas on both the north and south sides of the Maya Mountains contain very large cave rooms and trunk passages. The large chambers in Actun Tun Kul and Hich Tulz are two of the largest in the world. This is in contrast to the karst areas of neighboring Yucatan where the caves are usually smaller and shallower. Southern Belize has several reasons why the caves and karst are much better developed. These include: 1) the great amount of precipitation falling here because of the orographic effect of the Maya Mountains, 2) the greater relief provided by the Maya Mountains and the platforms of Cretaceous limestone fringing the mountain chain, and 3) the more agressive runoff coming from the Maya Mountains.

The geographical arrangement of rock types helps to explain why more and larger caves are formed in the Rio Grande and Chiquibul areas than in the larger limestone regions of Yucatan. Precipitation falling on the metamorphics and igneous rocks of the Maya Mountains ends up as aggressive runoff from the jungle clad slopes. Constantly high temperature, very high precipitation totals, and a high relative humidity result in a rapid decay of organic matter on the jungle covered slopes. This results in a great release of carbon dioxide to the soil which in turn is transferred to surface streams, resulting in a highly aggresive runoff. As the streams flow off the highlands they encounter the Cretaceous limestones of the intermediate karst plateaus, the Vaca Plateau north of the mountains in the Chiquibul area and the Rio Grande Plateau in the study area. The streams sink at the contact between these two rock types and re-emerge as giant springs at the contact with the clastic sediments. Over a hundred meters of relief have resulted in multiple layered caves forming in this area. This relief is lacking in the rest of Yucatan where cave development occurs at shallow depths. In addition, karst water is less aggresive in the rest of Yucatan since it flows over or through primarily limestone and is therefore nearly saturated in carbonates, thus smaller and shorter caves are the result. However, both relief and an aggressive source of water are present in Belize and huge caves are capable of being formed.

The area is characterized by streams becoming insurgent at the contact of the carbonate and non-carbonate rocks. Hundreds of square kilometers are devoid of surface drainage, no wonder the ancient Maya turned to the caves as a source of Zuy Ha, cave water which they sought for holy water. Scattered around the jungle are major resurgences where the rivers once again return to the surface before becoming insurgent once again. Belizean caves in many instances are segments of the large river systems draining the Maya Mountains and are thus large but discontinuous. Hich Tulz (= Tiger Cave) in the Rio Grande Karst is typical of this type of cave.

Hich Tulz has a surveyed distance of over four kilometers, but much remains to be done in the lower level stream passages.

It is a large cave segment adjacent to where the Rio Grande meets the coastal plain sediments. At this point one finds a large resurgence lagoon 38 m wide by 90 m long with a flow in excess of 14 cms. This level is represented in the cave by rapidly flowing streams which have not been explored. The explored section of the cave is primarily large paleo-trunk passage that is at least 18 m wide and 28 m high for a distance of over 1.000 m from the entrance. This narrows down to a stoopway before opening up into the largest room of the cave, a tremendous void measuring 70 m wide and 200 m long, with a ceiling up to 50 m high.

Several other caves have been found in the area, some containing human skeletal remains and pottery. This area has potential for having many other large and interesting caves. Upstream on the Rio Grande are several other cave segments where the river travels underground for several kilometers. These have been identified on topographic maps and aerial photos but have not been visited at the time of this writing. A word of caution is given for anyone wishing to do research in Belize or even visit the huge caves. The Archaeological Commissioner requries that anyone visiting a cave in Belize have an official permit ahead of time. There has been a severe problem with looting of archaeological materials and since every cave in Belize is a potential archaeological site because of the cave use by the Maya, the government is anxious about who visits the sites.

Summary

The Rio Grande Karst on the southern flanks of the Maya Mountains has an ideal environment for the formation of large passage caves and the formation of gigantic chambers. Conditions favoring the speleogenesis and karst formation include the high rainfall totals caused by the orographic effect of the Maya Mountains on the trade winds, the relief that is provided by the mountains and the raised limestone platforms fringing the mountains, and the aggressive carbon dioxide saturated water running off the jungle clad non-carbonate rocks of the Maya Mountains. This area has just started to be explored but already it has produced some extraordinarily large caves.

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Sintesi dei carsi di media ed alta quota della Grecia occidentale

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RESUM

L'autor descriu, de foma sintètica, les característiques del carst de muntanya mitjana i de l'alta muntanya de les serrralades d'Epiro i Pindos (Grècia).

S'analitzen, en profunditat, l'estructura litològica i les condicions climàtiques i es distingueix entre una tipologia de carst mediterrani o de depressions tancades de «terra rossa» en carsts d'alta muntanya i un carst submediterrani, de tipus alpí, en modelats glacials del Quaternari.

RESUMEN

El autor describe en síntesis las características del karst de la media y alta montaña de las cordilleras de Epiro y Pindos.

Se analizan en profundidad la estructura litológica y las condiciones climáticas, se distingue una tipología de karst mediterráneo o de depresiones cerradas de terra rossa en karsts de alta montaña, submediterráneo de tipo alpino en modelados glaciares del cuaternario.

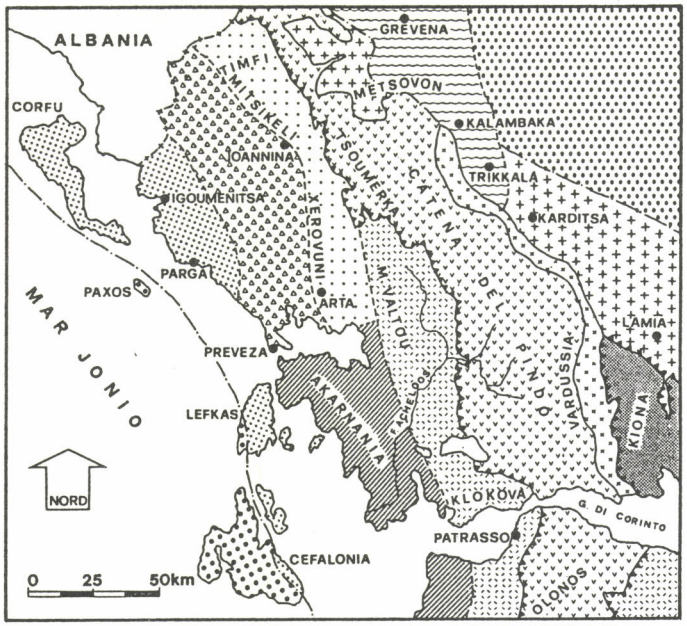
SUMMARY

The author synthetically describes the characters of the medium and high mountain karst of the Epirus and of the Pindos ange.

On the ground of the analysis of the lithostructural and climatic conditions is distinguished a tipology of mediterranean karsts or closed depression at terra rossa to high mountain submediterranean karsts of Alpine type at glacia-snowy quaternary modelling.

La Grecia occidentale (ca. 10.000 km^2 comprendendo Epiro, Pindo mediano ed il limite settentrionale dell'Etolia) è per ca. metà costituita de rocce carbonatiche alternate a flysch. Secondo AUBOUIN (1959) si distinguono (da Ovest ad Est) tre zone strutturali (appartenenti alle zone elleniche esterne) (Fig. 1 e 2): zona ionica, unità autoctona, zona del Gavrovo, autoctona, zona del Pindo, alloctona.

Il carsismo può essere diviso in zone a bassa quota (nella



CARTA GEOLOGICA DELLA GRECIA OCCIDENTALE

LEGENDA

- ZONA PUGLIESE E ZONA PREPUGLIESE
- ZONA IONICA ESTERNA
- ZONA IONICA MEDIA
- ZONA IONICA INTERNA
- ZONA IONICA IN GENERALE
- ZONA DEL GAVROVO-TRIPOLITZA
- ZONA DEL PINDO-OLONOS
- SOTTOZONA ULTRAPINDICA
- ZONA DEL PARNASSO
- ZONA SUBPELAGONIANA
- SOLCO MESOELLENICO
- ZONA PELAGONIANA
- PRINCIPALI SOVRASCORRIMENTI

Fig. 1. Carta geologica della Grecia occidentale. (da Aubouin modif.) (dis. G. Calandri-C. Grippa).

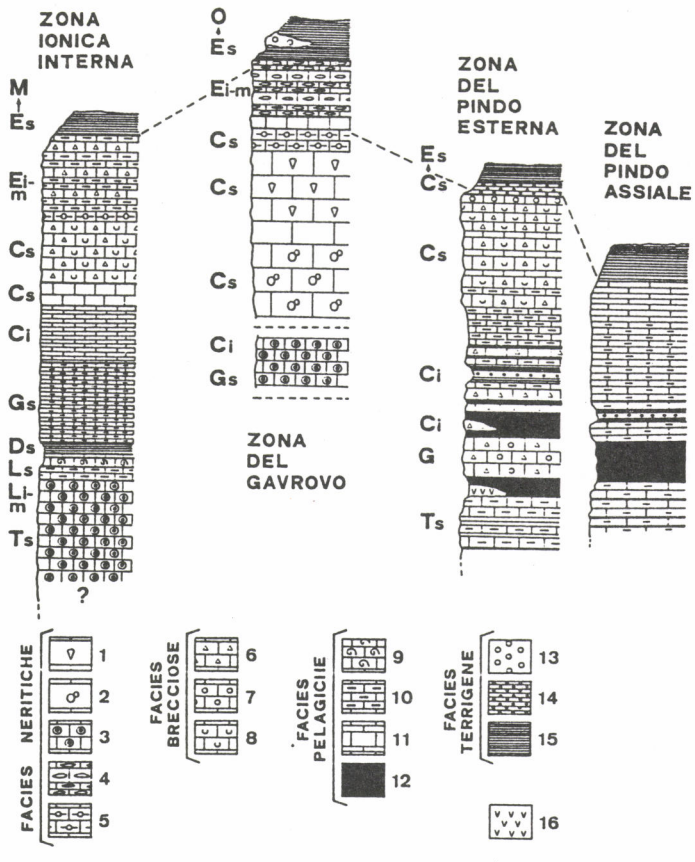


Fig. 2. Colonne stratigrafiche delle zone Elleniche esterne (da Aubouin modif.) (ridis. G. Calandri-C. Grippa).
I: calcari a Rudiste. 2: calcari a Gasteropodi. 3: calcari ad alghe. 4: calcari a foraminiferi terziari. 5: calcari a Orbitoidi. 6/7: calcari clastici a brecce. 8: calcari bioclastici a brecce. 9: calcari ad Ammoniti. 10: calcari pelagici. 11: calcari selciferi. 12: Radiolariti. 13: Conglomerati. 14: Arenarie. 15: scisti. 16: rocce verdi. M: Miocene inferiore. O: Oligocene. Es: Eocene superiore. Eim: Eocene inferiore e medio. Cs: Cretaceo superiore. Ci: Cretaceo inf. Gs: Giurassico sup. G: Giurassico. Ds: Dogger sup. Ls: Lias sup. Lim: Lias inf. e medio. Ts: Trias sup.

fascia ionica), caratterizzato da depressioni chiuse (polje, ecc.), con grandi accumuli di terra rossa, generalmente sviluppate durante il Quaternario, carsi di media quota (mediamente tra 900 e 1.700 m) a modellamento quaternario prevalentemente nivo-pluviale, e carsi di alta quota con modelli glaciali e carsici.

I rilievi della Grecia nord-occidentale, per condizioni strutturali e litologiche, climatiche, neotettonica, evoluzione postpliocenica, ecc., presentano una notevole varietà di tipi morfologici. Tra questi vengono sinteticamente confrontati alcuni esempi (fig. 3 e 4). Per ogni oarso sono sommariamente riassunti: a) denominazione, altezza del rilievo, potenziale calcareo, bibliografia. b) caratteri litostrutturali. c) Precipitazioni. Copertura vegetale. d) morfologie superficiali. e) carsismo profondo. f) modellamento ed evoluzione del carsismo.

Carsi di media quota

1.

a) Monti di Parga. Quota 1.000 m ca. Potenziale 1.000 ca. (BOUSQUET 1976, CALANDRI 1983).

b) calcari giurassici massicci (zona ionica esterna). Strutture anticlinali sovrascorse verso W.

c) precipitazioni: 1.000-1.200 mm (pluviali). Copertura prevalente macchia mediterranea degradata.

d) campi solcati frammentati a forme aperte. In basso depressioni (doline, polje). Grandi accumuli di terra rossa sui fianchi.

e) assorbimento disperso. Carsismo in profondità limitato dal substrato e dalla tettonica di compressione.

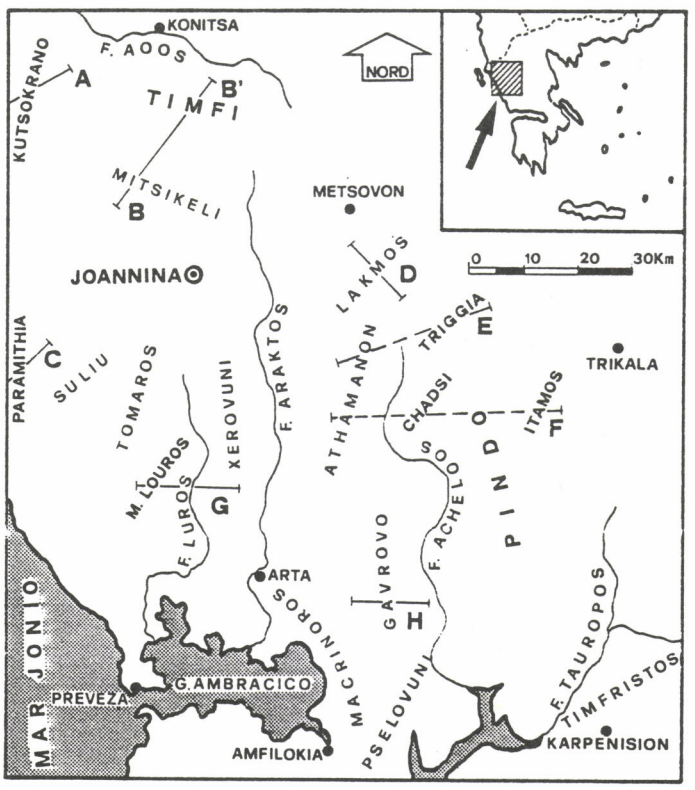


Fig. 3. Principali gruppi montuosi della Grecia occidentale. Traccia delle sezioni geomorfologiche (dis. G. Calandri-C. Grippa).

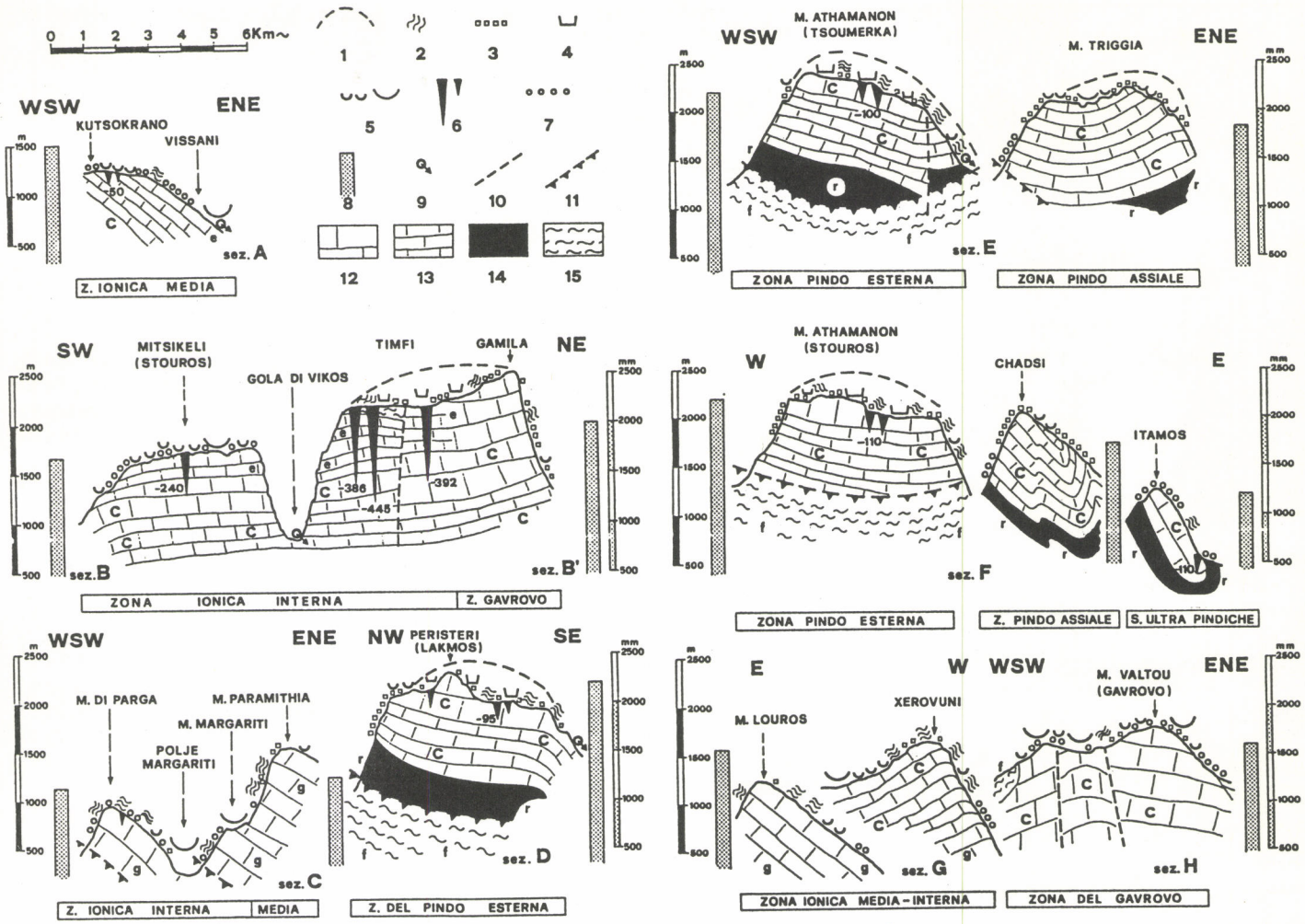


Fig. 4. Sezioni geomorfologiche schematiche dei principali gruppi montuosi prevalentemente carbonatici della Grecia nord-occidentale (dis. G. Calandri-C. Grippa). I valori delle precipitazioni si intendono approssimati. Le altezze dei simboli delle cavità verticali sono raddoppiate. 1: limite dei ghiacciai wurmiani. 2: campi solcati. 3: modellamento glacio-carsico. 4: processi periglaciali. 5: morfologie nivo-pluviali a doline, polje, acc. 6: cavità verticali. 7: copertura arborea. 8: precipitazioni. 9: sorgente carsica. 10: faglia. 11: sovrascorrimento. 12: calcari massicci. 13: calcari a plachette. 14: radiolariti. 15: flysch a dominanza argillitico. e: Eocene. c: Cretaceo sup. g: calcari del Giurassico. r: radiolariti del Giurassico. f: flysch zona ionica.

f) principale evoluzione del carsismo nel periodo bioalterante Mindel-Riss. Attualmente erosione suolo.

2.

a) Monti Xerovuni. Q. 1.614. Potenziale oltre 1.500 m (BOUSQUET 1976).

b) calcari giurassici (zona ionica interna). Struttura anticlinale.

c) 1.200-1.500 mm (pluvio-nivale). Marcata evapotraspirazione. Vegetazione degradata nella parte alta per fattori antropici.

d) marcata acclività. Campi solcati, sia Rundkarren (paleocarsismo), sia strutturali (evoluzione attuale, smantellamenti per gelifrazione sopra i 1.000 m). Doline di dissoluzione a grande taglia.

e) reticoli carsici disorganizzati. Assenza di cavità esplorabili: tettonica di compressione, scarsa porosità, ecc.

f) carso, parzialmente tipo «causse», dipendente dal modello strutturale. Carsismo solo nella fascia superficiale evoluto nell'interglaciale Mindel-Riss con processi di biocorrosione sotto copertura a terra rossa. Attuale evoluzione: Karren a forme aperte.

3.

a) Gavrovo (M Valtou) Q. 1.782. Potenziale oltre 1.500 m (BOUSQUET-CHARRE 1979, CALANDRI 1984).

b) calcari del Cretaceo sup. (zona del Gavrovo). Anticlinale calcareo compartimentato da faglie verticali longitudinali.

c) 1.400-1.500 (nivo-pluviali). Copertura boscata (conifere) ca. 50 %.

d) grande altopiano carsificato ad ampie depressioni chiuse (doline, uvale, polje) con depositi di terra rossa e bruna. *Lapies* liberi e residuali. Forte gelifrazione (Fig. 5).

e) assorbimento disperso, drenaggio controllato dalle fratture verticali. Cavità di corrosione lungo litoclasi.

f) Modellamento carsico iniziato alla fine del Pliocene dopo l'asportazione della copertura flyscioide. Formazione polje in clima umido prequaternario. Quaternario: colmamento depresioni e accentuazione della gelifrazione (fasi fredde), carsificazione accentuata: karren, ecc. (fasi caldo-umide). Assenza di ghiacciai quaternari. Attuale evoluzione: erosione, smantellamento forme carsiche per processi crionivali.

4.

a) Itamos (Pindo orientale) Q. 1.200. Potenziali 200-400 m (CALANDRI 1984).

b) calcari a microbrecce giurassici (scaglie ultrapindiche, AUBOUIN 1959). Scaglie molto strizzate, spesso ad asse subverticale sovrascorse verso W.

c) 1.000 mm ca. (pluviali). Forte evapotraspirazione. Vegetazione mediterranea degradata.

d) Forte acclività. Campi solcati frammentati a forme aperte, poco approfonditi, alternati a terra rossa (in basso).

e) Percolazione dispersa. Morfologie di corrosione tipo «fusoidi» lungo piani di frattura verticali (Pozzo Kodounotrypa –109).

f) Carsificazione favorita da neotettonica quaternaria. Resti di carsificazione dei periodi caldo-umidi quaternari. Attualmente ridotta per fattori climatici.

Carsi di alta quota

5.

a) Timfi Q. 2.480. Potenziali oltre 1.500 m (WORTHINGTON 1980, CALANDRI 1984).

b) calcari eocenici a placchette e calcari del Cretaceo sup. suborizzontali (zona ionica interna e marginalmente zona del;

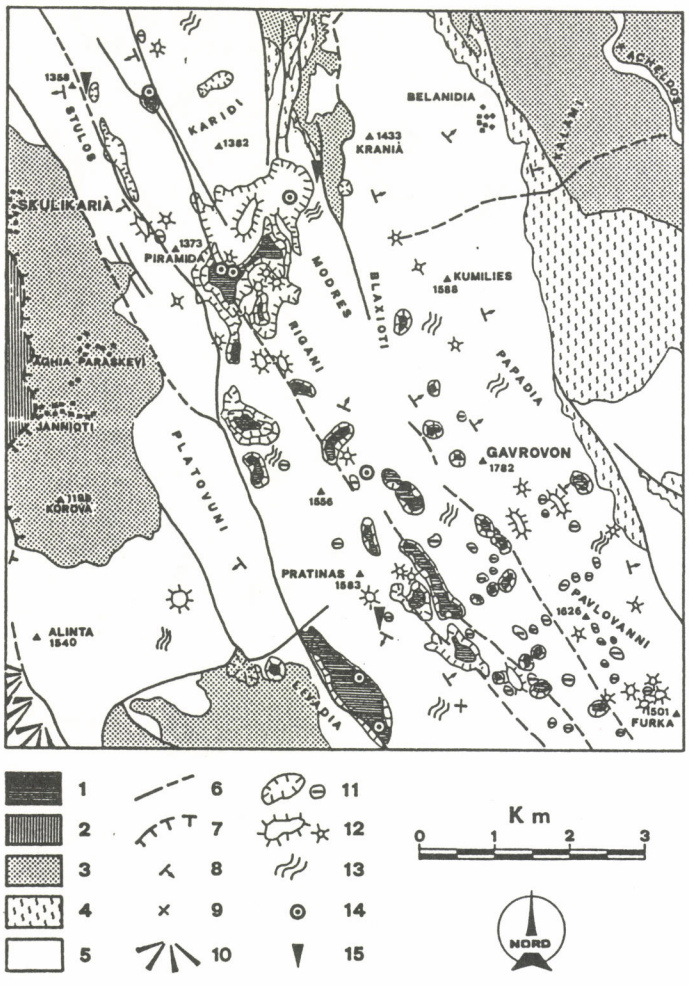


Fig. 5. Carta delle morfologie carsiche del Gavrovo (M Valtou) (dis. G. Calandri-C. Grippa).
1: terra rossa. 2: flysch arenaceo-zona ionica (Eocene sup.-Oligocene). 3: flysch del Gavrovo (Eocene-Oligocene). 4: calcari eocenici (zona del Gavrovo). 5: calcari sublitografici del Cretaceo (zona del Gavrovo). 6: faglia. 7: sovrascorrimento. 8: immersione strati. 9: strati orizzontali. 10: detriti e conoidi recenti. 11: polje, uvale, doline. 12: hum, chicot. 13: campi solcati. 14: inghiottitoio. 15: cavità.

Gavrovo). Grande monoclinale (debolmente immerso a SW), divisa in blocchi da grandi faglie verticali.

c) 2.000 m ca. (nivo-pluviali). Frammentaria prateria alpina.

d) Altopiano a modellamento glacio-carsico. Alta densità di doline, grande estensione di *Schichttreppenkarst*. Gelifrazione nella parte più elevata. Ampi depositi morenici.

e) intensa carsificazione profonda dipendente dalla tettonica fragile e dalla residua copertura flyscioide (ora in gran parte asportata) che ha favorito correnti incanalate superficiali. Grandi cavità verticali prewurmiane (Epos Chasm –445, Provatina –392 ecc.), a morfologie di corrosione ed erosione vadosa (anche per apporti di fusione glaciale), in parte sezionate da esarazione wurmiana.

f) Prima fase carsismo tardo-terziario. Modellamento legato alle glaciazioni quaternarie, carsificazione profonda anche in periodi caldo-umidi (depositi litochimici ecc.). Attuale evoluzione per gelifrazione e corrosione superficiale (campi solcati strutturali) de tipo nivo-pluviale.

6.

a) Peristeri-Megas Tropos (M. Lakmos) Q. 2.295. Potenziale ca. 1.000 m (CALANDRI 1984).

b) calcari massicci del Cretaceo sup. (a –100 ca. calcari a placchette) (zona del Pindo esterna). Struttura suborizzontale e piega a ginocchio (unità frontale sovrascorsa verso W).

c) oltre 2.000 m (nivo-pluviali). Prateria alpina molto frammentata.

d) nei calcari compatti: ripiani a morfologie glacio-carsiche (*Rundhockerkarst e Schichttreppenkarst,* doline a pozzo e imbuto, intaccate da gelifrazione, cavità sezionate dall'esarazione wurmiana ecc.). Nei calcari a placchette valloni e altopiani a morfologie a depressioni chiuse modificate dalla gelifrazione, argini detritici di nevaio ecc.

e) alta densità di cavità (80 al km^2) a Megas Tropos, prevalentemente prewurmiane di corrosione-erosione. Elevata carsificabilità nei calcari massicci, bloccata e controllata in profondità al contatto con i calcari a placchette suborizzontali con limitati approfondimenti vadosi.

f) Morfologia ereditata (versanti settentrionali) dal modellamento dei ghiacciai quaternari (Riss-Wurm) su cui si è sovrimposta l'azione carsica postwurmiana nivo-pluviale (campi solcati strutturali) e i processi periglaciali.

7.

a) Tsoumerka (M. Athamanon) Q. 2.395. Potenziale 1.100 ca. (CALANDRI 1984).

b) calcari massicci del Cretaceo sup. (sottesi da calcari stratificati a placchette) (zona del Pindo esterna). Sinclinale, fronte della falda del Pindo sovrascorsa compartimentata da faglie verticali.

c) oltre 2.000 m (nivo-pluviali). Cotica erbosa molto frammentata.

d) Altopiani a prevalente esarazione glaciale intaccata solo parzialmente dall'azione carsica e crionivale postwurmiana. Morfologie superficiali: campi solcati strutturali su superfici montonate e campi di doline a imbuto e pozzo congiunte modificate da gelifrazione. Elevata frequenza di cavità (superiori a 50 al km^2). Processi periglaciali negli accumuli detritico-morenici sui fianchi.

e) Carsismo profondo, testimoniato dalla frequenza di pozzi sezionati dall'esarazione glaciale, con cavità di erosione-corrosione (anche prewurmiane) in partecdi erosione vadosa subglaciale (fig. 6). Al contatto con calcari a placchette: morfologie clastiche (collassi gravitativi) anche imponenti e ridotte morfologie vadose di erosione regressiva.

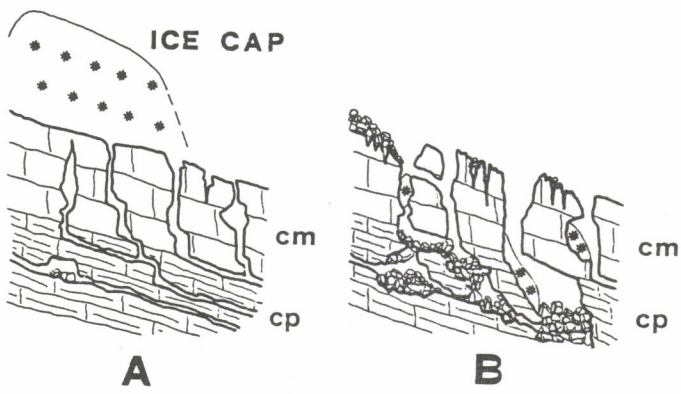


Fig. 6. Schema speleogenetico di diverse cavità dello Tsoumerka (dis. G. Calandri-C. Grippa).
A: Wurm. B: periodo attuale. cm: calcari massicci del Cretaceo sup. cp: calcari a placchette del Cretaceo sup.

f) Modellamento glacio-carsico quaternario. Evoluzione carsica (anche postwurmiana) favorita da deglaciazioni e da energia del rilievo, processi di distensione e neotettonica. Attuale evoluzione nivo-pluviale.

8.

a) Triggia Q. 2.204. Potenziale ca. 600-700 m.

b) Calcari pelagici a placchette del Cretaceo sup. (zona del Pindo assiale). Larga anticlinale sovrascorsa verso W: intensa ripiegatura per la plasticità della copertura sedimentaria.

c) 1.800 mm ca. (pluvio-nivali). Cotica erbosa continua. Copertura a conifere su detriti di, versante.

d) Altopiani e valloni a modellamento glaciale quaternario (circhi con accumuli morenici sul lato E). Morfologie chiuse a doline poco approfondite. Dominio dei processi di gelifrazione. Assenza di morfologie di corrosione superficiale.

e) assorbimento disperso, reticoli carsici molto frammentati condizionati da strati (cavità in interstrati non esplorabili).

f) Evoluzione carsica trascurabile durante tutto il quaternario. Modello crioclastico tuttora in fase evolutiva.

In sintesi i settori di media montagna (prevalenti strutture anticlinali) con carsi di tipo mediterraneo ad evoluzione attuale pluviale (es. Parga-Margariti) o nivo-pluviale (es. Xerovuni, Parami-

thia, Kutsokrano, ecc.) indicano un modellamento pleistocenico a forme (doline, campi solcati sotto copertura) ereditate dai periodi caldo-umidi (specie interglaciale Mindel-Riss) con degradazione nella fasi fredde ed attuale evolouzione in parte a campi solcati strutturali. Il carsismo; è ridotto in profondità per motivi litostrutturali (regime di compressione, ecc). Nei carsi nivo-pluviali più elevati (es. M. Valtou, Mitsikeli) l'evoluzione quaternaria ha approfondito il modellamento pliocenico (polje, uvale, ecc) con smantellamento delle morfologie carsiche per azioni crionivali nei periodi freddi.

I carsi di alta montagna, attualmente a regime nivo-pluviale (bilancio di dissoluzione specifica tra 80 e 100 mm per 1.000 anni), di tipo alpino con influenze mediterranee presentano nel Timfi e nel Pindo esterno (occidentale), a calcari massicci, un tipico modellamento glacio-carsico quaternario, con elevata carsificazione prewurmiana, anche in condizioni subglaciali, solo intaccata da campi solcati postwurmiani e da fenomeni periglaciali. Il carsismo nel Pindo assiale (Triggia, Chadsi) è controllato dalla tettonica duttile e dalla variazione di facies del cretaceo: calcari a placchette (in profondità nell'Athamanon e nei Lakmos) bloccano la carsificazione. Il medellamento glacio-nivale è esclusivamente trasformato dalla gelifrazione (detriti e accumuli crionivali).

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Las regiones karstificadas de México

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RESUM

Aquest article pretén fer una descripció general de les principals regions càrstiques de Mèxic, incidint especialment en la seva fisiografia, clima, geologia i tectònica, així com en les característiques més rellevants de les formes de dissolució, fent esment dels sistemes subterranis. La finalitat de l'article és la de fer un resum generalitzat del coneixement que es té en els nostres dies de les regions càrstiques de Mèxic.

RESUMEN

Este artículo comprende una descripción general de las principales regiones kársticas de Méjico apuntando especialmente su fisiografía, clima, geología y tectónica, así como las características más importantes de las formas de disolución destacando los sistemas subterráneos. La finalidad del artículo es dar un resumen generalizado del conocimiento que se tiene hasta nuestros días de las regiones kársticas de Méjico.

RESUME

Cet article comprend une description générale des principales régions karstiques du Méxique visant spécialement leur physiographie, climat, géologie et tectonique, ainsi que les plus importantes carctéristiques des formes de dissolution soulignant bien les systèmes souterrains. Le but de l'article est de donner un résumé généralisé de la connaissance que l'on a jusqu'à nos jours des régions karstiques du Méxique.

Introducción

México posee extensas áreas calizas, las cuales abarcan cerca del 30 % de su superficie. Gracias a la conjunción de factores geológicos, tectónicos, geográficos y climáticos se ha desarrollado un universo de formas kársticas, algunas consideradas únicas. Esto ha motivado que investigadores y exploradores de varias naciones efectuen estudios sobre dicho karst y sus cavernas, los cuales se difunden –con mayor o menor amplitud. Sin embargo, es cada vez mayor el interés que este tipo de estudios está despertando en México, debido a la magnitud de las áreas karstificadas y a los problemas que esto implica. Los estudios karstológicos y espeleológicos en México, se han venido efectuando de una manera muy lenta, desde 1940, con la llegda de científicos Españoles refugiados. A partir de los últimos 10 años, estos estudios se han incrementado notablemente, formandose los primeros grupos dedicados al conocimiento de las áreas kársticas de México.

Las grandes regiones kársticas

México cuenta con aproximadamente 600.000 km^2 de áreas con mayor o menor grado de karstificación, dependiente de sus condiciones físicas. De las 15 provincias fisiográficas en que se encuentra dividido el país (SPP, 1982), 8 son las que presentan el mayor grado de karstificación. A continuación se da un resumen de las principales carcterísticas de dichas provincias.

1) Península de Baja California –Constituida por montañas– bloque de rocas intrusivas y cadenas volcánicas, entre ellas se encuentran escasos y aislados afloramientos de calizas arrecifales del cretácico, principalmente en su porción norte. La karstificación está poco desarrollada debido al clima seco y caluroso que prevalece en la región. La Baja California no ha sido estudiada desde el punto de vista del karst, y sólo se han explorado algunas cavernas con escaso desarrollo horizontal.

2) Sierra Madre Occidental –Está formada por potentes capas– de rocas volcánicas del Terciario superior, las cuales muestran aislados afloramientos de calizas, que van del Precámbrico al Cretácico, predominando estas últimas. La karstificación es de poco desarrollo y presenta cavidades de escasa magnitud, debido a la influencia de su clima predominante, semiárido seco, aunque en la parte sur la kastificación es mayor por la existencia de climas más húmedos. No existen estudios del karst de esta región.

3) Sierra y Llanos del norte –Tiene importantes áreas en donde afloran calizas en forma de amplias lomas anticlinales aisladas. La edad de las calizas varía del Cámbrico al Cretácido, predominando estas últimas. Su karstificación es mediana, llegando a estar en algunas parte muy desarrollada. El clima de esta región es semiárido seco, con algunas variantes. Son escasos los estudios del karst de esta región, reportándose varias cavernas de poca extensión.

4) Sierra Madre Oriental –Es una cadena montañosa geológicamente compleja, en la que abundan las calizas del Cretácico, principalmente las de tipo arrecifal. Estas, se encuentran muy deformadas, fracturadas y afalladas lo cual ha ocasionado una topografía muy abrupta, en la cual existen grandes variaciones de altitud, desde los 100 msnm, hasta los 3.700 msnm, y una diversidad de climas, predominando los subhúmedos tropicales pero también tiene regiones semiáridas, húmedas y templadas. Generalmente las lluvias sobrepasan los 1.000 mm de promedio anual, principalmente en los bordes orientales de la Sierra.

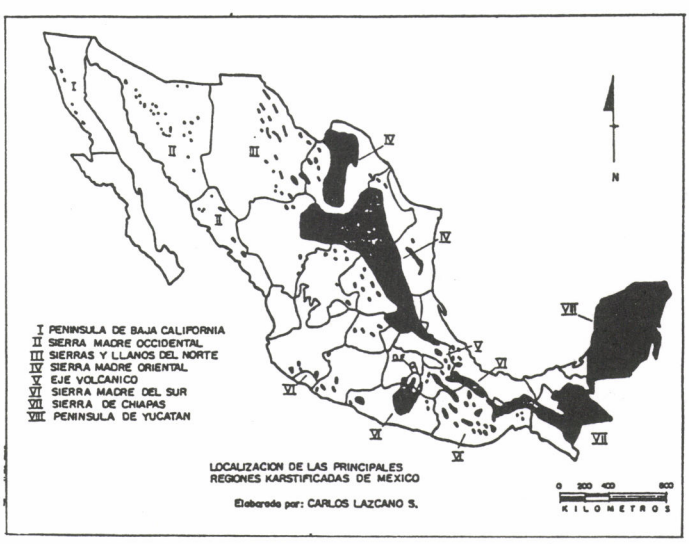
El karst se encuentra altamente desarrollado en muchos casos sobre mesetas anticlinales afalladas en sus flancos. Es probablemente, la región kárstica mejor estudiada, ya que son numerosas las publicaciones que existen sobre esta región. Destaca por sus cavernas más largas (Sistema Purificación, 55 km), profundas (Sistema Purificación, -895 m, Sótano de la Trinidad-834 m, Sótano de Tilaco-649 m, Cueva del Diamante-621 m y otras), y por sus grandes verticales (Sótano del Barro, tiro de 410 m, Sótano de las golondrinas, tiro de 376 m, Sotanito de Ahuacatlán, tiro de 288 m, y otras).

Además, la Sierra Madre Oriental, presenta en su porción norte importantes karstificaciones en yesos del Jurásico, con desarrollo de cavidades de mediana magnitud.

5) Eje Neovolcánico –Se trata de una amplia cadena de volcanes del Terciario y Cuaternario, con una orientación Oeste– Este, entre los que destacan el Citlaltepetl (5.670 msnm), el Popocatepetl (5.450 msnm), y la Iztaccihuatl (5.300 msnm), todos con nieves eternas y desarrollo de glaciares. En su extremo Este, se encuentran varios afloramientos calcáreos, aislados, pero importantes, los cuales no alcanzaron a ser cubiertos por los derrames de los volcanes. estos afloramientos consisten de calizas cretácicas que forman mesetas anticlinales con un alto grado de karstificación y un gran desarrollo de cavernas. Su clima es tropical muy húmedo (en las regiones Centro y Oeste del eje neovolcánico, el clima es templado) presentando precipitaciones anuales con promedios de 2.500 mm. Hasta la fecha esta región ha sido muy poco estudiada y explorada.

6) Sierra Madre del Sur –Es un sistema montañoso complejo, de rocas intrusivas, metamórficas, volcánicas y sedimentarias, el cual se extiende paralelo, al sur, del Eje– Neovolcánico. Presenta extensos afloramientos de calizas del Cretácito, los cuales se encuentran deformados, fracturados y afallados y en algunos casos afectados por cuerpos intrusivos y volcánicos. Su relieve es abrupto y presenta una amplia variedad de climas desde los secos, templados, hasta los muy húmedos y tropicales, los cuales han permitido una amplia karstificación.

En su porción Oeste, que mira al Pacífico, las calizas se encuentran en mesetas anticlinales aisladas, algunas muy amplias como la del Cerro Grande, la cual presenta cavidades con tendencia a tiros de grandes verticales (abundan las verticales de más de 100 m). El clima de esta región varía de tropical húmedo, a templado subhúmedo en las partes altas (mayores a los 2.000 msnm), tiene precipitaciones de 1.500 mm de promedio anual. La parte central de la Sierra Madre del Sur, localizada al sur de la ciudad de México, principalmente en el estado de Guerrero, consta de extensos afloramientos calcáreos muy karstificados, con gran desarrollo de ríos subterráneos, en varios casos de más de 6 km y cavernas verticales (la más profunda es el hoyo de San Miguel con-455 m). En la región más Oriental de esta Sierra se encuentran las áreas kársticas más activas y complejas de México; Zongolica, Huautla y Cuetzalán y las tres presentan sistemas subterráneos profundos y activos. En Huautla se han explorado los sistemas Huautla y Nita Nanta, con –1.250 m y –1.030 m respectivamente, que son las cavidades más profundas de América. En Zongolica existen grandes verticales (Sótano de Tomasa Kihaua, tiro de 330 m y el Sótano de Ahuihuitzcapa, tiro de 250 m), e impresionantes ríos subterráneos, muy difíciles de explorar. En Cuetzalán se encuentran varios sistemas complejos que son largos y profundos, entre los que destaca el sistema Cuetzalán, con más de 20 km de longitud y 587 m de profundidad. Esta región oriental de la Sierra Madre



del Sur tiene los más altos promedios de precipitación pluvial anual de México, entre 3.500 y 4.500 mm.

La Sierra Madre del Sur es otra de las regiones que ha sido objeto de numerosos estudios y exploraciones.

7) Sierra de Chiapas –En esta provincia existen extensos afloramientos de calizas del Cretácico, los cuales están muy afectados tectónicamente y aunado esto a un clima tropical muy húmedo, a templado subhúmedo, con altas precipitaciones, se ha desarrollado ampliamente el karst, así como importantes cavernamientos. Aún son pocos los estudios del karst de esta región, siendo cada vez en mayor número las exploraciones espeleológicas que visitan la zona. Las cavernas más profundas que se han encontrado hasta la fecha son el Resumidero del Pecho Blanco (–450 m), y el Sótano de Tenejapa (–330 m). Esta es una de las regiones més promisorias para nuevas exploraciones espeleológicas.

8) Península de Yucatán –Esta es la única región de México– compuesta en su totalidad por calizas, sus edades son del Terciario, y un poco del Cuaternatio y presentan un tectonismo somero. El clima es tropical subhúmedo con 1.000 mm de promedio anual de lluvias. La parte norte es una planicie con muy escaso relieve (0-30 msnm), en donde las calizas están muy karstificadas, predominan en esta región las cavidades inundadas llamadas cenotes. La parte sur presenta variaciones notables en cuanto al tipo de karstificación, debido principalmente a que tiene un tectonismo más acentuado que en el norte, aquí existen cavidades de cierta extensión (varios kilómetros) y profundidad media (alrededor de 100 m). La región ha sido objeto de numerosos estudios karstológicos y espeleológicos.

La investigación karstológica y espeleológica en México

Los primeros estudios fueron realizados por Robles Ramos (1950). En la Península de Yucatán, y por Bonet (1953), en la región de Xilitla, S.L.P. (Sierra Madre Oriental), ambos con orientación geológico-geomorfológica. Posteriormente se han efectuado trabajos aislados, con distintas orientaciones. Sin embargo, desde hace algunos años ya existen grupos, dentro de instituciones del gobierno, universitarias y privadas que se dedican a la investigación karstológica y espeleológica con diferentes orientaciones y aplicaciones. Las más importantes se han dado en la geotecnia, minería, hidrogeología y geomorfología, siendo más abundantes en estas dos últimas áreas.

El Instituto Nacional de Estadística, geografía e informática, ha efectuado importantes contribuciones al conocimiento de la geomorfología kárstica de México, al editar cartas geológicas y fisiográficas de diferentes escalas, de las regiones kársticas del país (SPP, 1981). La Universidad Nacional Autónoma de México (UNAM), y la Sociedad Mexicana de Exploraciones Subterráneas (SMES), han efectuado varios estudios geomorfológicos y espeleológicos en algunas regiones kársticas (Lazcano, 1983, 1985, SMES, 1982, 1983).

Estudios karstológicos con orientación hidrogeológica, los ha efectuado principalmente la Universidad Autónoma de Yucatán (UADY), (Gaona, Et. Al, 1980, 1980 b), y la Secretaría de Agricultura y Recursos Hidráulicos (Velázquez, 1985). Aplicaciones geotecnias han sido implementadas por la Comisión Federal de Electricidad, y por la Secretaría de Asentamientos Humanos y Obras Públicas. En cuanto a minería, ha sido el Consejo de Recursos Minerales, quien ha efectuado diversos estudios de mineralización en paleokarst (Cruz Ríos, Et. Ql, 1980).

Otras agrupaciones como la SMES y el Grupo de Espeleología de la UNAM, se han dedicado a la exploración y estudio de cavidades, principalemente en el ambito geológico y biológico. En los estudios de fauna cavernícola han destacado el Departamento de Acarología de la UNAM, y el Departamento de Acuacultura y Biología Marina de UADY.

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1065

Karst of Sicily – I) karst of carbonatic rocks

P. Madonia & Marcello Panzica La Manna

RESUM

Resum dels estudis i investigacions que ha dut a terme, en els darrers 50 anys, el Grup Sicilià d'Espeleologia

Els autors pretenen donar-nos una visió global de la distribució del fenomen càrstic en les roques carbonatades de Sicília.

El fenomen càrstic a Sicília es troba molt influenciat per les característiques climatològiques, estratigràfiques i tectòniques que varen originar les diferents subàrees i morfologies subterrànies. A continuació es fa una descripció de les àreas càrstiques més importants i més ben explorades.

a) L'àrea nord-oest, formada per les muntanyes de Trapani, Palermo, muntanyes de Trabia i Termini I i muntanyes de Madonie.

b) L'àrea centre-oest, formada per les muntanyes de Sicanian i Sciacca.

c) L'àrea sud-est, formada per les muntanyes d'Iblei.

d)L'àrea nord-est, molt més petita, formada per les muntanyes de Seloritani i caracteritzada per morfologies menys comuns i menys interessants.

RESUMEN

Resumen de los estudios e investigaciones llevadas a cabo en los últimos 50 años por el Grupo Siciliano de Espeología. Los autores han podido sacar una imagen general de la distribución del fenómeno kárstico en las rocas carbonatadas de Sicilia. El fenómeno kárstico en Sicilia está muy influenciado por las características climatológicas, estratigráficas y tectónicas que dieron lugar a distintas subáreas y morfológias subterráneas. El autor continua con la descripción de las áreas kársticas más importantes y mejor exploradas:

a) El área Noroeste formada por los mts. Trapani, Palermo, mts. Trabia y Termini I, mts. Madonie;

b) El área centro-oeste, formada por los mts. Sicanian y Sciacca;

c) El área Sudeste, formada por los mts. Iblei y otra área más pequeña en el Nor-este mts. Seloritani caracterizada por morfologías menos comunes e interesantes.

SUMMARY

From te studies and the researches carried out during the last fifty years by the Sicilian Speleological Groups, the authors have been able to draw a general picture of the distribution of the karst phenomena in the Sicilian carbonatic rocks.The karst phenomenon in Sicily is much influenced by the tectonic, stratigrafic and climatic features that give rise to different subaereal and underground morphologies. The authors continue with the description of the most important and well explored karst areas:

a) the North-Western area, formed by the Trapani Mts, Palermo, Trabia and Termini I. Mts, Madonie Mts;

b) the Centre –Western area, formed by the Sicanian and Sciacca Mts;

c) the South-Eastern area, formed by the Iblei Mts; an other smaller area in the North-East (Peloritani M. ts) is characterized by less frequent and interesting morphologies.

1066

Karst of Silicy – II Evaporite karst

Paolo Madonia & Marcello Panzica La Manna

RESUM

Després d'una curta descripció de les característiques geològiques més importants de les evaporites de Sicília, els autors fan una descripció general del carst en les evaporites sicilianes, basant-se en les dades obtingudes en les investigacions i les exploracions realitzades els darrers 10 anys pel Grup Sicilià d'Espeleologia.

Els afloraments vinculats a fenòmens càrstics s'han subdividit en 3 extenses àrees geogràfiques:

a) Sicília occidental (Vall de Belice)

b) Centre-sud de Sicília

c) Sicília oriental

S'inclou també una subdivisió addicional per a cadascuna de les àrees, d'acord amb els procesos morfogenètics càrstics, amb una anàlisi de les morfologies hipogees més importants.

RESUMEN

Después de una corta descripción de las características geológicas principales de las evaporitas en Sicilia. Los autores dan una descripción general del karst en evaporitas en Sicilia partiendo de los datos adquiridos en las investigaciones y exploraciones realizadas en los últimos 10 años por el Grupo Siciliano de Espeleología.

Los afloramientos en el fenómeno kárstico se han subdividido en 3 vastas áreas geográficas:
a) Sicilia occidental (Valle de Belice)
b) Centro-sur de Sicilia
c) Sicilia oriental
Se da una subdivisión adicional para cada área de acuerdo con los procesos morfogenéticos kársticos, con un análisis de las principales morfologías hipogeas y epigeas.

SUMMARY

After a short description of the main geological characteristics of evaporite rocks in Sicily, the authors, starting from dates acquired by the last ten years explorations and researches of Sicilian Speleological Groups, give a general description of evaporite karst in Sicily.
The outcrops interested by karst phenomena are subdivided into 3 large geographic areas:
a) Western Sicily (Belice valley)
b) Centre-Southern Sicily;
c) Eastern Sicily.
For each area is given a further subdivision in acordance with the prevalent karst morphogenetic processes, with an analysis of the main and epi-geal morphologies.

10291

Dos campos de dolinas en la Sierra de Segura. Ensayo de distribución espacial

Begoña López Limia
Geógrafa.

RESUM

En el marc de les Serralades Bètiques i, concretament, en la zona pre-bètica, els procesos de dolinització adquireixen una envergadura especial: Hi ha zones on s'aconsegueixen densitats de l'ordre de 80 dolines per Km².
En aquest estudi s'aplica el mètode analític proposat per Williams (1968) a 8 zones del carst poligonal de Nova Guinea, amb l'objectiu de conèixer la distribució espacial dels dos camps de dolines de la Sierra del Segura. Aquestes dues zones es troben situades en el sistema pre-bètic interior, i pertanyen a les províncies de Jaén (Pinar Negro) i Albacete (Calar del Mundo.)
Els elements del carst es desenvolupen, generalment, en base a certs factors específics, d'acord amb unes lleis de distribució precises. Per tant, la constatació d'aquest fet permet d'establir relacions amb factors estructurals, litològics i climàtics.

RESUMEN

En el marco de las Cordilleras Béticas y concretamente en el dominio Prebético, los procesos de dolinización adquieren una envergadura especial; hay zonas en las cuales alcanzan densidades de hasta 80 dolinas por km².
En este estudio se aplica el método analítico propuesto por Williams (1968) en 8 zonas del karst poligonal de Nueva Guinea, con el fin de conocer la distribución espacial en dos campos de dolinas de la Sierra de Segura. Estas dos zonas están situadas en el Sistema Prebético interno, perteneciente a las provincias de Jaén (Pinar Negro) y Albacete (Calar del Mundo).
Los elementos del karst se desarrollan generalmente en base a ciertos factores específicos, de acuerdo con unas leyes precisas de distribución. Por tanto, la constatación de este hecho permite establecer relaciones con factores estructurales, litológicos y climáticos.

RESUME

Dans le cadre des chaînes Bétiques et concrètement dans le domaine Prébétique, les processus de dolinization acquierent une envergure spéciale, il existe des zones dans lesquelles ils atteingnent des densités de jusqu'a 80 dolines par Km².
Dans cette étude on a appliqué la méthode analytique proposéé par Williams (1968) dans 8 zones du karst polygonal de Nouvelle Guinée à fin de connaître la distribution spatiale dans deux champs de dolines dans la Sierra de Segura. Ces deux zones sont situées à l'intérieur du systeme Prébétique Interne, qui appartient aux provinces de Jaen (Pinar Negro) y Albacete (Calar del Mundo).
En général les éléments du karst se développent en base á de certains facteurs spécifiques, en s'accommodant á des lois précises de distribution. Par conséquent, la constatation de ce fait permet d'établir des relations avec des facteurs structuraux, lithologiques et climatiques.

Introducción

La incidencia de los factores estructurales, litológicos y climáticos en las características espaciales de los karsts, puede ser evaluada cuantitativamente. El problema ha sido abordado a través de distintos enfoques desde que MATSCHINSKI (1962-1968) consideró la posibilidad de la existencia de alineamientos en los campos de dolinas.

El análisis de las asociaciones espaciales y del muestreo de las formas del karst, ha constituido una importante línea de investigación en los últimos años. A partir de PIELOU (1969), que estudió los métodos del análisis muestreal y la aplicación de diversos índices basados en distancias entre puntos contiguos, son numerosos los ejemplos del uso de estos índices en distintos karsts: KING (1962), GETIS (1964), SMALLEY y UNWIN (1968), W. WILLIAMS (1972).

Marco geológico

Litológica y estructuralmente, los dos sectores considerados se encuentran ubicados en el dominio del Prebético Interno, caracterizado por un predominio de los materiales carbonatados de edad Cretácica, y una tectónica de pliegues suaves y fallas. El Jurásico no aflora en estas áreas, ni se hallan representados materiales Terciarios.

Pinar Negro se localiza en la zona de contacto entre los dominios Prebético Externo e Interno, a una altitud media de 1750 m. Constituye una cuenca cerrada de 23,25 km^2, en la cual el relieve se dispone en una sucesión de anticlinales y sinclinales de direcciones comprendidas entre N 30-40 E para los más occidentales y N 20-30 E para los orientales.

El campo de dolinas se ha desarrollado en las calizas del Senonense superior (30-40 m. de potencia) que corona la serie estratigráfica de Pinar Negro (DABRIO GONZALEZ, 1973) y en el potente paquete dolomítico del Cenomanense (300 m.).

El Calar del Mundo supone el límite septentrional de la Sierra de Segura. Forma un macropliegue de 23 km. de largo por una media de 5 a 6 km. de ancho, y su estructura general es la de un sinclinorio cuyo eje principal es de dirección N 49 E, existiendo numerosos pliegues dentro de esta gran estructura, (RODRIGUEZ ESTRELLA, 1979).

Los fenómenos kársticos estudiados se han desarrollado en los materiales del Senonense inferior: calizas micríticas recristalizadas masivas de 187 m. de potencia.

Metodología

Para establecer en qué medida la distribución de las dolinas es aleatoria o se ajusta a modelos de dispersión en los sectores analizados, se ha seguido el método propuesto por W. WILLIAMS (1962) en el karst de Nueva Guinea.

El planteamiento parte de la consideración de la semejanza existente entre cuencas fluviales normales y dolinas, lo que ha llevado a estudiarlas como a cuencas de afluentes tributarios de un tipo especial.

Se determina así el contorno de las dolinas, haciendo pasar una línea por las cimas de las colinas que las circundan y los collados que las separan, quedando incluídas las áreas drenantes de la dolina.

En este trabajo, la delimitación se ha establecido a partir de fotografías aéreas a escala 1/32.000 y 1/7000, que permiten identificar claramente las formas kársticas, incluso en el caso de dolinas de escasas dimensiones.

Sobre el plano se han dibujado los sumideros de cada una de las depresiones, midiendo la distancia entre cada punto y los más próximos. El parámetro (La) se obtiene estableciendo la media entre todas las medidas.

La distancia media esperada en una población aleatoria infinitamente grande, con la misma densidad que la población que se está estudiando, define el parámetro (Le).

$$Le = \frac{1}{2\sqrt{D}}, \text{ donde D: densidad}$$

El resultado de R (razón entre las dos medias, La/Le), indica a qué modelo se ajusta la muestra. W. WILLIAMS (1972) establece tres modelos de dispersión, condiderándose en disposición arracimada (por zonas) cuando R=0, aleatoria si R=1 y hasta 2,1491 para un modelo ordenado.

Los campos de dolinas en la Sierra de Segura

En los dos sectores estudiados, el fenómeno de dolinización alcanza un gran desarrollo, con intensidades variables. Así, en Pinar Negro, con una densidad de 80 dolinas por Km^2, existen áreas donde se han observado hasta 243 depresiones, constituyendo la zona más altamente dolinizada de la Sierra de Segura. En el Calar del Mundo, los valores son también significativos, aunque más modestos, contabilizándose 1000 dolinas en los 55 km^2 de su superficie (LOPEZ BERMUDEZ, 1974).

El muestreo y el tratamiento analítico de las depresiones, se ha realizado en Pinar Negro y Calar del Mundo, sobre 3 sectores (de un km^2 cada uno), escogiendo aquellos donde el reconocimiento de los sumideros ha sido más completo.

En todos los casos, el valor de R (razón entre La/Le) es superior a 1, como se observa en el cuadro 1, donde figuran los valores de los distintos parámetros de cada uno de los sectores.

PINAR NEGRO

Población	N.º Sumideros	La	Le	R
1	243	0,063	0,032	1,968
2	204	0,068	0,035	1,971
3	178	0,062	0,037	1,675

CALAR DEL MUNDO

Población	N.º Sumideros	La	Le	R
1	51	0,116	0,070	1,657
2	76	0,122	0,057	2,140
3	65	0,116	0,062	1,870

De los valores de R se desprende pues, que las poblaciones se ajustan a modelos ordenados, alcanzándose incluso el valor máximo: 2,140 en uno de los casos. W. WILLIAMS obtiene en Nueva Guinea valores comprendidos entre 1,09 y 1,4, considerando casi aleatorias a aquellas poblaciones con índices inferiores a 1,2 y casi uniformes a las restantes. P. GARAY (1983) en el macizo del Mondúver (Valencia) llega a valores entre 1,7 y 2, comparables a los de la Sierra de Segura, (figuras 1 y 2).

Los índices reflejan la presencia de factores estructurales que controlan y determinan tanto su génesis como su posterior evolución, lo cual queda establecido comparando las orientaciones de los ejes de las dolinas con las principales directrices estructurales de la región.

En Pinar Negro, el estudio de las frecuencias relativas referidas a las direcciones de los ejes de las depresiones (muestra: 1380 dolinas) permite establecer tres orientaciones predominantes:

N 21- 30 E	7,8 %
N 31- 40 E	7,3 %
N 111-120 E	6,7 %

El 7,8 % del total de dolinas se desarrolla paralelamente a la dirección de los pliegues, que en esta zona es N 21-30 E. El segundo máximo coincide con la orientación de las grandes fallas inversas N 31-40 E de edad Tortonense, propias de una etapa de compresión, limitando una de ellas el sector en su vertiente oriental. Asimismo, se incluyen en este grupo las depresiones desarrolladas a partir de las fallas normales N20-40 E, cuya actuación fue posterior al Tortonense, en una etapa de descompresión. Las depresiones cuyos ejes están orientados N 111-120 O, siguen la directriz impuesta por la familia de grandes fallas de desgarre,

que presentan dos direcciones en la región: N 120 E y N 100 E, afectando al sector en su extremo septentrional.

En el Calar del Mundo el muestreo se ha realizado sobre un total de 253 dolinas, resultando predominantes los siguientes intervalos

N 46-60 O	13,04 %
N 61-75 O	13,83 %

Se han seguido los intervalos de 15º con el fin de comparar los resultados con los establecidos por RODRIGUEZ ESTRELLA (1979) respecto a la fracturación del Calar del Mundo. El máximo obtenido por este autor (21 %) está comprendido entre N 45 E y N 60 E, correspondiendo a fracturas de distensión posteriores al plegamiento, y paralelas a la dirección principal de éste. Así pues, los ejes de las dolinas se desarrollan perpendicularmente tanto a la dirección de los pliegues como de las fracturas. La propia estructura sinclinal del calar explica el alargamiento de los ejes mayores en este sentido.

La familia N 75 O coincide con un sistema de fractura que supone el 10,5 % del total de accidentes. Son fracturas coetáneas al plegamiento.

Existe un tercer máximo importante: N 16-30 E (9,48 %) que no guarda relación con las frecuencias obtenidas por RODRIGUEZ ESTRELLA para este sector. Sin embargo, el sistema de fallas N 27-33 E está ampliamente representado en el Prebético, situadas preferentemente en el sector occidental, pudiendo establecerse un condicionamiento estructural en este sentido. Este fenómeno fue constatado por MATSCHINSKI (1968) en el NO del Lago Constanza, donde dedujo que las alineaciones de dolinas estaban influenciadas principalmente por la tectónica de regiones adyacentes.

Conclusión

La aplicación de métodos analíticos y espaciales en el estudio de los procesos de dolinización, revela un hecho importante: los fenómenos kársticos no son aleatorios, y es evidente la existencia de factores específicos que determinan su organización.

El tratamiento analítico en estas dos zonas tan representativas sugiere la idoneidad del método en los campos de dolinas de las Cordilleras Béticas, siendo necesaria su aplicación en otras áreas de la península con el fin de comparar los resultados.

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Typological zonation of karst in the USRR

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RESUM

Les zones càrstiques ocupen una gran part del territori de la U.R.S.S. Per a efectuar una classificació d'aquestes zones càrstiques s'han pres com a criteris bàsics els factors de tipus geotectònic i fisiogràfic. Els principis teòrics d'enginyeria geològica i de tipologia regional del món, desenvolupats per E.M. Sergeev s'han utilitzat com a criteris de divisió tipòlgica de extensos territoris sotmesos a procesos càrstics intensos, situats a diverses zones climàtiques i amb una estructura geològica completa. Per a la realització d'aquesta classificació creuada s'han utilitzat dos sistemas independents d'unitats taxonòmiques, essent els principals factors del sistema l'estructura geològica i les peculiaritats climàtiques del territori objecte d'estudi.

Les categories neotectòniques establertes per N.I. Nickolaev (plataformes continentals, orogènies i geosinclinals) es consideren com unitats taxonòmiques de la zonació tipològica del carst del territori de la U.R.S.S. En el segon grup s'han considerat els diferents climes i paisatges. Els tipus de carst dels territoris s'estableixen a partir de la intersecció del grup d'unitats azonals amb les climàtiques.

Basant-se amb el mètode anteriorment esmentat, els autors han obtingut un esquema de megatipus del carst del territori de la U.R.S.S. Aquests megatipus es caracteritzen per les condicions i les pautes del procés de desenvolupament del carst. L'estudi d'aquestes constants és l'únic mètode possible per a la utilització racional de les zones carstificades.

RESUMEN

Las zonas kársticas ocupan una gran parte del territorio de la URSS. Para efectuar una clasificación de dichas zonas kársticas se han tomado como principios básicos los factores de tipo geotectónico y fisiográfico. Los principios teóricos de ingeniería geológica y tipología regional del mundo, desarrollados por E.M. Sergeev se han utilizado como criterios de división topológica de vastos territorios sometidos a procesos kársticos intensivos y situados en varias zonas climáticas, con una estructura geológica completa. Para realizar esta clasificación cruzada se han utilizado dos sistemas independientes de unidades taxonómicas, siendo los principales factores del sistema la estructura geológica y las peculiaridades climáticas del territorio objeto del estudio.

Las categorías neotectónicas establecidas por N.I. Nickolaev (plataformas continentales, orogenias y geosinclinales), se consideran como unidades taxonómicas de la zonación tipológica del karst del territorio de la URSS. En el segundo grupo se han considerado los diferentes climas y paisajes. Los tipos de karst de territorios se establecen por la intersección del grupo de unidades azonales con las climáticas.

Basándose en el método arriba mencionado, los autores han obtenido un esquema de megatipos del karst del territorio de la URSS. Estos megatipos se caracterizan por las condiciones y las pautas del proceso de desarrollo del karst. El estudio de estas constantes es el único método posible para usar las zonas karstificadas de un modo más racional.

SUMMARY

Karst is widely spread in the territory of the USSR. Geotectonic and physiographical conditions of the territory have been taken as principle in receiving schemes of karst zonation. Theoretical aspects of engineering geological and typological zonation of the Earth developed by E.M. Sergeev serve as a criterion in typological zoning vast territories subjected to intensive karst process development and situated in various climatic zones with complicated geological structure. Two independent systems of taxonomic units have been used in compiling cross-classification, the main factors of the systems are structural geological and climatic peculiarities of the territory under study.

Taxons of neotectonic zoning by N.I. Nickolaev (continental platforms, orogens and geosynclines) are considered to be taxonomic units of karst typological zonation of the territory of the USSR. Climate and landscape zones are the units of the second group. The types of the karst territories are established by intersection of the group of azonal units with climatic ones.

One the basis of the above-mentioned classification the scheme of megatypes of karst territories of the USSR has been obtained by the authors. Megatypes characterize conditions and law-governed regularities fo karst process development. The study of these regularities is the only possible condition to use karsted territories in the most rational way.

Complex development of the territories and protection of the environment are impossible without detailed study of engineering geological conditions and their variability in space. Karst widely spread in the territory of the USSR is considered to be the most unfavourable engineering geological process. Typological zoning is the only possible way to reveal the conditions of karstification within the vast territory of the USSR of a complex geological structure comprising four climatic zones.

Papers by Maximovich G.A., Gvozdetsky N.A., Rodionov N.V., Tchikishev A.G., Parmuzin Y.P., Tsykhin R.A., Domin L.V., Bersenev Y.I., Mamatkulov M.M., Tintilozov Z.K. et al. are dedicated to the problem of karst zonation. In proposed schemes taxonomic units based on geotectonic or physiographical conditions do not reflect the total variety of natural conditions of karst process development and regularities of its distribution in space.

Karst is known to be conditioned not only by azonal structural geological situation/tectonic controlling the distribution of karstic rocks differing in age and composition/but also by zonal climatic one. The above-mentioned groups of different conditions should be taken into account when revealing the main situations of karstification.

Theoretical aspects of engineering geological typological zoning of the Earth developed by Sergeev E.M. and Ershova E.B. serve as a criterion of typological zonation of karst territories. The authors take into account two principle groups of factors and offer double-row cross-classification. They use two independent systems of taxonomic units: the first is classified by structural geological features, the second –by zone indications.

Taxons of neotectonic zoning by Nickolaev N.I. are considered to be taxonomic units of geostructural series of karst typological zonation. The modern relief which influences on the depth of vertical distribution and the thickness of active water-exchange and karstification zones has been formed by tectonic movements of Neogene and Quaternary age. Geological structures differing in ages and neotectonic movements correspond to first order large areas: 1/continental platforms with slight Neogene--Quaternary movements; 2/continental geosynklines or orogens with active neotectonic uplift movements; 3/recent geosynclines with intensive contrast neotectonic movements.

Platfomrs are divided into the ancient Archean-Proterozoic /I/and young Epipaleozoic plates /II/according to the age of foundation, orogens - into Baikal or Upperproterozoic /III/, Paleozoic /IV/, Mesozoic /V/, Alpine /VI/ folding areas. Recent geosynclines are Uppercenozoic folding areas /VII/. According to structural conditions first order territories are divided into the areas of the second order.

Artic /A/, subarctit /B/, temperate /C/ and subtropical /D/ climate zones are considered to be zonal physical geographical units of the first order. Landscape zones are the units of the second order: polar, tundra and foresttundra, forest, forest-steppe and steppe, semi-desert and desert, mountain. Mega- and mesotypes of karst territories are obtained as a result of superimposing geostructural and landcape-climatic features of the first and the second order groups.

Megatype of karst territories is regarded as geostructural area with definite conditions of Neogene-Quaternary movements,

Megatypes of Karst Territories of the USSR

Climatic zone	Platforms of slight N-Q movements		Orogens of active N-Q uplift movements				Geosynclines of contrast N-Q movements
	I $PrePR_3$	II EpiPZ	III PR_3	IV PZ	V MZ	VI KZ	VII LateKZ
A Arctic				TM	AO		
B Subarctic	SB			PN	KO		
C Temperate	SB, RS	TU	BK	UR, KZ, AS, NT	AR, PR	CU, CR, CA	SK
D Subtropical				ST		TC, KD	

expressed in the relief, within the limits of which ancient and modern karst, controlled by climatic conditions, develops.

On the basis of the above-mentioned classification the scheme of megatypes of karst territories of the USSR has been obtained/ Table/. Following megatypes exist in the territory of the USSR:

I B, I C - the Siberian platform /SB/,
I C - the Russian platform /RS/,
II C - Turan plate /TU/,
III C - Baikal /BK/,
IV A - Taimir /TM/,
IV B - Paikhoi-Novozemelski /PN/,
IV C - the Urals /UR/, Kazakhstan /KZ/, Altai-Sayan /AS/, North-Tien Shan /NT/;
IV D - South-Tien Shan /ST/,
V A - Arctic Ocean islands /AO/,
V B - Kolymo-Omolonski /KO/,
V C - Argon /AR/, Primorski /PR/,
VI C - the Caucasus /CU/, Crimean /CR/, Carpathian /CA/;
VI D - Transcaucasus /TC/, Kopetdagski /KD/;
VII C - Sakhalin /SK/.

Typological approach to karst zonation gives wide opportunities since it makes possible to take into account both regional-geostructural and zonal climatic conditions. Each megatype reflects conditions of karstification and is characterized by definite regularities of its development. The study of this regularities permits one to forecast karst and its influence on landscape.

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Mapa de campo del Karst de Cuba

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RESUM

L'any 1980 s'inicià a Cuba la confecció d'un mapa càrstic d'utilització sobre el terreny i les corresponents investigacions dins el marc d'un acord entre els Instituts de Geografia de les Acadèmies de Ciències de Txecoslovàquia i Cuba.

L'autor, un dels caps dels equips de treball d'ambdós instituts, va preparar el projecte de treball conjunt, així com també la llegenda del mapa. En el treball de camp els fulls originals del mapa es van fer a escala 1: 50.000 (zones càrstiques) i 1: 100.000 (zones no càrstiques). El mapa definitiu serà imprès a color a escala 1: 250.000. A més del text, detallat, que l'acompanya, contindrà totes aquelles dades que ens han de permetre una aproximació a les característiques litològiques, geomorfològiques (tipològiques) i hidrogeològiques de la zona, així com les sedimentàries, l'erosió atmosfèrica i recobriment dels sòls de les zones englobades en el mapa.

El treball estarà totalment llest entre el 1987 i 1988.

Els resultats de la topografia realitzada a l'Est de Cuba foren elaborats a partir d'un full d'escala 1: 250.000 (Santiago de Cuba) que aquí presentem.

RESUMEN

En 1980 se inició en Cuba la confección de un mapa kárstico de utilización sobre el terreno y las investigaciones correspondientes en el marco de un acuerdo entre los Institutos de Geografía de las Academias de Ciencias de Checoslovaquia y Cuba.

El autor, como uno de los jefes de los equipos de trabajo de ambos institutos, preparó el proyecto del trabajo en conjunto, así como también la leyenda del mapa. En el trabajo de campo las hojas originales del mapa se hicieron a escala 1: 50.000 (zonas kársticas) y 1: 100.000 (zonas no kársticas), mientras que el resultado final del mapa será impreso en color a la escala 1: 250.000. Además del detallado texto acompañante proporcionará datos necesarios sobre características litológicas, geomorfológicas (tipológicas) e hidrogeológicas, así como también sedimentarias, erosión atmosférica y recubrimiento de suelos de las zonas kársticas englobadas en el mapa. El trabajo estará completamente terminado en 1987-1988.

El resultado de la topografía realizada en el Este de Cuba se elaboraron a partir de una hoja modelo 1: 250.000 (Santiago de Cuba) que se presenta aquí.

SUMMARY

In 1980 a karst land use mapping and pertaining research activities started in Cuba in frame of an agreement between the Institutes of Geography of the Czechoslavak and Cuban Academies of Sciences.

The author, as a head of the working teams from both Institutes, elaborated a project of the entire work as well as the legend of the map. Within the field work the original sheets of the map have been compiled in the scale 1: 50.000 (karst regions) resp. 1: 100.000 (non-karstic areas), whereas the final map will be printed in colours in the scale 1: 250.000. together with a detailed accompanying text it will give necessary informations on litological, geomorphological (typological) and hydrological characteristics as well as on sedimentary, weathering and soil covers of the karst regions mapped. The entire work will be concluded within 1987-1988.

The results of the mapping realized in the East Cuba were elaborated in a model sheet 1: 250.000 (Santiago de Cuba) that is presented.

Introducción

Los estudios y el levantamiento del mapa del uso de carso de Cuba a escala de 1: 250.000 empezaron en los años 1980-81 según el proyecto elaborado por el autor. En los años posteriores se realizaron trabajos respectivos en otras partes del territorio cubano y terminarán en el año 1987.

Objetivos del mapa

El mapeo forma parte del plan temático del Instituto de Geografía de la Academia de Ciencias de Cuba a de convenio de colaboración entre las Academias de Ciencias de Cuba y de Checoslovaquia. La confección de este mapa representa una tarea principal de la parte cubana, como apoyo a las necesidades prácticas de la economía nacional.

Las condiciones naturales del carso cubano, que ocupa el 65 % del territorio estatal, se reflejan en las particularidades del régimen de agua subterránea, de la cubierta sedimentaria o de la corteza de intemperismo, de la capa vegetal, en la erosión accelerada del suelo y en la estabilidad irregular de las rocas subyacentes. El mapa debe contribuir a la solucción de problemas de hidroeconomía que resultan importantes para la agricultura y otras esferas de la economía debido a que el desarrollo económico depende sobre todo de las aguas càrsicas. el mapa ha de servir asimismo para resolver problemas de protección del terreno contra las inundaciones que se producen muchas veces en el grado catastrófico durante las situaciones ciclónicas, causando daños en la agricultura, la industria y el transporte. El problema especial lo presenta la protección de suelo en cuanto a la erosión y sufosión –lo que afecta de una manera significativa la explotación agrotécnica del carso subyacente.

En general se trata de un mapa global que caracteriza las condiciones morfoestructurales, geomorfológicas, pedológicas, hidrológicas e hidrogeológicas. En la práctica se utilizará el mapa cómo un documento básico en la planificación del desarrollo de varias ramas de la economía nacional y de la creación y protección del medio ambiente en las instituciones de planificación y dirigentes, a niveles central, provincial y municipal.

Contenido temático del mapa

El mapa se levanta sobre la base topográfica, que contiene datos de situación vertical (isolineas de niveles y cotas importantes), la red fluvial y la situación topográfica antropógena (aglomeraciones urbanas, carreteras, ferrocarriles, presas etc.). Para la elaboración de las hojas de trabajo de autor iniciales se usan las copias fototípicas con el dibujo preciso del contenido especial. Como la base topográfica final se usa le mapa topográfico de Cuba a escala 1: 250.000 (I. C. G. C., E0522, ed reambul. 1972).

El mapa incluye informaciones sobre:

a)condiciones litológicas simplificadas;

b)condiciones morfoestructurales y geomorfológicas;

c)espesor de las cubiertas de suelo;

d)condiciones hidrológicas e hidrogeológicas;

e)situación espeológica.

Para la presentación de la litología se usan los mapas geológicos a escala de 1: 100.000.

El contenido morfoestructural y geomorfológico forma el componente más importante del mapa y para su elaboración se mapea en la base topográfica a escala de 1: 100.000, con empleo de fotografías aéreas e investigaciones de campo, según el procedimiento metódico siguiente:

a)estudio e interpretación de los materiales topográficos, pedológicos, geológicos y geomorfológicos y espeleológicos disponibles;

b)interpretación de relieve y de la red fluvial;

c)interpretación de fenómenos cársicos en fotos aéreas estereoscópicas;

d)revisión y completamiento en el campo;

e)dibujo de las hojas en escala de 1: 100.000.

La presentación del espesor de la cubierta de suelo se toma de los mapas pedológicos a escala de 1: 250.000.

La característica de la circulación de las aguas superficiales y subterráneas se presentan en forma de los datos cualitativos y cuantitativos, que resultan de estudio de los fenómenos hidrológicos en las estaciones hidrométricas, respectivamente obtenidos directamente en el campo, o de mediciones individuales de los elementos hidrológicos o por análisis de composición química del agua. Además de eso se utiliza el Mapa hidrológico de Cuba a escala de 1: 1 000 000.

Presentación del contenido temático del mapa

Los modos de representación de los elementos individuales del contenido temático están incluídos en la leyenda especial, elaborada por el autor según la leyenda especial aprovechada y por la Unión Internacional de Geografía para el levantamiento del mama geomorfológico del mundo. Se incluyeron a la leyenda símbolos y rayados necesarios para presentar elementos carsológicos necesarios, importantes.

La primera parte de la leyenda representa la litología de base, la segunda parte abarca los datos morfoestructurales y geomorfológicos (límites geomorfológicos, límites de morfoestructuras, fallas que se reflejan en el relieve, tipos genéticos del relieve, formas resultantes de la erosión diferencial, forman resultantes de otros procesos exogénicos, formas marinas y lacustres, formas y fenómenos cársicos, la edad del relieve). La tercera parte de la leyenda presenta los datos pedológicos y la cuarta parte los datos hidrológicos e hidrogeológicos.

Los elementos individuales de la leyenda están numerados. En los datos litológicos se indica el número de los rayados oficiales publicados en el Muestrario de escritura, señales y rayados, 4-ta edición, Kartografie, n.p. Praga, 1976.

En cada elemento de la leyenda se indica también el número de lápiz de color (Toison d'or colorama) para elaboración manuscrita de las hojas parciales del mapa. Si está indicado un número, se refiere al dibujo señalado o al rayado, si se indican dos números, el primero de ellos señala el color del área, el segundo el color de los símbolos (contorno) o de los rayados sobre área coloreada. Al seleccionar los colores se reparó más o menos en que la formas erosivo-denudativas se representan por color pardo, las cársicas por rojo, las marinas y lacustres –por azul, las acumulativas– por azul y verde, las abrasivas (marinas) –por verde, las de fondos– por amarillo. El rayado se eligió de modo que su gradiente estuviera aproximadamente en concordancia con las condiciones de pendientes del relieve.

Elaboración de las hojas de trabajo de autor

La parte de contenido del mapa se representa en seis hojas originales temáticos individuales sobre hojas impresas con la base topográfica.

En la primera hoja parcial se representa la litología de las rocas subyacentes. Cada área de la base litológica está claramente delimitada y numerada según la leyenda. Cada área en el mapa tiene su característica litológica escrita. En el mapa impreso estas características serán representadas según la leyenda. Los límites corresponden en esencia a los límites litológicos de los tipos geomorfológicos del relieve.

En la segunda hoja original se representan los tipos geomorfológicos del relieve y su edad. Al igual que en el caso precedente, aquí también cada área individual del tipo correspondiente del relieve está limitada claramente por el límite geomorfológico y lleva el número según la leyenda. En el mapa no aparecen áreas sin la calificación geomorfológica del tipo de relieve.

En la tercera hoja original se presentan los elementos del contenido morfoestructural y geomorfológico del mapa:

a) límites de las morfoestructuras;

b) fallas que se reflejan en el relieve;

c) formas resultantes de la erosión diferencial;

d) formas resultantes de varios procesos exogénicos;

e) formas marinas y lacustres;

f) formas y fenómenos cársicos;

En la cuarta hoja original se encuentran los datos areales de la potencia de las cubiertas de suelo.

En la quinta hoja original está presentada la división del territorio de acuerdo al grado de mineralización de las aguas subterráneas.

La sexta hoja original presenta características hidrológicas seleccionadas (divisorias hidrográficas, escurrimiento específico en litro . s^{-1} . km^{-2}. Además de eso se limitan también áreas de los distintos tipos de aguas subterráneas según la permeabilidad de las rocas subyacentes, y por último se destacan los manantiales concentrados (predominantemente de agua subterránea cársica), los pozos de observación importantes y las estaciones hidrométricas en las corrientes superficiales.

Las hojas originales del autor con el contenido temático se elaboran para las zonas cársicas sobre los mapas topográficos

a escala de 1: 50.000, para las zonas no cársicas a escala de 1: 100.000. Los originales de autor de todas las hojas parciales se generalizan después a escala de 1: 250.000. Durante estos trabajos se tiene en cuenta que la obra resultante de la generalización en la escala 1: 250.000 corresponda a los objetivos principales del mapa final.

Elaboración del texto acompañante explicativo

Para cada hoja del mapa se elaboran textos explicativos acompañantes. El texto será impreso al dorso de cada hoja del mapa individual.

Elaboración técnica de las hojas originales

La técnica de recopilación de las hojas originales se realizará en el mismo número que para las hojas parciales originales del autor, a escala de 1: 250.000 y según la leyenda determinada, incluyendo la coloración. La recopilación técnica debe ser realizada sobre una base resistente a las deformaciones. Hay que tener en cuenta las diferencias de temperatura y de humedad en condiciones cubanas y checoslovacas.

Elaboración de los originales cartográficos

La elaboración de los originales cartográficos para la edición del mapa se realizará para los colores individuales desde los originales técnicos. En la realización se puede proceder por los dos modos siguientes:

a) modo cartográfico clásico;
b) modo automatizado por medio de AKS Digikart.

De momento está preparada toda la tecnología del Instituto de Geografía de la Academia de Ciencias de Checoslovaquia en Brno para el primer modo. En el segundo caso habrá que realizar una confrontación experimental de la leyenda existente con las posibilidades de la representación con ayuda de AKS Digikart.

Etapas de levantamiento del mapa

a) trabajos de gabinete– elaboración del proyecto, de la leyenda, de las instrucciones para grupos individuales de trabajadores y de la hoja modelo;
b) obras preparativas– colección de los materiales informativos, evaluación de los datos, definir los conceptos de los fenómenos temáticos para los trabajos en el campo, selección de los datos obtenibles en varias instituciones nacionales y regionales;
c) trabajos de campo– comprobación en terreno y completamiento del dibujo de los fenómenos temáticos resultantes de los estudios de materiales obtenibles y de las interpretación de fotos aéreas, tipologización del contenido temático;
d) elaboración de los originales del autor;
e) elaboración de los textos acompañantes explicativos;
f) oponentura del mapa y del texto explicativo acompañante;
g) redacción final de las hojas del mapa a escala de 1: 250.000;
h) elaboración técnica de los originales;

Colaboración

El mapa de uso de carso de Cuba y los estudios correspondientes se realizan según el convenio sobre colaboración entre los Institutos de Geografía de la Academia de Ciencias de Cuba en la Habana y de la Academia de Ciencias de Checoslovaquía en Brno. Por parte checoslovaca participa también la Universidad Palacký en Olomouc. Por parte cubana el Instituto de Geografía de la A.C.C. colabora estrechamente con el Instituto de Geología de la A.C.C., con el Instituto de Geofísica de la A.C.C.(facilitación de las informaciones sobre los límites de la penetración del agua del mar a los sistemas cársicos de la tierra firme) con el Instituto de Suelos de la A.C.C., con la Facultad de Geografía y con la Facultad de Geofísica de la Universidad de la Habana, con el Instituto de Hidrooeconomía del Ministerio de la Construcción y eventualmente con otras instituciones según las necesidades, p. ej. con el Instituto de Botánica, el Instituto de Meteorología, y con las instituciones de prospección provinciales.

Conclusión

Teniendo en cuenta que los trabajos respectivos pasan hasta ahora según el proyecto y el plan temporal el autor y todos los colaboradores se quedan convencidos, que la elaboración de las hojas de autor de territorio entero de Cuba serán terminados durante este año y que el mapa final será publicado en el año 1988 y que cumplirá sus objetivos principales como documento útil científico y de uso práctico.

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Tipos de carst de Cuba Oriental

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RESUM

Durant l'elaboració del mapa del camp de carst de l'est de Cuba, realitzat per l'autor els anys 1980–1981, es van diferenciar vàries classes de carst en tres anticlinals i dos sinclinals de megaestructures morfològiques d'edat pre–Laramica, Laramica i post–Laramica, que constitueixen l'estructura de la regió (Anticlinori de Camagüey–Tunas–Holgüin, A. Sierra Maestra, A. Nipe–Cristal–Baracoa, Sinclinori de Guacanayabo–Nipe i S. Valle Central).
A la mateixa zona i un costat de l'altre, trobem diferents tipus de carst originats en diferents fases del Pre–Eocè, l'Oligocè, el Pliocè i el Quaternari, sempre sota control estructural i textural. Tant és així, que els paisatges càrstics són completament diferents. Alguns d'ells varen ésser fossilitzats per plegaments i orogènesis, per sedimentació de dipòsits marins més joves, per rediposició de recobriments alògens de l'erosió atmosfèrica o per transgresió marina. D'altres passaren a formar part de sistemes càrstics més recents. Un dels tipus de carst més interessant se'ns ofereix com un paisatge càrstic desenvolupat en la pteridotita serpentiforme mesozoica de les altes superfícies de denudació de l'Anticlinori Nipe–Cristal–Baracoa.

RESUMEN

Durante la elaboración del mapa de campo del karst del Este de Cuba, realizado por el autor en 1980–1981, se distinguieron varios tipos de karst en tres anticlinales y dos sinclinales de Mega–estructuras morfológicas de edad pre–Laramica, Laramica y post–Laramica que estructuran la región (Anticlinorio de Camagüey–Tunas–Holgüin, A.Sierra Maestra, A. Nipe–Cristal–Baracoa, Sinclinorio Guacanayabo–Nipe y S. Valle Central).

Se encuentran uno al lado del otro en la misma zona, diferentes tipos de karst originados en varias fases del desarrollo geomorfológico del pre–Eoceno, Oligoceno, Plioceno y Cuaternario, siempre bajo el control estructural y textural, y por ello tipos completamente diferentes de paisajes kársticos. Algunos de ellos fueron fossilizados por plegamientos y levantamientos, por sedimentación de recubrimientos de depósitos marinos más jóvenes, por reddeposición de recubrimientos de erosión atmosférica alógenos o por transgresión marina, otros pasaron a formar parte de sistemas kársticos más recientes.

Uno de los tipos de karst más interesante se nos ofrece como un paisaje kárstico desarrollado en la peridotita serpentiniforme mesozoinica de las altas superficies de denudación del Anticlinorio Nipe–Cristal–Baracoa.

SUMMARY

During the karst land use mapping of the East Cuba, realized by the author withing 1980–1981, various karst types were distinguished in three anticlinal and two synclinal mega–morpho–structures of pre–Laramic, Laramic and post–Laramic age had build the region (Anticlinorium Camagüey–Tunas–Holguín, A. Sierra Maestra, A. Nipe–Baracoa, Synclinorium Guacanayabo–Nipe and S. Valle Central.

Individual karst types originated in various phases of the pre–Eocene, Pliocene and Quaternary geomorphological development, always under leading structural and textural control, so that completely different types of the karst landscape are situated close together in the same area. Some of them were fossilized by folding or uplifts, by sedimentation of younger marine deposits, by redeposition of allogene weathering covers or by the sea transgression, others became part of younger karst systems.

One of the most interesting karst types appears to be a very complex karst landscape developed in the Mesozoic serpentinized peridotite on high denudational surfaces of the Anticlinorium Nipe–Cristal–Baracoa.

Introducción

En los años 1980–1981 dirigí las investigaciones y el mapeo carsológico en el territorio de las provincias cubano–orientales de las Tunas, Granma, Holguín, Santiago de Cuba y Guantánamo. Los trabajos en esta parte menos conocida de la Isla de Cuba iniciaron los estudios que tienen que ofrecer datos sobre la usibilidad económica racional y efectiva de los terrenos cársicos en todo el territorio cubano. Se realizaran según el convenio de colaboración entre los Institutos de Geografía de las Academias de Ciencias de Cuba y de Checoslovaquia.

Situación geológico–tectónica

El territorio mapeado se divide en cinco regiones morfoestructurales, las cuales pertenecen, a las macro–unidades faciales de las Antillas Mayores. Se trata de Anticlinorio de Camagüey–Tunas–Holgüín, de Nipe–Cristal–Baracoa y de Sierra Maestra, y de Sinclinorio de Guacanayabo–Nipe y Sinclinorio Central

Los anticlinorios están construídos principalmente por complejos de rocas vulcano–sedimentarias submarinas de Cretácico Inferior /Aptiano, Albiano/ y Superior/ Campaniano–Maestrichtiano Inferior/ y en menor parte también de Pre–Jurásico, Jurásico y Paleoceno Inferior /Paleoceno–Eoceno Medio/. Las formaciones piroclásticas, fuertemente plegadas, falladas y penetradas por cuerpos intrusivos abisales y hipoabisales de varias generaciones, contienen capas potentes carbonatadas. Los anticlinorios se formaron en la fase inferior de plegamiento larámico /entre cretácico Superior y Paleoceno/, en la cual se originaron también placas amplias de las ultramafitas serpentinizadas de edad probablemente premaestrichtiana. En el Senoniano Inferior casi todo el territorio se elevó sobre el nivel del mar en consecuencia de los movimientos subhercínicos y lo afectaron intensos agentes subaericos. En la faze superior de Larámico /la faze cubana/, entre Eoceno Medio y superior, afectó los anticlinorios el fallamiento radial muy diferenciado y instrusiones basálticas.

Los sinclinorios representan parageosinclinales, el desarrollo de las cuales empezó en el Eoceno Medio, pero su hundimiento principal cae hasta a los períodos después de Oligoceno Medio. Por eso la base de los sinclinorios está cubierta por formaciones carbonatadas del Eoceno, mientras que sus rellenos marinos sedimentaron hasta en Mioceno inferior. Restos erosivos de la cubierta basal así como de los rellenos se conservaron también en las partes marginales de los anticlinorios y en algunas cuencas tectónicas parciales.

En el Mioceno Inferior y Superior la mayor parte del territorio estudiado se hundió en el mar, mientras que en el Mioceno Medio y después en el Plioceno se encontró definitivamente en las condiciones de modelación continental. Sólo en sus márgenes litorales sedimentaron depósitos marinos de Mioceno Medio y de Plioceno.

El desarrollo geomorfológico en el Plioceno y Cuaternario es muy complejo debido a la combinación irregular de influencia de los movimientos diferenciados de la faze orogenética valaquiana de de neotectónica posterior así como de consecuencias de fluctuaciones glacieustáticas de nivel del oceano mundial. Generalmente se trata, en territorio entero, de varios períodos de una fuerte erosión lineal, que desmembró el relieve aplanado de los anticlinorios, y de la abrasión marina, la cual creó sistémas de terrazas marinas superpuestas en las zonas costeras. No obstante, en la parte occidental del Sinclinorio Guacanayabo–Nipe se formaron considerables depósitos marinos, marino–lacustres y fluvio–marinos aún en Pleistoceno Inferior. Otro producto importante de la sedimentación marina en el Cuaternario lo representan depósitos coralinos y pericoralinos de interglacial de Sangamoniano, los cuales bordean casi continuamente las costas de Cuba Oriental, extendiéndose hasta a los varios kilómetros a lo largo de la costa del Golfo de Méjico.

Situación carsológica

En dependencia del desarrollo geológico–técnico, de la posición areal y estatigráfica y el desarrollo geomorfológico se desarrollaron en varias partes de las morfoestructuras distintos tipos de carso.

Según su edad distinguieron las generaciones del carso mesozóico /mayormente de Pre–Senoniano y de Senoniano Inferior/, paleogénico /Paleoceno–Eoceno inferior y Oligoceno Medio/, neogénico /Mioceno Medio/, neogeno–cuaternario /Plioceno y Plio–Pleistoceno/ y reciente. Algunos relieves de paleocarso estuvieron fosilizados por levantamientos tectónicos fuertes o por la sedimentación posterior. Otros, después de su exhumación, se unieron con las generaciones de carso más jóvenes. En algunas partes de los sinclinorios se efectuó la fosilización de carso también por el hundimiento por debajo de nivel del mar actual.

La mayor parte del relieve cársico de la Cuba Oriental se encuentra y se desarrolla actualmente en condiciones climáticas

convenientes de la zona tropical estacionalmente húmeda con precipitaciones anuales promedias entre 800 - 3.000 mm. No obstante, el clima de este tipo no es uniforme en todo el territorio. En las partes surorientales el relieve cársico está actualmente fosilizado por condiciones semiáridas hasta áridas /precipitaciones anuales promedias entre 0-200 mm/.

Anticlinorio Camagüey–Tunas–Holguín

En la parte dorsal de los anticlinorios individuales y de Holguín con el relieve aplanado desenterrado de pre–Mioceno aparece el carso aislado. En el anticlinorio de Tunas está ligado con los afloramientos diseminados de capas y lentes de calizas metamorfizadas de Campaniano–Maestrichtiano Inferior, en la morfoestructura holguinera con bloques olistolíticos de calizas de Albiano–Cenomaniano–Turoniano y de Maestrichtiano–Paleoceno Inferior, pero también con restos de la cubierta continua de calizas de Aquitaniano–Burdigaliano Inferior. Las calizas forman torres empinadas, elevaciones cónicas o mesetas rodeadas por el relieve bajo sobre las piroclastitas. En la estructura hórstica de las Lomas Candelaria–Cupeicillo, de altura de 200–300 m, constituída de calizas y dolomítas recristalizadas de Albiano–Maestrichtiano–Paleoceno Inferior, se extiende el relieve de carso cónico y cupular con sistemas de poljas amplias. Se trata de un relieve premiocénico, levantado, desenterrado y trasformado en el Plioceno con restos de calizas y margas de Mioceno Medio y biocalcarenitas de Plioceno. Las partes septentrionales de este territorio cársico se encuentran todavía por debajo de los depósitos miocénicos y sangamonianos. Los sistemas cavernarios de carso desenterrado y enterrado comunican entre sí y se unen hidrológicamente con los sistemas más jóvenes de las cubiertas. Las alas septentrional y meridional del anticlinorio Tunas las cubren calizas y margas de Mioceno Inferior–Medio con lentes de anhidrita y de yeso formando extensas llanuras costeras. En sus cubiertas se encuentra el carso interestratal intenso con reservas de agua considerables. El caudal promedio de algunos manantiales alcanza hasta 300 litros/s. sin cambio del nivel dinámico.

Anticlinorio Nipe–Cristal–Baracoa

En esta morfoestructura se encuentran ampliamente desarrollado el paleocarso interestratal o enterrado de edad Maestrichtiano–Paleoceno Inferior en las capas de calizas turoniano–senonianas y de edad de Eoceno Medio en las calizas dolomíticas de Campaniano–Maestrichtiano–Paleoceno Inferior, miembros de los complejos vulcano–sedimentarios que rodean los macizos serpentinícos. Afloramientos de calizas cretácico–inferiores, que representan restos de bordes coralinos de antiguas islas vulcánicas, presentan pequeñas regiones de carso cónico. En las Cuchillas de Moa las calizas forman una cresta transversal de conos cársicos, la cual cierra valles profundos de cuatro arroyos. Sus corrientes se unen en la cueva compleja y la abandonan en la polja marginal como el Río Moa. En el relieve montañoso muy inaccesible de la Sierra de Purial de altura de 800–1.100 m se elevan montículos aislados constituídos de lentes de mármoles carsificados pre–campanianos. Dentro de la Cuenca de Ságua del Tánamo y en los márgenes de la Cuenca de Baracoa se conservaron numerosas mesetas–testigos, restos aislados de la cubierta carbonatada de Aquitaniano Superior. El carso más notable de este tipo lo representa la meseta de Yunque de Baracoa. El carso de meseta contínuo ocupa la Altiplanicie de Maisí, que se extiende sobre la estructura tabular de calizas de Mioceno Medio–Superior bordeada por calizas de Plio–Pleistoceno y de Sangomaniano. El centro de la unidad ocupa la superficie plana, lisa y inclinada de edad pliocena. La bordean terrazas marinas plio–pleistocénicas superpuestas de 22 niveles. Profundos cañones dividen esta escalera en varias partes. En la parte suroccidental afloran desde el subyacente de Mioceno cumbres de torres cársicas enterradas, construidas de calizas y dolomítas pre–jurásicas. La parte más alta de este relieve pre–miocénico está aplanada, desenterrada, y forma altillanuras de la Sierra Verde y de la Altiplanicie de Chafarina, perforada por dolinas de tipo cockpit. El territorio se encuentra actualmente en el clima semiárido.

Aparte de carso carbonatado aparece en la Sierra del Toldo o en las Alturas de Baracoa /parte septentrional del anticlinorio/ el paracarso accidentado, desarrollado en peridotitas serpentinizadas y serpentinitas pre–maestrichtianas. Este tipo de carso ocupa altillanuras /1.000 – 600 m de altura/de edad por lo menos paleogéna, cubiertas con una potente corteza de intemperismo laterítica. Las precipitaciones abundantes de 2.000 – 2.400 mm, que caen allí durante el año entero, y el ambiente ácido de pluviselva continua /Pinus caribea/ provocan disolución de densos sistemas de venas de cuarzo y de calcita y sufosión del material desintegrado de la roca madre a los huecos subterráneos. Estos procesos producen el origen de amplios campos de lapiaz, dolinas secas y lacustres, uvalas irregulares, cuevas y resolladeros activos.

Anticlinorio Sierra Maestra

El carso de este anticlinorio representa parte del relieve montañoso, que culmina por el Pico Turquino /1.972 m/, el punto más alto de Cuba. Existen allí cuatro tipos de carso distintos. En todo el territorio se encuentran localidades pequeñas de carso aislado, que se desarrolló en forma de elevaciones cónicas y cupulares constituidas de lentes o intercalaciones de calizas recristalizadas, miembros de un complejo vulcano –sedimentario cretácico–paleogénico. En la sierra de Pilón pertenece a este tipo de carso montículos–testigos, residuos pobres de la cubierta carbonatada de Aquitaniano y de Mioceno Medio. El tipo de carso mesético con poljas someras y valles secos se extiende en la estructura tabular domificada de calizas de Mioceno Medio–Superior, que cubre el extremo occidental del anticlinorio. Por el sistema de terrazas marinas superpuestas marginales esta unidad se semeja esta unidad, denominada la Meseta de Cabo cruz, con la Meseta de Maisí. El tipo de carso costero de origen continental–marino ocupa las mesetas litorales, construídas de calizas de Mioceno–Superior y Plio–Pleistoceno, que bordean el pie de la escarpa meridional del sistema montañoso de la Sierra Maestra o las cuencas marginales de Santigo de Cuba, de Siboney–Daiquirí y de Baconao. El tipo de carso cupular y cónico de edad pre–miocénica hasta pliocénica, con poljas y semipoljas, valles secos y activos, sistemas cavernarios y desfiladeros estrechos, determinados por sistemas de fallas paralelas, representa el Carso de Guira–Baire. Ocupa una estructura tabular residual de calizas de Eoceno Medio, que está acostado sobre el complejo de piroclastitas en la ala septentrional del anticlinorio.

Sinclinorio central

La parte axial del synclinorio ocupa zonas del carso interestratal desarrolladas en los miembros carbonatados de los rellenos bastante heterogéneos de edad de Eoceno Medio–Superior. El caudal de algunos pozos profundos alcanza hasta 700 litros/s. de agua. En los domos locales, que forman numerosos mendips, se encuentra el carso aislado con yacimientos aprovechables de manganeso. En los afloramientos marginales de las calizas compactas de Eoceno Medio se desarrolló una franja accidentada de carso cónico complejo con poljas pequeñas y cañones fósiles de los ríos antiguos mortificados por levantamientos. En conglomerados y areniscas de la Altiplanificie de Santa María del Loreto, que limita en el Sur el sinclinorio, se encuentra el conjunto rico de formas para– y pseudocársica. No obstante, el tipo de carso más extendido lo representa el carso mesético que ocupa la guirnalda de mesetas marginales guantanameñas y el interior de la Cuenca del Segundo Frente. Las mesetas, compuestas de estratos carbonatados de Eoceno Medio y de Aquitaniano–Mioceno Medio, se destacan por superficies planas horizontales, combadas e inclinadas, separadas por cañones profundos activos. Las formas cársicas representan en primer lugar amplias poljas y semipoljas someras, que alcanzan alturas hasta de 800 m. La zona axial de

braquianticlinal de la Meseta de Guaso la ocupa el carso cupular fósil, ligado con calizas compactas de Eoceno Medio. La parte oriental del sinclinorio se encuentra actualmente en condiciones semiáridas hasta áridas /O – 200 mm de precipitaciones anuales/, pero el carso interestratal profundo contiene reservas considerables de agua fósil.

Sinclinorio de Guacanayabo–Nipe

Esta morfoestructura representa el carso de llanuras y interestratal más amplio de todo el territorio de la Cuba Oriental. Se desarrolló en estratos sinclinalmente combados de Eoceno Medio, Aquitaniano–Burdigaliano, Mioceno Medio y Plioceno, penetrados por varias estructuras hórsticas locales. Los acuíferos de carso interestratal de varios niveles contienen gigantescas reservas de agua subterránea con rasgos artesianos. Su cantidad anual aprovechable alcanza el valor calculado alrededor de 1.5 mil millones de m^3. El conjunto de formas exocársicas más notables del sinclinorio ocupa cuestas marginales, constituídas de calizas de Eoceno Medio y de Aquitaniano–Burdigaliano. Las partes más altas de las cuestas están desembradas en conos y torres empinados, separados entre sí por poljas y semipoljas pequeñas o por cañones profundos de ríos alóctonos. La zona litoral de la Cuenca de Nipe está ocupada por el intenso carso costero, desarrollado en las biocalcarenitas de Mioceno Superior–Plioceno. Las rocas forman crestas monoclinales aqueadas que cierran las bahías amplias de tipo bolsa. En la cresta de la Península de Carbonera se desarrollaron poljas pequeñas, rellenadas por lateritas transportadas desde las serpentinítas del Anticlinorio Nipe–Cristal–Baracoa.

Conclusión

El mapeo carsológico de Cuba Oriental facilitó muchos conocimientos nuevos sobre el desarrollo del carso diferenciado en relación con la estructura distinta y con el clima bastante variable de la zona tropical estacionalmente húmeda, aclaró distribución areal de distintos tipos de carso y construyó la base sólida para el aprovechamiento económico racional y para protección del carso y de sus valiosos recursos naturales.

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Hidrothermal and Superficial Paleokarst of the Oshskiye Gorki Area/Kirghizia, USSR

Pavel Bosák

RESUM

Les calcàries del carbonífer Inferior, plegades i tectonitzades, estan essent avui dia seccionades en diversos blocs separats, per exemple a Chilmayram, Chiulustun, Tyuya Muyun, Takhti-Suleuman, Yalgyzarcha i a d'altres turons, que constitueixen «mogots» fòssils, probablement del Juràssic Inferior, exhumats des del Juràssic al Neogen continental i el recobriment marí. Des del Juràssic fins el Neògen trobarem pujols aïllats, de més d'un quilómetre de longitud i un màxim de 500 m. d'altura. Les cavitats sub-aèries dels pujols són: 1)hidrotermals i 2) «fredes». L'activitat hidrotermal està relacionada aquí, probablement, amb el període orogènic alpí (postbécretàcic?) Es van formar laberints de coves, relativament petites, així com cavitats en forma de cúpula. Subseqüentment es varen emplenar de sediments, constituint dipòsits del complexe calcita–barita. Es mundialment famós el dipòsit de Tyuya Muyun, de coure, urani i vanadi. Els dipòsits d'interès econòmic, d'urani, es varen originar a partir d'una sèrie d'infiltracions de solucions d'aigua de pluja que transportaven urani, coure, vanadi, etc. a través de les pissarres negres dels voltants. Les coves normals «fredes» estan parcialment fossilitzades per clasts continentals del Cretaci Inferior, barrejats amb argiles, dipòsits del tipus «terra–rossa» i/o d'altres materials del Quaternari recent.

RESUMEN

Las calizas del carbonífero inferior plegadas y tectonizadas están siendo recientemente diseccionadas en varios bloques separados (por ejemplo Chilmayran, Chiulustun, Tyuya Muyun, Takhti-Suleuman, Yalgyzarcha y otras colinas) que representan mogotes fósiles probablemente del Jurásico Inferior exhumados desde el Jurásico al Neógeno continental y la cobertura marina. Desde el Jurásico hasta el Neógeno hay colinas aisladas con más de 1 Km. de longitud y un máximo de 500 m. de altura. Las cavidades subaéreas en las colinas son: 1) hidrotermales y 2) «frias». La actividad hidrotermal está relacionada probablemente con el período orogénico alpino (Postcretáceos?). Laberintos de cuevas, relativamente pequeñas, así como cavidades en forma de cúpula se formaron y subsecuentemente se rellenaron con depósitos del complejo calcita–barita. Aquí se encuentra el mundialmente famoso depósito Tyuya Muyun de cobre, uranio y vanadio. Los depósitos de interés económico de uranio se originaron durante infiltraciones de soluciones de agua de lluvia que transportan U, Cu, V, etc. a través de las pizarras negras de los alrededores. Las cuevas normales «frías» están parcialmente fosilizadas por clastos continentales de cretácico inferior parcialmente rellenas con arcillas, depósitos de tipo terra–rossa y/o con relleno cuaternario reciente.

SUMMARY

Highly folden and faulted Lower Carboniferous limestones are recently dissected into several separate blocks / e.g. Chilmayram, Chiulustum, Tyuya Muyun, Takhti–i–Suleyman, Yalgyzarcha and other Hills/ which represent fossil mogotes of probably Lower Jurassic age exhumed from Jurassic to Neogene continental and marine cover. Individual hills are /1/ hydrothermal and /2/ «cold». Hydrotheermmal activity is connected here probably with Alpine orogenic period / post–Cretaceous?/. Relatively small cave labyrinths as well as cuppola–shaped caverns were formed and subsequently filled with complex calcite–baryte fills. World known Tyuya Muyun copper and uranium vanadate deposit is located here. Economic deposits of uranium were originated during infiltration of weathering solutions transporting U, Cu, V etc. leached from surrounding black shales. Normal, «cold» caves are partly fossilized by Lower Cretaceous continental clastics, partly they are filled with clays, terra rossa like deposits and/or by young ? Quaternary fill.

Il carsismo della regione carseolana

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RESUM

L'àrea de les Muntanyes de Carseolani es troba situada entre Simbruini-Ernici, Marsica i els Apenins de Sabina (Itàlia Central). Aquí exposem nous mapes geològics i geomorfològics, dades morfomètriques a base de fotografia aèria i treballs de camp fets a aquesta zona.

Els processos càrstics i les superfícies càrstiques s'han desenvolupat, essencialment, sobre paleo-superfícies i paleovalls del Pliocè, del Villafranquià i del Plistocè Mitjà. Els rius subterranis provenen del model hidrogràfic plio-plistocènic i el seu interès ve motivat pels següents factors: 1) L'erosió diferencial entre calcàries i el complexe argila-arenisca. 2) L'elevació i fallada amb tendències tectòniques entre el horst (estructures carbonatades) i el graben (estructures detrítiques amb conques fluvials tancades). 3) Els canvis climàtics plistocènics amb transport de sediments dins de les coves.

Les cavitats tenen tres nivells hidrogeològics d'evolució. En algunes d'elles, la galeria terminal es troba situada en una superfície d'encavalcament. Els encavalcaments i les falles invertides són deformacions pre-Quaternàries. Els esforços d'expansió i de tensió són propis de l'era Quaternària i la seva activitat prossegueix encara avui (a les cavitats de Carseolani es duen a terme avui dia estudis sismotectònics amb mètodes espeleològics)i van ésser els responsables de les formes càrstiques hipogees i epigees. Les surgències de les zones càrstiques es localitzen a les conques fluvials de Turano i Salto (al N.O. i N.E. de les Muntanyes de Carseolani), en competència amb els antics rius plio-plistocènics de Carseolani.

RESUMEN

El área de los Mts. Carseolani se encuentran entre Simbruini-Ernici, Marsica y los Montes Apeninos de Sabina (Italia Central). Exponemos nuevos mapas geológicos y geomorfológicos, datos morfométricos a base de fotografía aérea y trabajos de campo en esta zona.

Los procesos y llanuras kársticas se hallan esencialmente sobre impuesto en paleosuperficies y paleovalles de edad Pliocena, Villafranquiense y del Pleistoceno Medio. Los ríos subterráneos proceden del modelo hidrográfico Plio-Pleistocénico y tienen interés debido a los siguientes factores: 1) erosión diferencial entre calizas y el complejo arcilla-areniscas; 2) elevación y fallado con tendencias tectónicas entre horst (estructuras carbonatadas) y graben (estructuras detríticas con cuencas fluviales cerradas); 3) cambios climáticos pleistocenos con transporte de sedimentos en las cuevas.

Las cavidades tienen tres niveles hidrogeológicos de evolución. En algunas la galería terminal está en planos de cabalgamiento. Los cabalgamientos y las fallas inversas son deformaciones pre-Cuaternarias. Los esfuerzos de expansión y tensión son de la era Cuaternaria y tienen actividad todavía hoy (continúan actualmente estudios sismotectónicos con métodos espeleológicos en las cavidades de Carceolani), y controlaron las formas kársticas hipogeas y epigeas. Las surgencias de las zonas kársticas se encuentran en las cuencas fluviales de Turano y Salto, (al NW y NE de los Montes Carseolani), allí, también estaban en competencia los paleoríos pliopleistocénicos de Carseloani.

SUMMARY

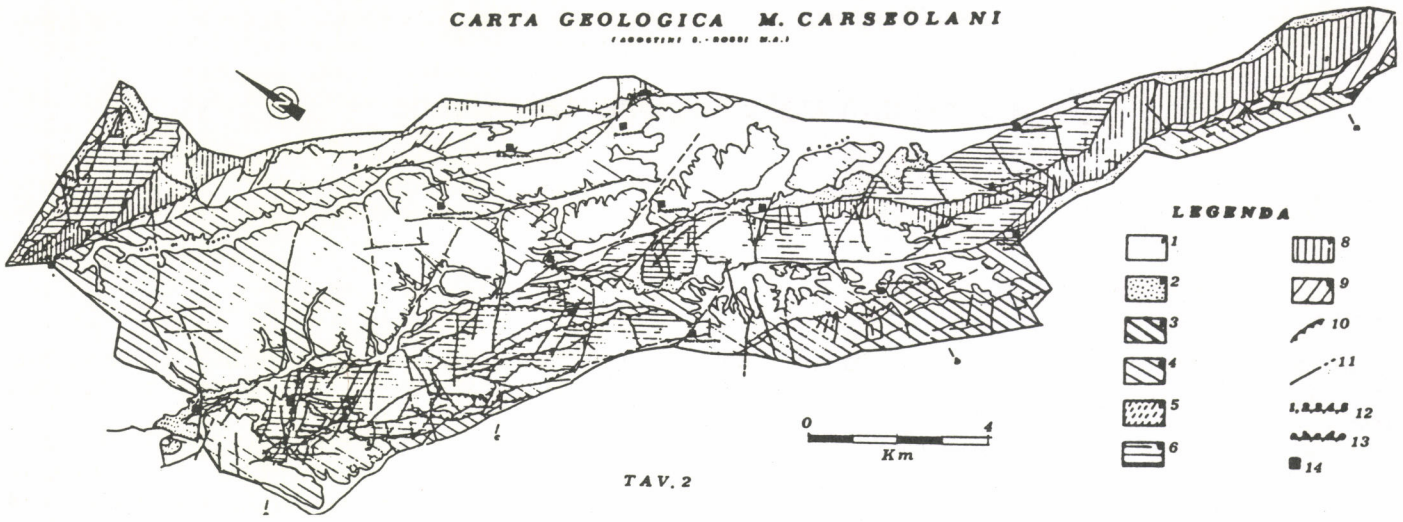
The area of Carseolani Mts. is between Simbruini-Ernici, Marsica and South Sabina Apennines Mountains (Central Italy). We explain new geological and geomorphological maps, morphometric data by aerophotos and field survey about this area.

The karst processes and karst plain areas, are mainly superimposed on paleosurfaces and paleovalley, of: Pliocene-age, Villafranchiano-age and medium Pleistocene-age. Underground rivers come from Plio-Pleistocenic hydrographic pattern, they are interred because of these factors: 1) Differential erosion between limestones and clay-sandstones complex; 2) Uplifting and faulting with tectonic trends between horst (carbonate structures) and graben (terrigenous structures with closed river basins); 3) Pleistocenic climatic changes with phases of transport of sediments in the caves.

The caves have three hydrogeological levels of evolution. In some caves the terminal gallery is over overthrust-planes. *The overthrust planes and inverse faults are pre-Quaternary deformations. Transexpansive and tensive stress are of Quaternaria age and they are still active today (sismotectonics studies with speleological methods are in progress in the Carseolani caves), they controlled the karstificated ipogeus and epigeus landforms. The springs of karst areas are in the Turano and Salto rivers basin, (at NW and NE of the Carseolani Mts.) there, also the Plio-Pleistocenic paleo-rivers of Carseolani were in confluence.*

La regione dei Monti Carseolani si situa nell'Appennino Laziale-Abruzzese (Italia centrale) limitata ad Ovest e Sud dalla catena Simbruina-Ernica, ad Est dalla catena del Velino e della Marsica, e a Nord dalla catena del Cicolano e Sabina.

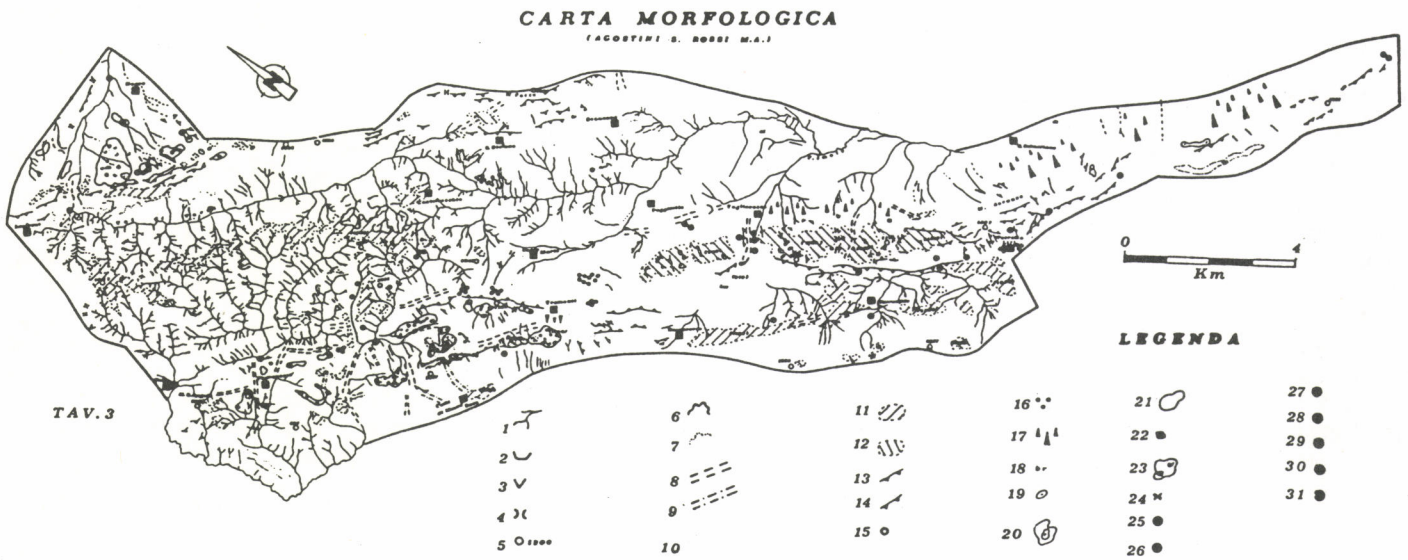
I termini affioranti evolvono stratigraficamente de una successione di calcari mesocenozoici di piattaforma (in cusi si attua la nota trasgressiones miocenica) ad emipelagiti del Serravalliano, per terminare con il complesso flyschoide torbiditico a litologia arenaceo-argillosa e fauna tortoniana. Il Pliocene sup. e il Quaternario sono testimoniati da morfosculture e depositi continentali. Sempre alla stessa età vanno riferite le forme carsiche ipogee ed epigee che si impostano sulle deformazioni prodottesi per stress soprattutto tensionali. Contemporaneamente per tutto il Quaternario continua il sollevamento della catena (pleistocene medio) e si registrano almeno tre cicli climatici freddi. La struttura geologica ripete l'assetto tipico dell'Apennino con unitá e sottounità strutturali giustapposte sui fianchi orientali per sovrascorrimento del basamento calcareo sui flysch. Il fianco occidentale delle catene è definito da faglie dirette con rigetti superiori ai 1000 m. Dal Pleistocene inferiore nuove deformazioni (o la ripresa di vecchi



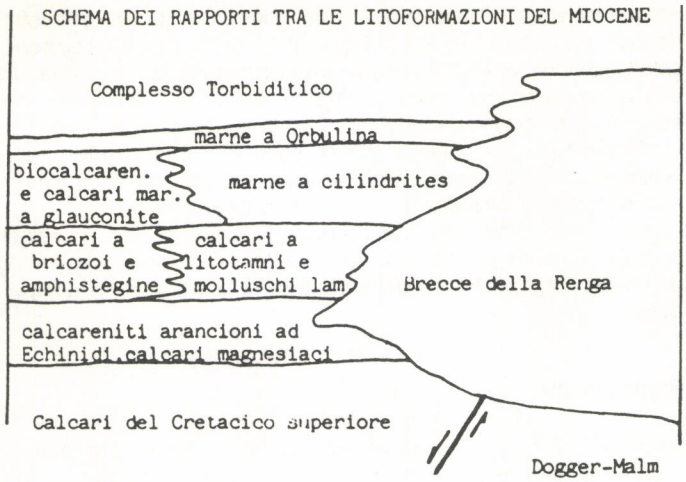
1– *Alluvioni* (a)
2– *Detrito* (dt)
3– *Brecce della renga* (Br)
4– *Flysch* (fy)
5– *Marne ad orbulina* (m)
6– *Miocene calcareo* (Mc)
7– *Cretacico superiore* (c_2)
8– *Cretacico inferiore* (c_1)
9– *Sovrascorrimento*
10– *Faglie*
11– *Serie campionate (1,2,3,4,5)*
12– *Tracce profili geologici (a,b,c,d,e,)*
13– *Principali abitati*

lineamenti), tutte di carattere distensivo o transespansivo, ridefiniscono l'assetto morfostrutturale dell'area. Nel Pliocene superiore le fosse strutturali dove affiorano i terreni terrigeni miocenici, non erano ancora depresse per erosione differenziale, e l'idrografia tagliava indifferentemente le strutture per confluire in bacini più «costieri» verso NW o a SE, lungo le tipiche e permanenti direttrici orografiche appenniniche. Il sollevamento differenziato tra gli Horst carbonatici e i Graben con depositi flyschoidi condizionava il procedere dell'erosione differenziale che chiudeva in più bacini l'idrografia superficiale. Si sono innescati così del trafori sotterranei con inghiottitoi diretti. I tracciati ipogei avvengono principalmente sotto la verticale delle paleovalli o lungo faglie trasversali di difficile interpretazione nella storia tettonica della area. Terrazi morfologici paleovalli e una probabile paleosuperficie di età Villafranchiana, hanno costituito durante tutto il Quaternario le aree preferenziali per lo sviluppo del carsismo di superficie. In esse si compongono i principali apporti sia alla falda di base che alle grotte di attraversamento, che hanno i loro percorsi attivi sospesi sulla prima. Si hanno dunque grotte impostate lungo faglie normali alla catena, da cui parte delle acque del bacino fuoriesce velocemente dall'unità idrogeologica. La falda di base invece sarebbe subordinata all'asseto strutturale regionale, confluendo il drenaggio profondo in sorgenti di notevole portata collocate ben oltre la periferia dei Carseolani, dove già nel Pliocene superiore confluiva l'idrografia superficiale. Dopo l'aggiornamento della carta geologica con nuovi rilevamenti, è stata eseguita una carta morfologica generale ed analisi morfometriche sulle morfologie carsiche epigee. I risultati e il loro commento sono espressi nelle tavole seguenti.

A tutt'oggi le grotte conosciute sono circa 30 così raggruppabili tipologicamente: A) Inghiottitoi attivi e inghiottitoi fossili sovrasp-



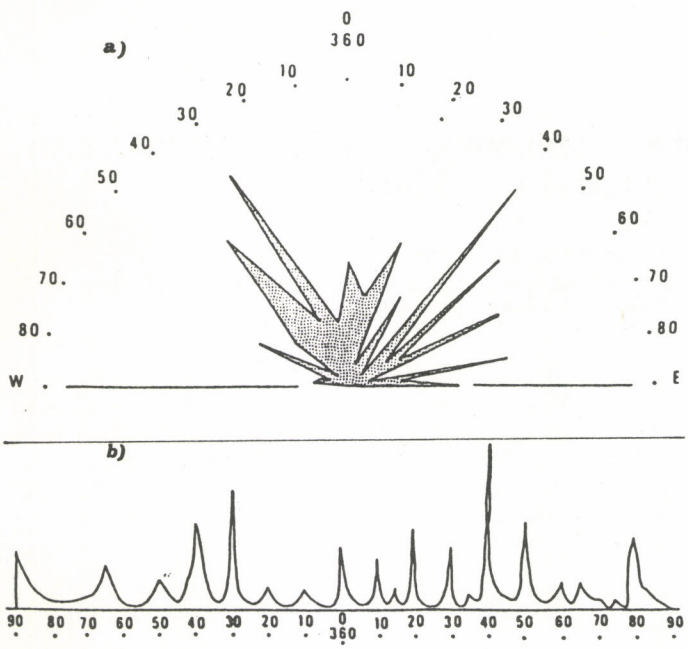
1 *Reticolo idrografico*
2 *Valli a fondo piatto*
3 *Valli riincise con asimmetria marcata*
4 *Selle*
5 *Principal vette e culminazioni orografiche con relativa quota*
6 *Calanchi*
7 *Pseudo calanchi e scarpate in colluvi e alluvioni*
8 *Paleovalli di 2° ordine*
9 *Paleovalli di 1° ordine*
10 *Paleobacini lacustri di 900 m*
11 *Paleosuperficie di 1000 m sulle arenarie*
12 *Paleosuperficie spianamenti sui calcari (950-1200 m)*
13 *Scarpate h ≡ 10m*
14 *Scarpate h + 10m*
15 *Frane di flusso e miste*
16 *Paleofrane*
17 *Versante normalizzato*
18 *Brecce antiche crasificate e tettonizzate*
19 *Doline*
20 *Pian.Riincisa da doline*
21 *Piani carsici*
22 *Karren*
23 *Pian.Carsiche a doline e karren*
24 *Canion carsici troncati da faglie*
25 *Risorgenza*
26 *Inghiottitoio*
27 *Cavita'tettonica*
28 *Tronco di condotto fossile e/o inattivo*
29 *Grotta decorticata per erosione o troncata da faglie*
30 *Pozzi su faglia*
31 *Inghiottitoio ostruito*



Tav 6-8 Forme carsiche epigee areali

PDK – *Piani riincisi da doline di medie dimensioni e con «isole» di roccia interessata da Karren.* DDoline *di media dimensione che riincidono campicarsici isolati sui pendii macro doline.* P– *Piani carsici su tronchi di paleovalli con approfondimento di origine tettonico-carsica.* K– *Karren su dorsi o superfici di roccia a sviluppo anisotropo secondo le direttrici tettoniche dell'area.* DK– *Piccole doline e Karren isolati su lembi di terrazzi montani e vallivi. Forme di «alta montagna» sovraimposte ad antiche superfici piane in prossimità di morfologie nivo-glaciali o periglaciali.*

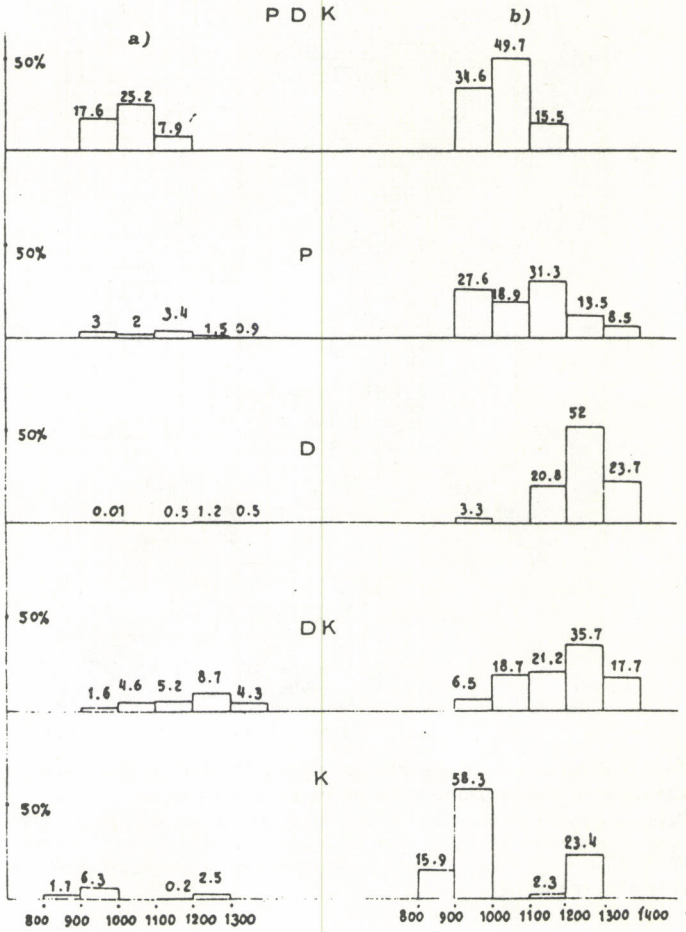
posti ai primi (Sistema di Pietrasecca, Gr. Grande del Cervo; Luppa; Val di Varri: Imele,; Sistema B.Cenci, Ovido di Verrecchie; Tufo e Acqua Nera). B) Risorgenze dei sistemi di cui sopra o più generalmente di canalizzazioni con ingressi sconosciuti ma a direttrici note su base geologico-strutturale. (Imele, Vommeca, Pietrasecca, etc.) C) Grotte tettoniche e tronchi di canalizzazioni intercettate dall'arretramento dei versanti lungo pareti di faglia, (Cola I e II, Gotte di Capistrello, Callararo). Quest'ultime grotte costituiscono il più antico sistema carsico ipogeo conosciuto, completamente isolato dall'asseto strutturale definitosi con il Quaternario, in relazione però con i lineamenti morfologici e l'asseto di quella che era la catena tardo sin orogenica (pliocene sup.). Nelle grotte del gruppo A si riconoscono tre evidenti livelli di stasi, l'ultimo dei quali polifasato in quattro orizzonti (evidenti solo in grotta) nell'ambito di 2m. Le forre ipogee attuali terminano a volte lungo un piano orrizzontale (spesso con «risorgenze» interne) che ben si raccorda con i piani do scorrimento rilevati dai dati di superficie.



Tav. 5 Diagramma polare e curva di distribuzione delle lineazioni da foto aeree B.N. dell'area carseolana.

I picchi principali ben coincidono con i sistemi di dedormazioni tettoniche, in particolare il picco N20°E coincide con faglie trascorrenti destre che «deviano» o sbarrano i percorsi ipogei.

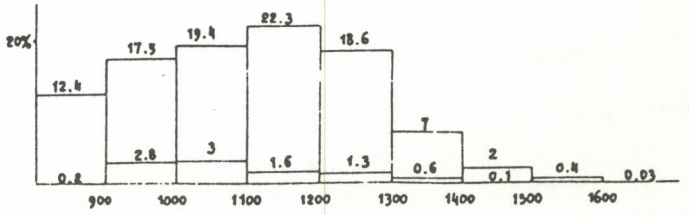
La possibilità di correlare gli ingressi ipogei attivi e fossili con terrazzi fluviali, interni od esterni ai bacini chiusi, e gli stessi terrazi con specchi lacustri a fauna pleistocenica, permette di avanzare un ipotesi di cronologia sull'evoluzione morfologica dei procesi carcisi. Contribuiscono, inoltre, alla cronologia morfologica lembi di paleosuoli industrie preistoriche. In sintesi i tronchi vallivi superficiali risalirebbero al Pliocece Superiore-Pleistocene inferiore, gli ingressi degli inghiottitoi attuali risulterebbero di età medio



Tav. 6

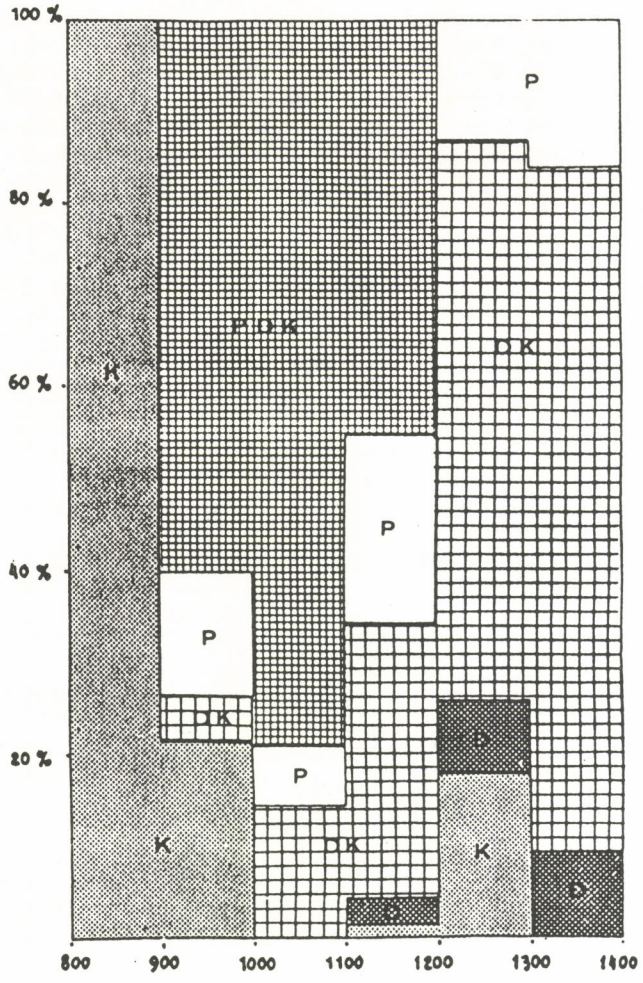
A) Posta uguale al 100 % l'estensione di tutte le singole forme carsiche epigee, sono espresse in % di estensione le singole forme nei diversi intervalli di quota. b) Posta uguale al 100 % l'estensione totale della singola forma carsica epigea, sono espresse le % di distribuzione nei diversi intervalli di quota.
Dall'analisi emerge che le forme PDK sono le più estese e individuano un intervallo 900-1200 mt dove si sviluppano i principali fenomeni carsici areali di superficie. Interessante notare il concentrarsi di K a quota 850 e 1350 m in prossimità delle faglie longitudinali, bordiera ed interna, che delimitano la paleosuperficie villafranchiana. Le forme PDK sono tipiche di piani soggetti a ripetuti cicli di erosione, sedimentazione e riincisione. Le forme K denotano zone a fessurazione decisa con sistemi deformativi coniugati.

pleistocenica, il loro approfondimento sarebbe avvenuto durante il Pleistocene medio. Le soglie attuali e il livello polifasato, ed oggi riinciso, dovrebbero collocarsi nel tardo Pleistocene-Olocene. Al Pleistocene inferiore potrebbero collegarsi le gallerie alte raggiungibili solo dall'interno delle grotte, come pure quelle forme d'ingressi obliterate da imponenti frane. Le quote indicherebbero che i sollevamenti principali dellacatena sono da riferirsi al Plioce-



Tav. 7

100 % = area totale di affioramenti carbonatici. Distribuzione delle aree nei diversi intervall di quota e % delle superfici areali incarsite epigee negli stessi.



Tav. 8 Diagrama normalizzato per ogni intervallo di quota ove si riassume la distribuzione delle forme carsiche epigee.

Appare evidente la concentrazione di forme «areali» in prossimità della paleosuperficie villafranchiana (1100 m.c.a.), di ripiani più antichi (1.400 m.c.a) e più recenti (850 m.c.a). Esse marcano stasi di sollevamento e azioni in clirni favorevoli ad erosioni carsiche di tipo «areale».

ne superiore e al Pleistocene medio. Il livello polifasato starebbe ad indicare complesse azioni legate a fattori di portata, trasporto solido, concrezionamento, (cioè fattori climatici) non escludendo azioni neotettoniche relativamente modeste sotto l'aspetto del sollevamento della catena.

Paleosismi, preistorici e storici, sono ben documentati nelle grotte e sono oggetto di uno studio specifico con metodi speleologici in corso di svolgimento per tutte le cavità dell'area.

I processi carsici integrate dunque alla struttura dei Carseolani si sono sviluppati dinamicamente durante il Quaternario registrando l'evoluzione geologica del settore nelle sue molteplici componenti.

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The Great Caucasus as the classical karst and speleological Region of the Earth (The prospects of speleological discoveries)

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RESUM

Durant més de dues dècades s'han estat duent a terme una sèrie d'investigacions espeleològiques al carst del Gran Caucàs, confirmat-se més de 1.500 fenòmens espeleològics. D'entre ells, cal destacar la cavitat més profunda de la U.R.S.S. : la cova de Snezhnaya, de 1.370 m. En un futur no molt llunyà no seria estrany de descobrir les cavitats més profundes de la Terra, precisament en les extenses roques calcàries de Geòrgia. Són, doncs, fundats els motius que fan sospitar l'existència de les cavitats subhoritzontals més grans a les conques dels rius subterranis de Machishta (la descàrrega mitja anual dels quals és de l'ordre de 9,3 m^3/seg., amb un màx. de 197 m^3/seg.)

RESUMEN

Durante más de dos décadas se han llevado a cabo investigaciones espeleológicas en el del karst del Gran Cáucaso. más de 1.500 fenómenos espeleológicos han sido descubiertos aquí. Entre ellos está la cavidad más profunda de la URSS-Snezhnaya de 1.370 m. En el futuro próximo se podrían descubrir las más profundas cavidades de la Tierra en las calizas masivas de Georgia. Existe una rigurosa justificación para el descubrimiento de los mayores sistemas de cavidades subhorizontales en las cuencas de los ríos subterráneos Machishta (cuya descarga anual media es de 9,3 m^3/seg. máx 197 m^3/seg. etc.).

SUMMARY

Speleological investigations of karst in the Great Caucasus are carried our over two decades. More than 1.500 speleological objects have been discovered here. Among them is the deepest cave of the USSR-Snezhnaya 1.370 m. In the nearest future at the calcareous massives of Georgia the deepest karst caves of the Earth could be discovered. There exists rigorous substantions for the discovery of the largest subhorizontal cave systems in the basins of underground rivers Machishta /mean annual discharge 9.3 m^3/sec, max 197 m^3/sec/etc.

The mountainous karst of Georgia is developed in the rather complex geological structure and relief. Here are represented and carstified the Upper Jurassic rocks, all stages and substages of cretaceous system of the Lower Paleogene with total magnitude of more than 2.500 m. Very often stratified, poorly stratified and solid karstified stratum alternate in the sections. Within the boundaries of separate massivs these rocks being subjacent with bayou and bathian sandy-agrillaceous and volcanogenic deposits are lowered deeply under the main drainage levels, which is very important for the underground water flow and development of karst features in the abbyssal parts of karst stratum.

The Great Caucasus is characterized by large scale karst processes developing mainly under the favourable geological and geographical conditions. Thus, the most karstified and large speleological region of the Great Caucasus –the calcareous belt of the West Georgia and that of Sochi region– coincides with the zone of maximum atmospheric precipitations, total annual volume of which allowance for so called «horizontal» precipitations makes up at places not less than 3.000 mm. The favourable preconditions for karsting are created by the deep ruggedness of the relief and the orographic isolation of the majority of massivs, jointing and shattering of the rocks. Under consideration of geological and tectonic conditions in the Great Caucasus area there are singled out the types of mountain and lowland karst, which differ from each other by the character of tectonic movements and the circulation of karst water, i.e. by the conditions of speleogenesis.
(Tintilozov Z.K. 1976).

The systematic speleological investigations of karst in the Great Caucasus are carried out over two decades. During this period by the efforts of georgian speleologists and those from the other republics of the USSR more than 1.500 speleological objects (by the preliminary data) have been discovered. The Great Caucasus and mainly the karst region of the West Georgia is rich with already discovered and partialy investigated carst caves. By the prospects of speleological discoveries this region has no rivals in the USSR, and doesn't give way to the first-rate «speleostates» of our planet.

Among the most famous karst caves of the Great Caucasus one is to mention the New Afon cave system, its volume is over 2 million m^3 and Sneznaya– one of the deepest (–1.370 m) vertical cave system in the world. Possibly in the nearest future it will become the deepest one since there is a real perspective to reach the depth of 1.800 m. In this respect are of some interest partially investigated caves Napra (–970 m) in the Bzibi massiv, Kuibishevskaya (–950 m) in the Arabika massiv and others. In the abbyssal part of Arabika massif (caves Kuibishevskaya and Ilukhina) the routes of underground rivers are traced. They are discharged at the Black Sea beach zone and under the sea level in the vicinity of the resort Gagra. The difference in ellevation marks between the head of the Kuibishevskaya cave and the outflow of the famous vaucluz Reprua at the territory of old Gagra is 2.180 m. Thus the existance of the deepest karst hydrosystem of our planet is confirmed. Not long ago, the speleologists of the Vakhushti Institute of Geography have discovered an extremely picturesque Tskhaltubo cave (the West Georgia) with total length up to 3 km. In spite of the fact that in recent years have been done a lot, still we have a vague idea about of the most interesting karst objects of this region. Among them there are still unaccessible for a man the underground river basins of Mchishta, Rechki, Reprua, Tsachkhura, Kholodnaya Rechka (the West Georgia) and many others –very promising speleological objects. The nature itself «took care» of these remarkable monuments filling up their entrances with fast flowing low temperature (7-II°C) vaucluz springs. The heaving narrow fractures of these hidden caves are also unpassable for the man.

There is the supposition that in the basins of the above mentioned underground rives of Georgia there can be discovered and investigated still unknown large cave systems. This concerns mainly the river Mchishta. As it is known, its source lies in the Bzibi Alpine massiv, the distinctive geomorphological feature of which is its high jointing and dissected surface that stipulates the quick percolation of abudant atmospheric precipitations into the abbyssal parts of the massiv. One gains the impression, that the major part of run-off of the Bzibi massif the total area of which is 560 m^2 is drained by the river Mchishta with mean and maximum discharge of 9,12 and 197 m^3/sec. The high-water at Mchishta coincides with the spring season, and is associated with thawing at the numerous snow fields located at the flat surfaces and slopes of the Bzibi massif. The Mchishta's run-off increases considerably also during the heavy and continious rains. The question arises how move the huge volumes of water in the labyrinth of the Bzibi massif?

What is the hydrography of underground rivers and lakes, oscillation of their levels, the topography of cave passages. These questions and many others still remain unsolved. One is clear, that the river Mchishta along its coarse creates the complex labyrinths of well washed underground passages with the assumed length of many tenths or even some hundred kilometres. This is our prognosis based on some indirect facts, which long ago required the checking and confirmation. But in what way? The daring attempt of speleologist-aqualungists who hardly penetrated into the labyrinths of the Mchishta through the flooded channels, didn't crowned with success. After diving to the depth of 40 m. in the main siphon and overcoming 70 m long sloping pipelike water –filled passage they had to retreat due to strong ascending cold water flow. To penetrate into the underground halls from the surface through the natural wells and pits also became impossible– due to their tightness. Under such circumstances the most reliable means for revealing the carst caves are the geophysical methods.

In September, 1982 above the outflows of the River Mchishta (Abkhazia) the first geophysical reconnoitring expedition at the specially selected points, between villages of Barmish and Otkhara, has carried out the vertical electric zonding. The result was fantastic. The geophysical observations confirmed the existance of formarly unknown water and air filled giant halls at the depth of 50-70 m. the geophysical data has confirmned our prognosis that the Mchishta hides down in in its realm the huge halls and passages. For comparison, it is interesting to note, that the areas of massivs where the largest cave systems in the world are embeded /Dublyanski, Ilukhin, 1982/ are inferior to the basins areas of the large underground rivers of Georgia (see table). As per the other parametres the calcareous massivs of the West Georgia leave the most favourable impression as well.

Name of cave, country	total length km	massif area km^2 where the cave is embedded	maximum length of massif, km
Flint-Mammoth, USA	471,0	30-35	8,5 x 7,5
Optimisticheskaya, USSR	153,3	0,8	1,9 x 2,2
Holloch, Switzerland	139,8	4,6	5,0 x 2,3
Mchishta, Georgian SSR	?	150	35 x 15
Tsachkura, Georgian SSR	?	200	25 x 25
Tsivtskala, Georgian SSR	?	100	18 x II

The assumption on the bonding of the Mchishta and Sneznaya is of great interest. We believe, that the Mchishta and Sneznaya caves are the parts of the single Mchishta hydrogeological system. If this supposition comes true, our country will get the cave system of extra class.

Since the confirmation of our scientific prognosis on the existance of the great cave system, in the interior part of Mchishta, there arises the necessity of realization of the complex developing programm. At the beginning the work must be based on the results of complex geophysical observations. To enter the abbyssal part of Mchishta it will be necessary to build the tunnel at the outflow of underground river. The Sneznaya and the Mchishta are not the unique among the perspective caves of the Caucasian karst. Among the recently investigated vertical caves at the Arabika masiv we can name the Kuibishevskaya precipice (950 m) at the far end of which there is a large hall with the following parametres: length 130 m, width 80 m, height 270 m, volume 600.000 m^3 (Klimchuk, Rogoznikov, 1984). The hall of this height hasn't been known in the USSR.

Among the most perspective underground karst bassins of the Great Caucasus, where the complex multikilometre long waterflooded cave systems can be discovered we can name Rechkhi (the mean annual discharge 3,70 m^3 sec, Okhachkue massiv), Reprua (2,2 m^3/sec, Arabika) Tsachkhura (3,0 m^3/sec, Askhi) and many others. In the latter one (as per Maruashvili L.I. 1969) the cave system of some hundred kilometres long is hidden.

Thus the forthcoming speleological investigations of the Great Caucasus promise to be of great interest both in scientific and applied aspects.

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El karst del Valle del Rio Seco (Sierra del Caurel, Galicia, noroeste de España)

Joaquín G. de Azcárate

RESUM

En aquest estudi, s'intenta donar una visió objectiva de l'origen i desenvolupament de les formes càrstiques de la vall de riu Seco.

El procés de carstificació es veu interromput per varis factors: la discontinuïtat litològica de la vall, on s'alternen calcàries i materials no calcaris, l'abrupta morfologia del paisatge i, finalment, les falles que interrompen les bandes calcàries. No obstant, l'activitat tectònica associada a aquestes falles, facilità els primers passos en el desenvolupament del carst.

Actualment, el clima humit i l'acció adicificant de la vegetació, són els responsables de la considerable descalcificació de les formes litogèniques de la majoria de les coves.

RESUMEN

En este estudio, se intenta dar una visión objetiva del origen y desarrollo de las formas kársticas en el valle del río Seco.

El proceso de karstificación se ve interrumpido por varios factores: la discontinuidad litológica del valle donde alternan calizas y materiales no calcáceos; la abrupta morfología del paisaje y finalmente las fallas interrumpiendo las bandas de caliza. Sin embargo, la actividad tectónica asociada a estas fallas, facilitó los primeros pasos en el desarrollo del Karst.

Actualmente, el clima húmedo y el efecto acidificante de la vegetación, son los responsables de la considerable descalcificación de las formas litogénicas en la mayoría de las cuevas.

SUMMARY

In this study, an objetive view over the origin and development of the Karstic forms in the Rio Seco valley is made.

The Karstic process is being obstructed by several factors; the mixed geology of the valley, including limestone and not calcic materials alltoghether; the extreme abrupcy of the landscape, and finally the faults interrupting the limestone strips.

Nevertheless, sometimes tectonic activity asociated with faults facilitates the first steps on the Karst development.

As a result of ancient fractures and dissolution processes, sinks and caverns do occur.

Nowadays, the humide climate and the acidifyng vegetation, are responsible of a remarkable decalcification on the lithgenic forms in the caverns.

Introduccion

La comarca del Caurel, situada en el sureste de la provincia de Lugo, es una de las zonas de Galicia, junto con la Sierra Encina da Lastra y la vega de Mondoñedo, más interesante desde el punto de vista geoespeleológico, debido a la potencia y extensión de la caliza. En ella, se encuentran diferentes formas kársticas de interés, como el lapiaz «O Taro Blanco», la sima Aradelas (la más profunda de Galicia, con -160m.) o la cueva de la Ceza por donde discurre el segundo río subterráneo más largo de la Comunidad.

Sin embargo, el presente trabajo, se centra en el estudio de un determinado valle de la Sierra, que bien podría considerarse como prototipo de otros de la zona, con similares características geológicas y morfológicas.

Caracteres

–*Localización*: El río Seco nace en la «devesa da Rogueira», en la vertiente septentrional del pico «Formigueiros» (1643 m.), y desemboca en el río Lor, junto a la Ferrería de Seoane (54 m.). La línea divisoria de aguas, marca la extensión de la cuenca, la cual pertenece al Término Municipal de Folgoso de Caurel.

–*Clima*: Para la caracterización climática, me he basado en los datos de la estación meteorológica de Pedrafita do Cebreiro, que, pese a no pertenecer a la comarca, es suficientemente representativa debido a su proximidad y altura.

La zona posee un clima Oceánico con ciertas influencias de Mediterraneidad debido, sobre todo, al déficit hídrico del estío. A causa de la abrupta morfología, toma gran importancia el gradiente altitudinal de las precipitaciones (Guitián F. et al 1985). Así, mientras en la desembocadura del río Seco(540 m.) se recogen sobre 1100 mm., en la cumbre de Formigueiros, situada a unos 6 km. del lugar anterior, se espera una precipitación de 2500 mm.

De nuevo, como consecuencia de la abrupta morfología, la temperatura va a oscilar en función del gradiente altitudinal. La temperatura media anual desciende 1° C por cada 150 m. ascendidos hasta los 1100 m. A partir de ahí, la temperatura desciende más lentamente. Por ello, se espera que en la desembocadura, la temperatura media anual sea de 12° C, en Moreda sea de 10° C y en la cima de Formigueiros sea de 6 C°.

–*Vegetación*: La sierra del Caurel, se encuentra en una zona de transición entre dos regiones biogeográficas distintas: la Eurosiberiana y la Mediterránea. (Amigo J. 1985)

La presencia de bandas de calizas, va a llevar asociada una flora muy característica, que supone una alternativa ecológica muy interesante, distinta a la de los materiales silíceos. Destacan, por su fuerte ligadura al sustrato calcáreo, las comunidades de hayedos, encinares y roquedos. Donde yacen los materiales silíceos se instalan robledales y castañedas, que en sus etapas de degradación, dan lugar a retamales y brezales.

Morfología e Hidrología

La sierra del Caurel, está constituida por una serie de montañas disimétricamente plegadas, en dirección NE-SO y fuertemente fracturadas y falladas.

Las fuertes diferencias de altitud, conforman una topografía accidentada, con profundas gargantas y relieves muy marcados, en los que la erosión diferencial ha acentuado el aspecto fracturado. (Guitián et al 1985). El río Seco ocupa una de esas gargantas salvando un desnivel de casi 1000 m. en 5 km. El cauce del río Seco, se abre paso aprovechando zonas de contacto entre materiales y posibles fracturas. Las laderas difieren en cuanto a su morfología: la izquierda, es más abrupta y elevada que la derecha, debido a que desciende del eje central de la sierra, mientras que la otra, proviene de una ramificación perpendicular a dicho eje, que divide dos cuencas de alimentación del río Lor.

Debido a la acción erosiva, se han formado estrechos valles asimétricos, caso del río citado, en el cual los resaltes residuales de cuarcita, pizarras o calizas, contrastan fuertemente sobre el terreno. La cabecera discurre por un anfiteatro que actúa de cuenca de recepción de los numerosos regatos, recordando a un circo glaciar. El límite inferior de este anfiteatro coincide con la disminución del gradiente altitudinal, suavizándose la pendiente del río. Perpendicularmente al talweg discurren riachuelos que desaparecen en el estío; éstos proliferan mucho mejor en las laderas de la margen izquierda, pues las pizarras y cuarcitas, más abundantes que las calizas, son más impermeables, por lo que la formación de corrientes de agua se verá más favorecida que en la ladera opuesta, en la que al predominar los materiales calcáreos, hay una mayor filtración.

En la desembocadura, así como en otras zonas del curso medio y bajo, se produjo un proceso de sedimentación de materiales arrastrados por la corriente, formándose pequeñas vegas aluviales.

Geología

El área de estudio se encuentra integrada en la denominada «Zona Asturoccidental-leonesa». Estratigráficamente se caracteriza por poseer series muy potentes del Paleozoico Inferior, plegadas y desarrollando esquistosidades de flujo. Son las rocas sedimentarias metamorfizadas las que ocupan la mayor parte de la sierra, junto con pequeñas áreas de sedimentos recientes (Abril J. 1981).

Las series que aparecen, pertenecen a los siguientes períodos:

–Cámbrico Inferior: Constituido por las series de Cándana Inferior, Medio y Superior. La primera está formada esencialmente por una sucesión de cuarzo-esquistos, cuarcitas y pizarras, todas ellas agrupadas en pizarras, areniscas y cuarcitas de Cándana Inferior y Medio en el mapa geológico (Figura 1 ; base geológica

FIG. 1

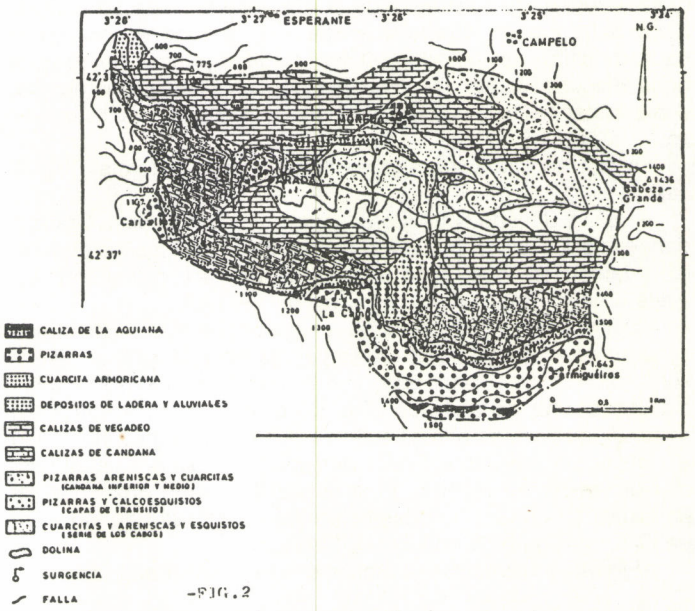
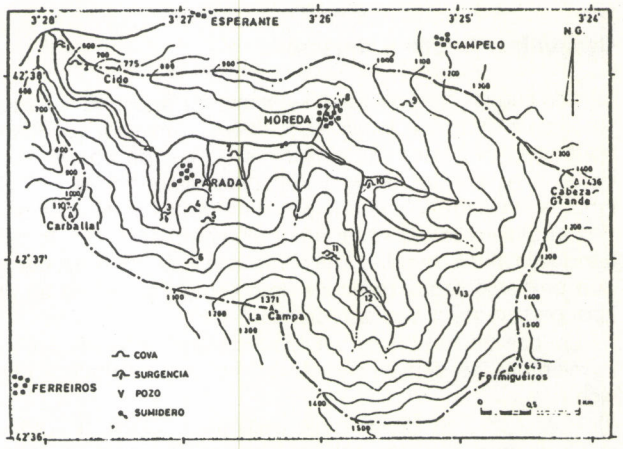


FIG. 2



recogida del I. G. M. E. año 1981). La serie de Cándana Medio es la de mayor diversidad litológica de la zona; En el mapa se agrupan conjuntamente con los materiales de Cándana Inferior, para las rocas no carbonatadas, mientras que las carbonatadas, calizas dolomías y mármoles, se agrupan en calizas de Cándana. La serie de alternancias se caracterizan por su complejidad a escala de afloramiento. Viene representada por pizarras y calcoesquistos. La última serie del Cámbrico Inferior es la caliza de Vegadeo, formación carbonatada con varios miembros de naturaleza detrítica.

–Cámbrico Medio y Superior-Tremadoc (Ordovicio Inferior): Representado por cuarcitas areniscas y esquistos.

–Ordovicio: Las rocas más representativas son la cuarcita Armoricana, pizarra de Luarca y de la caliza de la Aquiana.

Por último aparecen las formaciones del Cuaternario, que corresponden a sedimentos recientes caracterizados por su limitada

potencia. Según su origen y morfología, pueden ser de tipo aluvial o coluvial, y se sobreponen a la caliza de Vegadeo.

Dinámica y formas del Karst

El proceso de alteración Kárstico no tiene igual importancia en el área de calizas de la zona. En la ladera de Cido y Moreda la filtración de agua es casi total, llegando hasta el nivel de base del río, a través de la zona vadosa. La corriente circula bajo tierra desde que empieza a atravesar la caliza, aflorando de nuevo en la desembocadura al río Lor en forma de surgencias.

En la ladera opuesta, el agua que se filtra por la caliza no alcanza el nivel de base del río, debido a la limitada potencia de ésta. Los materiales impermeables subyacentes impiden la circulación vertical del agua, lo que hace que la mayoría de las corrientes sean superficiales, aunque también las haya subterráneas como la que origina «A cova do río de Parada». Este se forma a partir del agua de filtrado que atraviesa la zona vadosa de la capa de caliza de Vegadeo. Al llegar a la capa impermeable, el agua discurre sobre ella produciendo una circulación forzada, como lo manifiesta el potente manantial que aparece en dicha cueva.

En el área estudiada aparecen las siguientes formas Kársticas:

–Lapiaz: Situado entre Moreda y el monte de Cabeza Grande, donde la caliza aflora casi uniformemente entre pequeños pastizales y bosquetes que, poco a poco, tienden a ir colmatando de suelo orgánico los rellanos y las grietas de lapiaz.

–Dolinas: Se encuentran en el monte de Cido. Su origen seguramente se deba a la rotura de una bóveda en una galería subterránea. Sus dimensiones son bastante parecidas, llegando a alcanzar una de ellas los 20m. de diámetro; sin embargo su profundidad no llega a los 3m. en su punto más bajo. Esto, unido a la abundante vegetación hace que sean muy difíciles de diferenciar del resto del entorno. Pese a ser de las denominadas de hundimiento, aun no ha aparecido ninguna cavidad en la ladera de Cido que pudiera ratificar su formación.

–Simas y cuevas: Se estudian en el siguiente apartado.

Cavidades: Origen y desarrollo

Las cuevas de este valle, se caracterizan por su corta longitud y escasez de formaciones litogénicas. La relativa abundancia de materiales calcáreos, no se ve correspondida con la existencia de alguna cavidad de considerables dimensiones. En algunos lugares, se debe a la heterogeneidad de los materiales que impiden el desarrollo del karst; en otros, como en el monte del Cido, aunque la masa de caliza sea compacta y homogénea, las galerías que probablemente se encuentren en su interior no se abren a la superficie de forma apreciable.

La localización de las cavidades viene señalada en la figura 2, mientras las demás características se describen a continuación:

2) –Cova da Ferrería (enclave geológico: Caliza de Vegadeo)
a) Morfología: Sus dos entradas contiguas dan paso a una sala llena de bloques, la cual se estrecha hacia el fondo en dirección a una boca semiobstruida.
b) Génesis: Su formación se debe al ensanchamiento de las juntas de estratificación, en la cual hubo un relleno detrítico posterior.
4) –Cova do Pradairo (Caliza de Vegadeo)
a) Morfología: Se abre al exterior en forma de grieta alargada y estrecha a ras de suelo. Hacia el interior se abre una galería alargada y estrecha de paredes paralelas, que se va cerrando.
b) Génesis: De claro origen tectónico, formada a favor de una diaclasa cuyo piso inclinado coincide con la orientación de los estratos. La dirección uniforme y las secciones homogéneas son típicas del proceso de formación tectónico.
5) –Cova do Castro(Caliza de Vegadeo)
a) Morfología: Formada por una única galería de casi 50 m. de sección homogénea en forma de ojo de cerradura. Aparecen algunas formaciones, bloques, gours y golpes de gubia
b) Génesis: Su origen se debe a un proceso de conducción de aguas. En las zonas más bajas y de sección pequeña, la conducción debió de ser forzada como lo muestra la roca compacta y homogénea. En las demás zonas se produjo una conducción libre a través de las juntas de estratificación.
3) –Cova do río de Parada (Caliza de Vegadeo)
a) Morfología: Consta de unas pequeñas galerías comunicadas por gateras, todas ellas recorridas por el río que dificulta el acceso
b) Génesi: Originada por un proceso de conducción forzada de agua
8 –Pozo dos Vereciños (Caliza de Cándana)
a) Morfología: Formado por una sima de –16 m. en cuyo fondo se abre una galería de forma elíptica con abundantes bloques.
b) Génesisi: Se trata de una sima de hundimiento comunicada al exterior por una diaclasa.
9) –Cova das Choias (Caliza de Cándana)
a) Morfología: Consta de una galería horizontal de sección homogénea con una pequeña bifurcación ascendente en su final.
b) Génesis: Originada a partir de una diaclasa vertical. En su etapa final de formación hubo un considerable relleno detrítico.
7) –Cova do Tarelo (Caliza de Vegadeo)
a) Morfología: En su interior se abre una pequeña galería que por medio de un pozo de 12 m. se comunica con unas salas inferiores.
A lo largo de todo su recorrido aparecen numerosas formaciones.
b)Génesis: Se debe a la conducción libre de agua a través de las juntas de estratificación y las fisuras.
10) –Cova do Vello (Pizarras)
a) Morfología: Formada por dos galerías ascendentes y paralelas que se unen al final. Por una circula el agua actualmente y por la otra circuló en otra época estando en la actualidad fósil.
b) Génesis: Se diferencian dos etapas: En la primera la galería de acceso se originó como consecuencia de la conducción forzada de agua a través de las juntas de estratificación. La zona activa se corresponde con el curso actual del río.
11) –Covas do Oso (Caliza de Vegadeo)
a) Morfología: Sus tres cavidades de menos de 25 m. de recorrido, están formadas por una única galería de secciones homogéneas.
b) Génesis: Su formación fue debida al ensanchamiento de las juntas de estratificación por acción del agua de filtrado.
12) –Cova de Longo de Meu: (Caliza de Vegadeo)
a) Morfología: Una rampa descendente conduce a una larga y estrecha galería con abundantes depósitos de arcilla. Hacia su mitad se abre una gatera que conduce a una sala inclinada en la dirección de los estratos, con numerosas ramificaciones y rampas, una de las cuales comunica con el exterior.
b) Génesis: Debido al considerable buzamiento, el agua excavó las rampas que desembocan en el nivel inferior, en donde la disposición de las galerías en arborización, fue originada a favor de las diaclasas junto con la acción del agua.

Por último resaltar el avanzado estado de descalcificación de las formaciones litogénicas. El importante aporte de CO_2, procedente de la descomposición de la frondosa vegetación que se desarrolla encima de la mayoría de las cavidades, hace que el agua al llevarlo disuelto, favorezca la disolución de la caliza.

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El sistema kárstico de Wit-Tamdoun (Alto Atlas Occidental, Marruecos)

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RESUM

El sistema càrstic de Wit-Tamdoun (Gran Atles Occidental, el Marroc), amb més de 15 km. de longuitud total i amb un riu subterrani, és la xarxa subterrània més gran coneguda de tot el continent africà.

Aquest sistema es desenvolupa a la planície de Tasroukt, en un nivell calcari-dolomític de l'Oxfordià Mitjà, de 30 m. de gruix. L'estructura geològica, suaument plegada, és quasi horizontal.

Hidrogeològicament, aquest nivell calcari és un aqüífer càrstic intercalat entre dos nivells margosos de caràcter semipermeable.

El sistema s'alimenta de les aigües de pluja que reb de l'altiplà, les quals, després d'infiltrar-se pels nivells calcaris superiors (amb formes exocàrstiques diverses) i per les margues, assoleixen el nivell calcari oxfordià, per a sortir finalment a l'exterior (la major part) a la surgència de Wit-Tamdoun.

En aquest comunica presentem l'última topografia del sistema càrstic i analitzem els condicionants geològics i hidrogeològics del mateix.

RESUMEN

El sistema kárstico de Wit-Tamdoun (Gran Atlas Occidental, Marruecos), con más de 15 km. de longuitud total y un río subtarráneo, es la mayor red subterránea conocida en todo el Contiene Africano.

Se desarrolla en llanura de Tasroukt en un nivel calizo-dolomítico del Oxfordiense Medio, de 30 m. de espesor. La estructura geológica, suavemente plegada, es casi horizontal.

Este nivel calizo, hidrogeológicamente es un acuífero kárstico intercalado entre dos niveles margosos con caráracter semipermeable.

El sistema se alimenta de las aguas de lluvia que recibe la meseta, que después de su infiltración a través de los niveles calizos superiores (con formas exokársticas diversas) y de las margas, alcanzan el nivel calizo Oxfordiense, saliendo finalmente al exterior –la mayor parte– por la fuente de Wit-Tamdoun.

En este comunicado presentamos la última topografía del sistema kárstico y analizamos los condicionantes geológicos e hidrogeológicos del mismo.

RESUME

Le système karstique de Wit-Tamdoun (Haut Atlas Occidental, Maroc) est le plus grand rèseau souterrain connu de tout le continent africain, avec plus de 15 km. de longueur totale et une rivière à l'intérieur.

Il se développe dans le plateau de Tanoukht, à la faveur d'un niveau calcaire-dolomitique du Oxforfien Moyen de 30 m. d'épaisseur. La structure géologique est doucement plissée, presque horizontale.

Hydrogeologicament, ce niveau calcaire est un aquifère karstique intercalé entre deux niveaux marneux avec caracter sémiperméable.

L'alimentation du système vient des eaux tombées sur le plateau; après l'infiltration à travers des niveaux calcaires supérieurs (avec des formes exokarstiques diverses) et des marnes, elles gagnet le niveau calcaire ofordien et, en dernier lieu, sortent à l'exterieur –la plus partie– par la source de Wit-Tamdoun.

Dans cette communication nous présentons le dernier plan levé du réseau karstique, et nous analysons les condicionants géologiques et hydrogéologiques du système.

I.– Introducción

El Sistema Kárstico de Wit-Tamdoun es la mayor red subterránea conocida en el contiene Africano. Alcanza una longuitud total superior a los 15 kilómetros, encontrándose topografiados hasta el momento 14.407 metros (Abril de 1985). En su interior, la única boca conocida del Sistema –surgencia del torrente subterráneo que lo recorre– se localiza a unos 40 km. al NE. de Agadir, en el *Plateau* de Tasroukt, coronado por el Taourirt Moulay Ali (1.789 metros), máxima altitud del Alto Atlas Occidental. Las coordenadas geográficas correspondientes a la boca de la cavidad son:

30º 40' 52" L.N.
9º 20' 38" L.W.
1.320 m.s.n.m.

(Hoja topográfica, a escala 1:50.000 NH-29-XV-4a, IMOUZZER DES IDA DU TANANE, editada en 1961).

En cuanto a su encuadre geológico regional, el *plateau* se localiza en el Dominio Atlásico, en materiales pertenecientes al sector Mesozoico plegado del Alto Atlas Occidental, y muy cerca del gran Accidente Sud-Atlásico, que hace de límite con los Dominios Anti-Atlásicos y Sahariano.

II.– Geología

La región de los *Ida ou Tanane* presenta un conjunto de materiales mesozoicos con estructuras y modelado análogos al Jura francés (AMBROGGI, 1954). Son frecuentes los relieves invertidos, con valles encajados que siguen los ejes anticlinales y los suaves sinclinales en zonas de meseta.

II.1.– Estratigrafía

La serie estratigráfica del plateau de Tasroukht abarca prácticamente todo el Jurásico, presentando las siguientes características:

–MALM: Pueden distinguirse seis tramos, de menor a mayor antigüedad:

Tramo 1: alternancia de calizas, limos, arcillas y margas de color rojizo, con más de 220 metros de potencia. Este tramo corresponde a lor relieves residuales que coronan el plateau, alcanzando los 1.789 m. (Taurirt Moulay Ali.)

Tramo 2: Calizas oscuras, a veces brechoides y margocalizas amarillentas; de aspecto tableado, y potencia de 37 metros, conforman la tabla caliza donde se modela superficialmente el plateau y se sitúan las formas de absorción exokársticas.

Tramo 3: Margas y margocalizas abigarradas de colores amarillo, gris y violeta. Presentan algunas venas de yeso fibroso secundario. Alcanzan 20 metros de potencia.

Tramo 4: Calizas grises esparíticas, en bancos muy gruesos. Presentan laminación cruzada frecuente, corales, braquiópodos, etc., de facies marina muy somera.
Las denominamos CALIZAS DE WIT-TAMDOUN, al ser el tramo donde se desarrolla la cavidad y en cuya base surge el torrente subterráneo. Posee un espesor de 30 metros. Su edad es Oxfordiense Medio (Rauraciense Inferior de AMBROGGI, 1954).

Tramo 5: Margas y margocalizas grises y amarillas, con fauna muy abundante (braquiópodos, lamelibranquios, gasterópodos, etc.); 30 metros de potencia.

Tramo 6: Calizas dolomíticas amarillentas y margas abigarradas. Alcanzan 38 metros de espesor.

–DOGGER: Aparece como un potente conjunto de areniscas, conglomerados y margas, de color rojo predominantemente, y también amarillos y grises. La potencia es de 310 metros.

–LIAS: Alternancia de calizas, margocalizas y margas, con colores grises y amarillentos, y un espesor de 265 metros. Hacia la base aparecen arcillas y areniscas rojas, que se apoyan sobre unas coladas basálticas, que hacen el papel de muro de la serie Jurásica.

Las asignaciones cronoestratigráficas anteriores se han establecido en base a datos de AMBROGGI (1954).

II.2.– Estructura

El relieve del *Plateau* de Tasroukht posee un condicionante claramente estructural. Corresponde a una *tabla* carbonatada, suavemente plegada, que cae bruscamente en su borde Norte, mediante un pliegue en rodilla; hacia el Sur, se transforma en suave anticlinal, sucedido por otro pliegue sinclinal de gran radio, cuyos flancos apenas buzan 5-10º. Los ejes de los pliegues se orientan en dirección aproximada N 90º-100º E, siguiendo las directrices generales Atlásicas.

Esta disposición en pliegues suaves está fuertemente retocada por la fracturación, a favor de la cual se encaja la red de drenaje subaérea y –en el caso de los macizos kársticos–, condiciona la subterránea.

En el plateau se observan en superficie tres familias de diaclasas, que corresponden a pulsaciones tectónicas diferentes. Las correspondientes a la 1ª fase se orientan en torno a N 5º-10º E, siendo bastante penetrativas a escala del macizo. La 2ª fase se encuentra representada por un sistema de fracturas conjugadas de direcciones N 90º–100º E/N 145º E (que responden a un esfuerzo principal comprensivo de dirección ESE/WNW). Esta familia suele aparecer con escasa continuidad.

Por último, las correspondientes a la 3ª fase, se orientan en torno a N 100º-125º E, sensiblemente paralelas al eje de los pliegues, muy continuas y bien observables en el campo.

Asimismo se localizan fallas de salto en dirección (siniestras) con orientación N 25º E/80º NW.

En cuanto a la geometría de la red kárstica destacan como direcciones principales la N 90º-110º E/N 180º E y el intervalo N 25-40º E, y, con menor importancia, el intervalo N 145º-155º E. También se observa en el interior de la cavidad un sistema de fallas de salto en dirección orientadas según las direcciones N 15º-25º E –siniestras– y N 170º-175º E (dextras).

III.- Hidrogeología

III.1.- Funcionamiento hidrogeológico

Las calizas de Wit-Tamdoun constituyen el principal nivel acuífero de la serie descrita. Otros niveles arrojan caudales poco significativos.

El funcionamiento hidrogeológico del *plateau* de Tasroukht, es el típico de un *karst de mesa;* las aguas pluviales se infiltran por una serie de dolinas y un polje central, modelados en las calizas del Malm pertenecientes al tramo 2. Un pequeño arroyo desmantela parte del polje y drena sus aguas hacia el W. Presumiblemente es ésta también la dirección de circulación subterránea generalizada. Según AMBROGGI (1954) esta circulación se daría a favor del eje sinclinal que estructura la parte central de la meseta. Esto no se confirma para el conjunto de la cavidad, con una dirección de N 40º E en los 1.500 metros más cercanos a la boca. De esta manera podemos decir que existen importantes tramos que se desarrollan a favor de fracturas no necesariamente ligadas al eje del sinclinal.

Las aguas meteóricas, en una red esencialmente endorreica, penetran a través del lapiaz, simas y depresiones cerradas de las calizas tableadas de la altiplanicie, alcanzando las margas y margocalizas del tramo 3, semipermeables, que atraviesan para llegar al nivel calizo-dolomítico de Wit-Tamdoun. La cavidad actúa como colector o dren central, que posteriormente evacúa las aguas al exterior por la boca del sistema.

Eventualmente, parte de las aguas, pasarían a través de las margas inferiores (tramo 5), llegando a otro nivel calizo (tramo 6), donde se localiza una pequeña surgencia llamada Aïn Tinquit, de carácter intermitente.

El paquete margoso superior a las calizas de Wit-Tamdoun, ejercería un doble papel: como regulador por «goteo» lento de las aguas infiltradas, y con algunas vías de circulación «rápida», que explicaría el incremento súbito de caudal (típico de acuíferos kársticos «rápidos»), que se registra tras las lluvias fuertes de invierno. Wit-Tamdoun alcanza caudales de 135 l/seg en marzo (DIJON, 1964), convirtiéndose en la segunda surgencia del Alto Atlas Occidental; en verano, apenas alcanza la decena de litros/segundo.

Es interesante destacar el carácter permanente de la surgencia de Wit-Tamdoun, frente a la marcada concentración de lluvia en la región durante un corto período del año.

La cuenca hidrogeológica que drena la surgencia de Wit-Tamdoun, queda limitada: Al Norte por el eje anticlinal (E-W) del Taurirt Moulay Ali. En las otras tres direcciones, aproximadamente por los bordes acantilados del *plateau*. La cuenca así definida tiene una extensión de unos 10 km^2.

Al objeto de comprobar teóricamente, si las aportaciones «autóctonas» permitirían la alimentación del sistema, hemos efectuado una estimación del balance hidrogeológico. Para ello hemos considerado un volumen de agua evacuado por Wit-Tamdoun y surgencias asociadas, de aproximadamente 0,65 Hm^3 anuales. Para una cuenca de 10 km^2 y una lluvia media de 225 mm/año, se obtiene una cantidad de agua precipitada anualmente cercana a 2,25 Hm^3. La evapotranspiración real (2,25-0,65 = 1,60 Hm^3 por

año), representaría sobre el 70 % de las precipitaciones, valor bastante verosímil para estas latitudes. En consecuencia, no parece necesario invocar aportes «alóctonos» de acuíferos adyacentes, quedando cerrado el balance.

III.2. Aspectos hidroquímicos

Se ha realizado un muestreo de aguas a lo largo del río y afluentes subterráneos de Wit-Tamdoun, así como en algunas pequeñas surgencias relacionadas con distintos tramos de la serie estratigráfica, con un total de 31 análisis distintos.

El resultado de los dos grupos (aguas de Wit-Tamdoun y el resto de las surgencias) ofrece una sensible diferencia, con un menor contenido iónico en las aguas de Wit-Tamdoun (200-350 mg/l, frente a las muestras ajenas al sistema kárstico principal (más de 400 mg/l.

Dentro de la cueva, el agua del cauce principal presenta un pH entorno a 8,1, mientras que en los afluentes este valor desciende a 7,9, valor más cercano al resto de los manantiales analizados.

Sobre el lecho del cauce subterráneo precipitan sales disueltas (esencialmente carbonatos). El contenido iónico de las aguas aumenta puntualmente por los aportes laterales subterráneos, llegando al exterior con 340 mg/l de iones disueltos.

Las facies hidroquímicas son bicarbonatadas cálcicas, con una relación Mg/ Ca entre 0,74 y 1.06 dentro de la cavidad, descendiendo hasta 0,53 en las otras muestras del entorno, evidenciando esto el origen calizo-dolomítico de las primeras, y el carácter exclusivamente calizo del segundo conjunto.

IV. Algunas consideraciones sobre la red subterránea de Wit-Tamdoun

La cavidad de Wit-Tamdoun constituye una red kárstica hidrogeológicamente activa, de carácter esencialmente lineal.

Actualmente se encuentran topografiados 14.407 m. (datos de Abril de 1985, resultado de la expedición WIT-TAMDOUN 1985, organizada por la Sociedad Excursionista de Málaga) y más de 15 km explorados, lo que la convierte en el mayor sistema kárstico africano conocido. La poligonal principal alcanza 6.630 m.; en sus primeros 1.500 metros de recorrido, desde la entrada del sistema, mantiene una dirección N 40 E. Posteriormente, la dirección de conjunto es aproximadamente N 100 E, retocada en detalle, a favor de fracturas más o menos transversales (ver la planta topográfica), que representan con frecuencia aportes de agua laterales.

La cueva en sí, constituye un gran colector de trazado y circulación acuífera esencialmente horizontales, con algún tramo fósil o de funcionamiento excepcional en cuanto a circulación de aguas se refiere.

La morfología interior ofrece secciones ovaladas, siguiendo la estratificación, a veces de contorno ojival con fracturas bien visibles a techo, y también formas estrechas y elongadas con disolución por escurrimiento vertical del agua. Es frecuente la presencia de «banquetes», en ocasiones asociados a terrazas con sedimentos groseros de tipo fluvial. Ocasionalmente, existen grandes desplomes, en relación a sectores muy fracturados.

En cuanto a formas de reconstrucción, los espeleotemas parietales y cenitales son escasos, y quedan reducidos a las partes no activas.

La parte activa ofrece gran número de lagos y abundantes gours de distintos tamaños, con frecuencia desfondados por la acción erosiva del agua.

Las salas son escasas, adyacentes a la galería principal, y de morfología troncocónica, algunas de ellas cercana al centenar de metros de altura, verdaderas chimeneas o pozos campaniformes. En estas Salas se localizan aportes de agua verticales, por infiltración, registrándose fuertes goteos continuos.

Señalar, por último la presencia de depósitos travertínicos en la boca de la cavidad, cuya acreción no continúa en la actualidad, ya que gran parte del agua es derivada por una pequeña acequia hasta un depósito artificial, dedicado a facilitar tanto el abastecimiento humano como a la escasa agricultura y ganadería de la zona.

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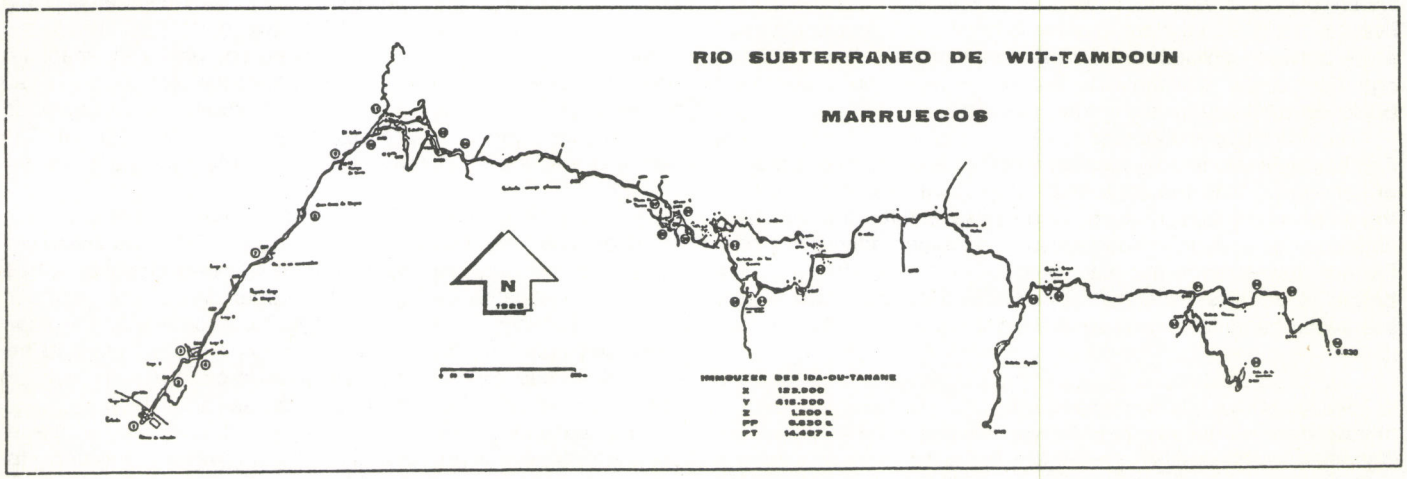

Lokohong Cave. Further Data on the Central Western Part of the Karst of Sagada, Mountain Province, Luzon, Philippines.

*Claude Mouret**

RESUM

Amb la cova de Lokohong, el sistema de coves Latipan-Sumaging-Lamiyan aconsegueix un desenvolupament de 3.975 m. (ocupant d'aquesta manera el segon lloc del país) i una profunditat de 163 m. (ocupant així el primer lloc del país). Aquests resultats són el fruit dels treballs del CASC de Saint Montan (Ardèche, França) i de l'autor (1982 a 1984) El treball presenta les característiques de la cavitat, el lloc que ocupa en el carst de Sagada, l'evolució del sistema (anomenat també, per a abreujar, «Latipan-Lokohong»). Es desenvoluparen diferents punts. La cavitat s'obre, aproximadament, al voltant dels 1.400 m. d'altitud i a 17º 04' de latitud Nord.

RESUMEN

Con la cueva Lokohong, el sistema de cuevas Latipan-Sumaging-Lamiyang alcanza el desarrollo de 3.975 m. (ocupando actualmente el segundo lugar del país) y la profundidad de 163 m. (ocupando actualmente el primer lugar del país). Estos resultados son el fruto de los trabajos del CASC de Saint Montan (Ardèche, France) y del autor (1982 a 1984). El trabajo presenta las particularidades de la cavidad, su lugar en el Karst de Sagada, la evolución del sistema, llamado para simplificar «Latipan-Lokohong». Se desarrollan diversos puntos. La cavidad se desarrolla aproximadamente alrededor de los 1.400 m. de altitud, a 17º 04' de latitud Norte.

RESUME

Avec Lakohong cave, le système de grottes Latipan-Sumaging-Lamyang atteint le développement de 3975 m. (actuellement second chiffre du pays) et la profondeur de 163 m. (actuellement premier chiffre du pays). Ces résultats sont le fruit des travaux du CASC de Saint Montan (Ardèche, France) et de l'auteur (1982-1984). L'article présente les particularités de la cavité, sa place dans le karst de Sagada, l'evolution du réseau, appelé par simplicité «Latipan-Lokohong». Divers points sont developpés. La cavité se développe vers 1400 m. d'altitude, à 17º 04' de latitude Nord environ.

The karst of Sagada, explored from I979 to I985 by french teams** (I, 7, 8) has been presented by (I) and (9) for its general features. The central western part has been the matter of a specific paper (6) and the longest cave of the area has been described (3). This paper presents the Lokohong cave, its place in the karst and reconstructs the local evolution. Lokohong cave is the more recently discovered part of the Latipan-Sumaging-Lomyang (LSL) cave system (3), now called Latipan-Lokohong. This latter is presently the deepest cave in the Philippines (-I63) and the second longest one (3975 m) (5). The elevation of the Lokohong entrance is nearly of I360 m (Latipan: I332, Sumaging I: I394, Lomyang: I420, by reference).

Structure of the Lokohong Cave

(All the flow conditions given here after correspond to Octubre 1984)

There are two main levels connected by a large shaft. The upper level has several tributary passages an a temporary (?) water flow (± 2 l/s). The lower level is followed by a permanent river (± 15 l/s). To the south of the large shaft, an upper passage party between collapsed boulders connects with the Lokohong entrance; below, a complicate vacuum between huge collapsed boulders still features the former passages.

The Main Upper Passage is 427 m long; it connects the Pig Pen empty rimstone pool, located on the side of the main passage of Latipan (3) with the large shaft. Just downstream of Pig Pen, the passage is relatively narrow and has several fossil wall-shaped rimstone pools. A deep flooded lower passage underlie this part. Further downstream, the main passage suddenly enlarges, just before it receives the two upstream tributaries, which are somewhat hanging at the top of flowstones with rimstone pools. Downstream of this place, the size of the main passage enlarges once more, for both its width and its height. There is now a permanent (?) water flow; the floor, more regular, is covered by coarse sediments (sands, pebbles) mostly, with locally some finer ones (silts, clays, fine-grained sands). Then, there are two more tributaries. The main passage continues until a young collapse of the roof, and a more narrow part leading to the Upper Chamber, characterized by very bulky collapsed boulders. This latter is only an enlargement of the main passage.

The two upstream western tributaries are connected together by a choked passage: boulders upstream of the choke, silts downstream of it, i. e. on the side of the downstreammost tributary. This latter extends up to the base of a shaft. Two narrow low passages prolongate it at the ground level, up to a sump.

The two eastern tributary passages bring more water than the two previous ones. The more upstream one extends up to a strong narrowing, behind which some noise of water may be heard sometimes. A lateral shaft is the main source of water (< 0.1 l/s) during the normal flow conditions. The other tributary receives also water from the ceilling (< 0.1 l/s) The downstream western tributary arrives between the Upper Chamber and the large shaft. It can be separated into two parts: the further one is narrow, in the rock and temporarily floored by dormant (?) water; the other one (NW-SE) derives from the rejuvenation of an old passage choked by very coarse sediments rich in rounded allochtonous pebbles, which size may reach up to 20 cm. The part near the Upper Chamber is partly floored by collapsed bulky boulders.

The Lokohong part, connecting the Lokohong entrance and the large shaft, has been very deformed by numerous collapses, which progressively generated a large rounded chamber with a nearly flat inclinated ceilling. At the upper end of the chamber, vacuums between the boulders allow the access until the short outer passage (7). This one receives some water from outside, during the heavy rains. Earth from outside can be seen filling up the space between the boulders as far as 16 m deep.

The Lokohong part above described may be a former continuation of the previous downstream western tributary, for reasons of elevation and of alinement. Later on, this former single passage has been cut trough by the large shaft, but the evolution of this part of the cave may be more complex.

The Lower Passage begins at the upstream sump of the river

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(which is the downstream sump of the Latipan cave(3), continues through a tridimensional maze of uncollapsed passages, then enlarges up to the large shaft, at the bottom of which the water (around 15 l/s) enters a narrow hole between calcitized boulders. Afterwards, the water enters opened fractures between destabilized rocks still in place; it can be seen again further downstream, between very unstable bulky boulders. To the south of the shaft, the main lower passage is completely deformed by collapses of huge extension, but still features some former normal passage. Some of the boulders are of a particularly large size (see map). The collapsed area extends further south than the Lokohong opening.

The Pig Pen Upper Passage is only a narrow passage ending at the base of a shaft, where some water is dropping (< 0.05 l/s).

Relations between Lokohong Cave and the Latipan-Sumaging-Lomyang Cave System and Evolution Phases

The existence of the Lokohong cave was already deducted from the observations made in Latipan, around Pig Pen (3). However, the wall of the empty rimstone pool of Pig Pen faces upstreamwards i. e. Latipan anomaly which can know easily explained by the local setting. The other walls of rimstone pools are symetric of this confusing one.

The pattern of the Lokohong cave fits the evolution phases settled for the LSL cave system (3). After the phase I corresponding to the Lomyang cave, the Phase II shows a very consistent pattern of passages, associated with coarse sediments with big pebbles of rocks allochtonous to the karst. In Lokohong, the downstream western tributary of the main upper passage has the same type of sediments and is in the alinement of Sumaging (3); it may be its downstream continuation, later on disturbed by the collapse of the entrance doline of Sumaging I. Therefore, this continuation belongs to the possible phase IIb, corresponding to a flow in the Sumaging passage, after the Latipan entrance dried up.

The Main Upper Passage corresponds to the phase III: drying of the former active passage. Possibly, the two western upstream tributaries may correspond to an early phase III, the waters of Sumaging entering the «Labyrinthe» (Maze), (located near and to the north of the Sumaging entrances), probably itself in connection with them. We assume now for the Maze an origin different than in (3), due to the comparison of the shapes of the passages with those newly discovered in Lokohong.

The present river is now phase IV and the huge collapse at the southern end of Lokohong in therefore a phase IVb.

The eastern tributaries of the main upper passage range between the phases III to V.

Place of Lokohong cave in the central Western part of the Karst

The main upper passage is a nearly fossil collector, only followed by small flows during the normal conditions. Possibly, it may still be flooded during the strongest typhoons. Downstream of the large shaft, which was probably smaller during the phase III, this collector probably followed a passage now completely destroyed by the collapses IVb and located in elevation above the present river. Hypothetically, it might correspond to the intermediate level of Natividad cave (7). The river is believed to be the same one than this of Natividad, for reasons of magnitude of the flow and of general setting of the karst. The gap between the two corresponding ends of caves has been evaluated as follows, for the streams (7): difference in elevation: 74 m; likely length of the passage: 485 m, assuming an average slope of l5.25 % and a sinuosity ratio of l.30.

The Bukong and Kiosk caves cannot be linked to Lokohong, for the moment being. Moreover Bukong is probably located below Lokohong, if it extends far enough.

Some comments on the formation of the passages and on the sediments

Nothing very new can be added for the sediments (3). The coarse ones with big allochtonous pebbles are related to the phase II, when large flows entered the karst through its western margin, into passages now partly or completely choked.

Concerning the formation of the passages, a new clear fact is the existence of certain of them along inclinated fractures: main upper passage: cross-sections s, u, v, x, dd; western tributaries: bb, cc; eastern ones: gg to ii. This feature exists also in the «Labyrinthe».

The collapsed areas well developed, specially in the southern part of the cave. Along the main upper passage, a local collapse is at the cross-section t. A better developed one is the «Upper Chamber». The main collapse-cross-section b, c, d, e– concerns very large destabilized volumes, due possibly to the existence of several passages (one has been infered above in this paper) and to a strong erosion by the underlying river during the phase IV. This area is not beneath a low of the groud surface, but under a slope. The maze near the upstream sump of the river of Lokohong is probably a potencial source-area for a future collapse.

Conclusions

The Lokohong cave, part of the Latipan-Lokohong cave system allows a good clarification for the understanding of the central western part of the karst, as it greatly fills up the gap between several caves not yet linked together: Latipan, Natividad, Kiosk and Bukong. Lokohong confirms what was expected from the observations made in Latipan, fits with the evolution phases already settled, but has no specificity for the sediments. It shows good examples of collapsed areas. Further explorations are hoped to bring new connections with other caves for this 3975 m long cave system, in order to better interpret this small karst.

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Addendum

In January 1986, Natsumi Kamiya (Tokyo Speleological Survey Group), Jessie Degay (Sagada) and the author were able to find the junction between the Latipan cave and the Lomiyang swallow hole. Together with this short branch, the whole length of the Latipan-Lokohong cave system is now longer than 4000 m. The depth is still the same (-163).

Stone Forests in China

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RESUM

Els deserts de pedra són molt freqüents a les regions climàtiques tropicals i subtropicals. La majoria de deserts de pedra es desenvolupen en la fràgil calcària de Maokuo, calcària pura de gruix considerable (espessor màx. dels estrats superior als 30 m.) i de fractura vertical. Els deserts de pedra es formen, principalment, per l'erosió del subsòl.

Els deserts de pedra de les depressions càrstiques i valls es caracteritzen per la seva gran extensió i densa distribució. Les columnes de pedra dels cims dels turons càrstics són curtes i estretes. Els boscos dels vessants es caracteritzen per presentar uns trets intermitjos entre els boscos de les depressions i els boscos dels cims de les muntanyes.

RESUMEN

Los desiertos de piedra están ámpliamente distribuidos en las regiones climáticas tropicales y subtropicales. La mayoría de los desiertos de piedra se desarrollan en la delicada caliza de Maokuo, pura y gruesa (espesor máx. de los estratos superior a 30 m.) con fractura vertical. Los desiertos de piedra se forman principalmente por la erosión del subsuelo.

Los desiertos de piedra en las depresiones kársticas y valles se caracterizan por inmensas individualidades y densa distribución; las columnas de piedra en las cimas de las colinas kársticas son cortas y estrechas; los caracteres de los bosques de las laderas de las colinas están entre los bosques de las depresiones y los bosques de las cumbres de las colinas.

SUMMARY

The stone forests widely distributed in the tropic and subtropic climatic regions. Most stone forests develop in the pure, thick (max. bed thickness over 30 m) and gentle Maokuo limestone with vertical fractures. The stone forests are mainly created by the subsoil erosion.

The stone forests in the karst depressions and valleys are characterized by individualities huge and distribution dense; the stone columns on the karst hill tops are short and small; the characters of hill-slope forests are between the depression-forests and hilltop-forests.

Introduction

The stone forest is defined as the group of stone pillars with over 5 m high. If less than 5 metres high, it is generally named stone teeth. The stone forests broadly distribute in the palaeotropical and subtropical climatic areas, such as in Lunan and Kinming of Yunnan Province, Puding and Meituan, Guizhou Province, Xingwen of Sichuan Province, Luota, Huayuan and Yongshun in Hunan Province (Fig. 1). The stone forests not only make the natural scenery more bearty, but also attract great munbers of karstologists and geographers to look into the origination of the forests.

There are a lot of hypothesis to explain the development of the stone forests. Ma Xirong (1936) suggested that it was resulted from the surface dissolution of limestone. Jie Xieyi (1966) described the development of stone forest should be with the conditions of: (1) very thick limestone; (2) the dipping of limestone formation must be near horizontal or gentle, generally the dipping angle less than 10 degrees; and (3) it develops in the vados zones and commonly occurs in the watershed or near watershed areas. In «Karst Research of China» (1979), the author pointed out that the stone forests should be developed in the conditions of thick and gentle folded limestone, rainy and humid palaeoclimate and the palaeolandforms suitable to water vertically dissolving the limestone. Ren Meie (1980) stated the stone forests are the collections of stone pillars separated by the dissolution along the fissures in horizontal and thickness limestone, distribute on the slopes of basins nearny the water divide zones and are the palaeotropical karst features. Chen, Song, and Sweeting (1985) recognized that the forest are dominantly produced by the subsoil erosion and retransformed by the dissolution of rainwater.

In the larst few years, author have investigated the stone forests in Lunan, Xingwen, Huayuan, Meituan, Yongshun and Lengshuijiang. Some conclusions may be worked out.

Lithology and Geological Structures for Stone Forests Development

The stone forests are dominantly developed in the thick pure limestones (Table 1). The Lunan Stone Forest mainly develops in the lower Permian Maokuo limestone, the maximum thickness of the bed may rach up to 30 metres and more. The Xingwen stone forst distributes in the third section of Maokuo (Plm^3), the biodetritus limestone with 5 metres of the maximum bed thickness. The stone forest in Buermen Park, Yongshun County, Hunan Province, is developed in Ordovician dark pink limestone with 1-3 m layer thickness. Only the xiaopaiwu forest in Huayuan County distributes in the dolomitic limestone with about 2 metres of single bed thickness.

The most of stone forests are developed in the gentle or

Table 1. Chemical compositions of limestone the stone forests developed in.

Site	Formations	Composions (%)				
		CaO	MgO	R_2O_3	SiO_2	loss
Lunan, Yunnan	Maokuo (Plm^1)	31.95	20.60	0.62	0.29	46.54
	Maokuo (Plm^2)	56.12	0.05	0.32	0.29	43.42
	Maokuo (Plm^3)	55.33	0.08	0.10	0.04	43.22
Luota, Longshan, Hunan	Maokuo (Plm)	50.70	1.12	0.67	6.66	
	Maokuo (Plm^{1+2})	53.13	1.11	0.10	0.33	43.82
		55.89	1.38	0.06	0.51	39.01

horizontal limestone or dolomitic limestone, such as the dipping angle of Maokuo limestone in Lunan is about 10° or less. Stone forest limestone in Xingwen varies in the range of 7-17°. Ordovician limestone in Buermen Park is less than 10°, the dipping angle of dolomitc limestone in Xiaopaiwu is less than 20°. It has been discovered that the high and huge stone forest is generally developed in the block of gentle limestone and the dipping angle less than 15°, while the shorter and smaller one in the limestone with the dipping higher than 15°. There is no any possibility for stone forest to develop in the high dipping limestone (Group of Luota Karst, 1984).

The development of stone forest is closely related to joints and fissures. In the process of folding by the geoforce, the rigid limestone rocks is eassyly broken as to form the vertical opening, joints and fissures which are nearly right crossed each other, or say conjugated joints or fissures. For example, the Lunan stone forest is controlled by the net of joints and fissures of N20°W, N50°W, N60°E and EW with 80-90° dipping angles. Xingwen stone forest is affected by N60-70°W, N35-25°W, N5-30°E and N70-80°E. The stone forest in Buermen Park is restricted by N45°W, N80°E and N65°W joints and fissures. Also Luota forest is dominantly controlled by the joints of N50°W and N30-40°E.

Main Types of Stone Forests

According to the covering conditions of the stone forests may be divided into 3 groups: (1) Bared stone forest; (2) covered stone forest and (3) buried stone forest. Based on the geomorphological occurence of stone forests, it may be classified: (1) stone forest on the hill top (hilltop stone forest); (2) stone forest in the depressions and valleys and (3) stone forest on the hill slope. These three types are described as follows:

(1) Stone forests in the depressions and valleys

The depression and valley-stone forests are characterized by the big dimensions, large distributing areas and stone pillars be perfectly separated. Take Lunan sone forests for example, the Dashilin, Xiaoshilin and Mother-son going for a walk etc are all developed in the karst depressions covered by one metre or more Quaternary sediments and with many karst dolines, sinkholes and subsurface drainage systems. The Sword Peak Pond is a typical karst natural lake. During the rainy season, the water could be drained out by the undeground drainage system, the groundwater table will rise up, sometime, the depression is flooded, for example, the tourist path in Unique Scenic spot depression was covered by over one metre of water. Another example is that there is a surface stream in the Xiaopaiwu karst depression which the stone forest develops.

(2) Hilltop stone forest

The pillars are grown up on the complete base. The heighth of the indivial pillar is short, generally about 10 metres or little more, sometime may reaching upto 30 metres. The covers on the base rock is less than 1 m. Commonly, the covering sediment is short of, such as the New Stone Forest in Lunan.

(3) Hill-slope stone forest

The features are between the stone forests of depressions and hilltop. It is closely related to the stone teeth.

Origination and Evolution of Stone Forest

The main mechanism of the stone forest development is the subsoil erosion of soil water to enlarge the fissures and separate the rocky block.

Author paid attention to the relationship between the soilwater hydro-dynamics and the stone forest develpment during the investigating Xingwen stone forest. The weathered and corroded limestone is gradually covered by the residuary materials or soil which contains aboundant humus and CO_2 through the biogence. When the rainwater with little CO_2 drops on the ground surface, it will absorb the CO_2 of soil air and released directly from the biogences on one hand, on other hand, it penetrates downward in the soil. The penetrating water takes two ways, one moves down as the soil water, the other as the surface water moving in the contact zone between the limestone surface and soil (Song, 1985). The surface flow is the main dynamic factor to enlarge the vertical joints and fissures, while the erosion ability of the surface flow will be greatly losen after flowing the distance about 2-3 m. In the section of strong erosion, the fissures and joints are rapidly enlarged and widened. In the part of less erosion ability, the water way is narrow. Therefore, the subsoil erosion feature is like a long funna. Due to the space of fissure narrowing in the vertical direction, a part of soil water will flow to the contact and mix with the saturated surface flow. So the mixing flow will get new erosion ability to corrode the limestone, and the feature like the string of beads may be discovered. It the elevations of two neighbour soil-filled pits is different, the soil water might flow from the higher one to the lower one through the fissure or joint. In the rainy season, the temporary underground water saturation zone is formed and the rather horizontal subsoil tube would be developed. Though under the gravitation the velocity of vertical penetrate flow is higher than that of horizontal flow and the horizontal flow is tempeorary. The erosion of horizontal flow containing high CO_2 content is very strong.

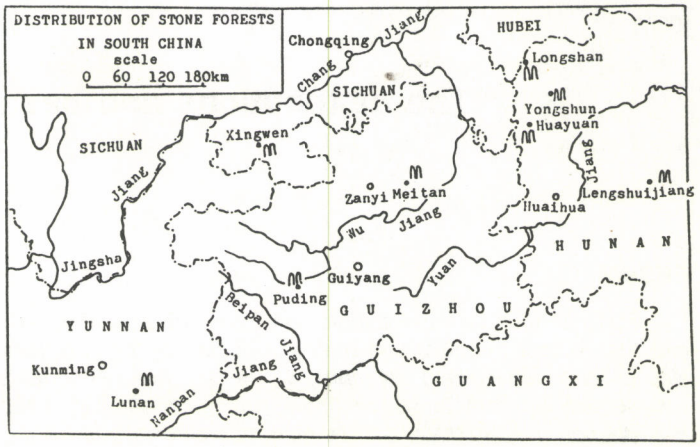
The slope erosion makes much soil with great humid and organic materials in the depression bottoms. The speed of stone forest development in depression is 10 times higher than that of the forest on the hilltop (Yan Qingtong, 1982), that means the stone forests on the hilltop and in the depressions may simultaneously develop and the size of stone forest on the hilltop is smaller than the depression-stone forest mormally 20-30 m, max. 35 m high. Generally, the base of hilltop stone forest is exposed, the main mechanism is the rainwater erosion. Sometimes, the weathering is more stronger than the stone forest development. Thus, the Xingwen stone forest on the hilltop is the residual one with only 1 or 2 pillars on one hill.

The erosion of rainwater on the top of stone pillars has created the solutional cups, bows, basins, small gully and flut the depth of the both is from several mm to 1 m. The rainwater erosion is playing important role of shortening the stone forest. From this point of view, the speed of stone forest development is determined by the soil water and surface water not the rainwater.

Stone Teeth and Stone Forest

There are some different point of view about the relationship between stone teeth and stone forest. Someone state that the stone forest is developed from the stone teeth (Zhang Shuyue,

Fig. 1.



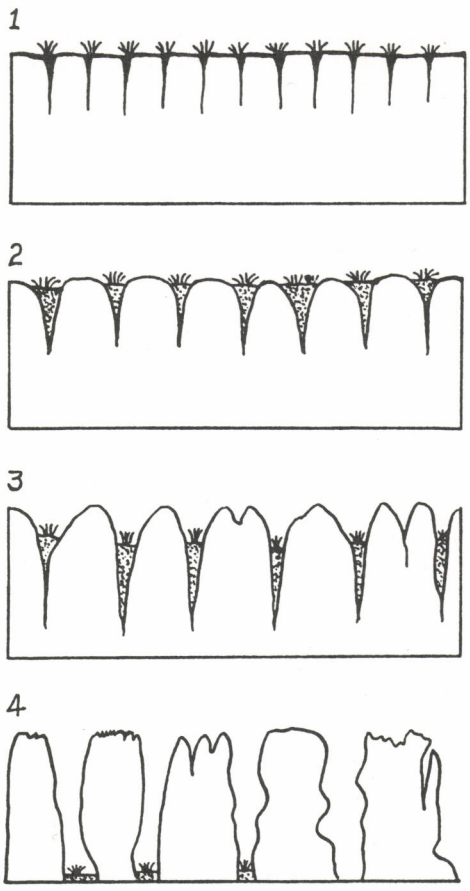
1984). The others argued that it is possible for stone forest developing from stone teeth, also stone teeth may develop from stone forest.

In fact, the relationship between stone teeth and stone forest is very complicated. The synpothises of stone forest developing from the stone teeth is correct, but it is only taken place in the position with gentle dipping and thick limestone with a lot of vertical joints or fissure nets, and covered by the organic and humid soil. The Lunan stone forest is a good example. In the place where the cover is very thick and the soil is well conservated, the depth of subsoil water erosion is stabilized, the limestone is homogeneously dissolved under the soil though the intensity of the erosion in the joints and fissures is comparable high. Hence, it is possible just the stone teeth develops. If the soil in homogeneously covers on the limestone and soil ground surface is continously lowed down, the strong erosion zone is gradually gone down too. The thickness of soil layer is not uniform everywhere, that means in the joint and fissure zone, the soil is thick but other part thin. In the evolution process of stone forest, the joint and fissure are gradually and strongly enlarged and deepened. The erosion intensity in the thin soil cover zone or the composed places is weak. The large fissure is the main water moving way, there is generally developing the sinkhole or shaft. Thus, the stone teeth may evolute to the stone forest (Fig.2).

In the place of the dipping more than 15°, the joints or fissures probably are developed well but they are not vertical on the ground surface. With the enlarging of joints and fissures, the upper part of limestone block is commonly cut off and the heighth of the limestone block is restricted. In other words, the stone teeth is the principle karst features.

If the soil contains high content of calcareous materials, the soil water is already saturated before it reaches on the contact surface of limestone with soil. Thus the joints and fissures are widen very slow and it is very difficult for stone forest to develop.

If the soil water erosion zone is very stable after the stone forest developed, the base of the forest is erosed for a long time and the stone pillars will be falled down. The base of the falled pillar will develop new stone teeth.



The evolution stage of the stone forest
1 original fissured limestone
2 and 3 subsoil erosion to enlarge the fissures and form the stone teeth
4 stone forest development

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10268

The distributions and basic features of caves in china

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RESUM

Tots els tipus de roca soluble són freqüents a la Xina, sobretot els estrats carbonatats, on s'hi han desenvolupat nombroses cavitats. Aquest treball fa una breu introducció de les principals característiques quant a la seva distribució i desenvolupament en alguns terrenys, incloent els tipus de cavitats més importants, les etapes del seu desenvolupament, les formes de seccions transversals, les característiques hidràuliques, classificació d'espeleotemes. etc. S'inclou un mapa nacional simplificat de la segona part del nou atlas (CHINAKARST), molt més extens, que hauria d'ésser publicat.

RESUMEN

Todos los tipos de roca soluble están ámpliamente distribuidos en China, los estratos carbonatados en especial, han desarrollado numerosas cavidades en todo China. Este trabajo introduce brevemente las características básicas sobre su distribución y desarrollo en algunos dominios, incluyendo principalmente tipos de cavidades, etapas de desarrollo, formas de secciones transversales y características hidráulicas, clasificación de espeleotemas, etc. Se adjunta un mapa nacional simplificado del mapa principal de la parte segunda del nuevo atlas (CHINAKARST) que debería ser publicado.

SUMMARY

All the kinds of soluble rocks are widely distributed in China, particularly the carbonate strata have developed numerous caverns over whole China. This paper is briefly introduced the basic features about their distri butions and development from several domains, which mainly include kinds of caves, development stages, forms of cave cross sections and hydraulic features, classification of speleothems etc. A national map simplified from the leading map of part two in the new atlas (CHINAKARST), that should be publishing, is attaching in this paper.

Karst caverns as the most representative phenomena are very much developed either in south and north or in east and west of China. The problems about caverns developments are very complex, for the limited space, this paper is only discussed the related features in brief.

(1)Kinds of Karst Cavern Systems in China

The signification of karst cavern is meaning that the soluble rocks formed a certain space as cave in itself by water dissolution in primary; except that, the karstification of any cave is always accompanied with hydrodynamic and mechanical erosion, deposition, biogenic process and cavitation etc. Usually the total volume to be destroyed by these processes together as ions state in water flow singulary.

Basing the kinds of soluble rocks and karst features, the kinds of cavern systems in China may be simply classified in Table 1.

KARST FEATURES	KARST KINDS	KARST VARIETIES	KINDS OF KARST CAVE SYSTEMS
PURE KARST	Carbonate rocks karst	Bare carbonate rocks Karst	Bare carbonate rocks cave systems
		Buried carbonate rocks karst	Buried carbonate rocks cave systems
	Sulphate rocks karst	Bare sulphates rocks karst	Bare sulphate rocks cave systems
		Buried sulphates rocks karst	Buried sulphate rocks cave systems
	Halides rocks karst	Bare halides rocks karst	Buried halides rocks cave systems
		Buried halides rocks karst	Buried halides rocks cave systems
COMPOUND KARST	Carbonate–Sulphate–Halides compound karst	Bare carbonate – sulphate – halide compound	Bare carb. – sulph. –hali. compound cave systems
		Buried carbonate–sulphate – halide compound karst	Buried carb. – sulph. – hali. compound cave systems
	Sulphate–halide compound karst	Bare···	Bare··· cave systems
		Buried···	buried··· cave systems
SIMILAR (OR PSEUDO) KARST	Red beds	Bare and buried karst in different kinds	Related bare and buried cave systems in different karst varieties
	Earth layers		
	Other clastic rocks		
	Metamorphic rocks		
	I gneous rocks		

(2)Classification of Carbonate Rocks'Cave Systems

As to the carbonate rocks, the dimensions of their cave systems are very different, their cross sections will be limited from the small passage-way with 0.2 m in diameter to ever 100 m of great subsurface hall in highness; which volume of single hall in many cave systems are always larger than 5.000 m^3. A series of cave's halls and passage-ways to be developed together make up a cave system.

In first, the carbonate rock's cave systems may be based on their lithological characters to separate into limestones, dolomites, argillaceous carbonate rocks and siliceous carbonate rocks etc. cave systems, which will respectively take the Yaolin Dong Cave in Tonglu of Zheijiang, Yunshui Dong Cave in Beijing and Longgong Dong Cave-Yuhua Dong Cave in Pengze of Jiangxi as their representative cave systems.

Seccond, many other principle will be using to divide the cave systems; for examples: 1. basing their patterns to separate into linear, toothing or meandering, feathering, netting and branching or dentritic etc. cave systems (fig. 1); 2. basing their levels

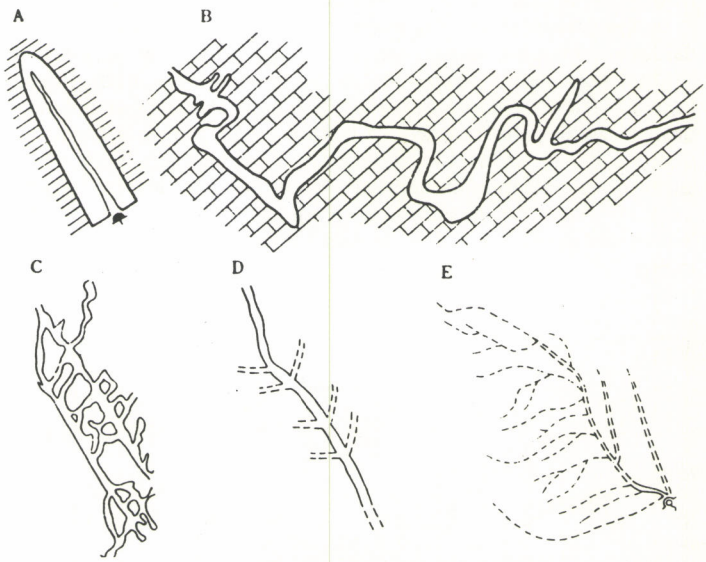

Fig. 1. Several typical patterns of cave systems A. linear type (southeast Sichuan); B. meandering type (west Hubei); C. network type (southeast Guizhou) (1); D. feathering type (southeast Guizhou)(2); E. dentritic type (west Guangxi-from Chen Wenjun).

structure to class single level, double levels, multi-levels etc. cave systems (Fig. 2); 3. basing the positions of cave outlet to separate dividing zone, valley slope, river bank, lake bank and coastal etc. cave systems.

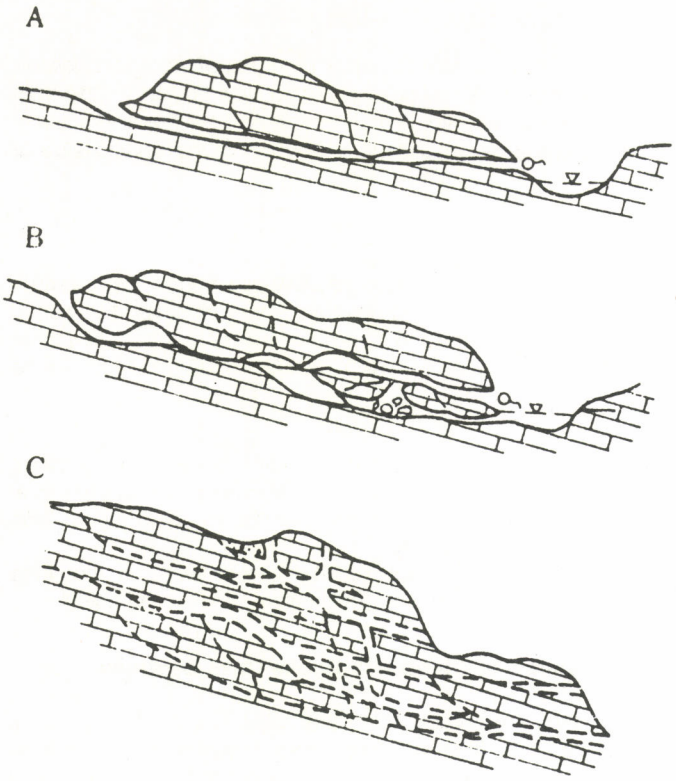

Fig. 2. Level structural types of cave systems A. single level type (west Hubei); B. double type (north Guizhou); C. multi-levels type (south Sichuan)

Otherwise, according to their development features, it is able to separate the early, middle and late stages; considering the structural unit, karst hydrodynamic condition, climatic condition, climatic factor during developed stages, deposition characters in cave, the fossils of ancient man and vetebrates as well as the chronological data, it is able to give the classifications of cave systems on each principle.

Third, the cave systems with larger flow over 0.5 m^3/s in dry season may call ground river; but basing the flow origins, that may be separated into the three kinds, which are: 1. wallet-ground river, most of that flow from sinking and pouring surface stream in concentrative state; 2. percolating water-ground river, most of its flow from percolating and coverging ground water and 3. mixture flow-ground river, most of its flow with the both origins from surface concentracted stream and a great deal of percolating ground water. The number of Known ground river systems is about 3.000 in south and southwest China, among them many larger ones with their catchment area from over 100 Km^2 to over 1.000 m^2 have the maxium flow quantity from over 5 m^5 to over 300 m^3 per second, which in several typical regions are compared in Fig. 3.

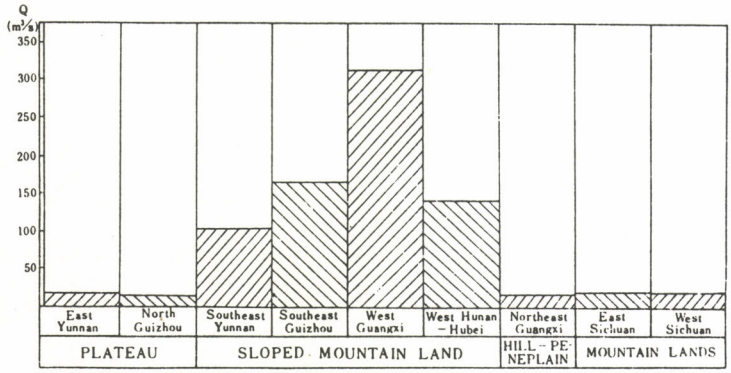

Fig. 3. Comparison of maximun discharges of ground rivers in typical karst regions of China.

(3)

Hydraulic Features and The Forms of Cave Cross Sections Owing to the changes of geological textures and flow character, the forms of cross sections in caves, which have been undergone continuous evolution, are variety in different positions of same system even of same passage-way. Their main forms may express as typification in Fig. 4.

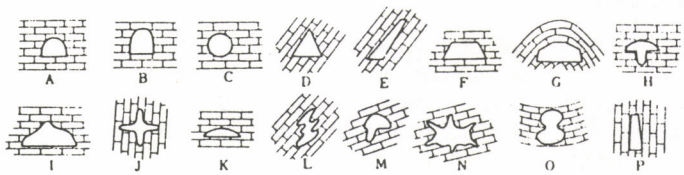

Fig. 4. Typical forms of cave cross sections

All these forms are controlled by different combination of structural conditions such as fissures, bedding plane and fault, hydrodynamic features including free, confined and other states as well as flow quantities' changes.

(4) Classification of Cave Deposits

The deposits in caves are very abundant, which are mainly included chemical, mechanical, biogenic and mixture kinds. (3)

Basing the speleothems'geneses with the closed relationships to flow features, the cave deposits may be separated into:

1. Chemical deposits: A. flowing water kind, included dripping flow, tube flow, fissure flow,sheet flow, floor flow, capillary flow, foggy flow and condensed flow etc. types; B. static water kind, mixture water kind and special water kind; each type will produce different deposits as a series of speleothem.
2. Mechanical deposits: clays, sands, gravels, colluvium, cave earthy mineral bed and cave placer deposits etc.
3. Biogenic deposits: cave fossil skeleton accumulation, cave shells bed, cave bird droppings and cave humus.
4. Cave mixed deposits: cave mechanical-biogenic deposits, cave mechanical-chemical deposits, cave biogeneic-chemical deposits and cave mixed deposids, cave biogenic-chemical deposits and cave multi-mixture deposits.

The important problems about three phrases'flow are discussed in another paper.

(5) Main Stages of Caves' Developments

All the features and dimensions of cave depositions have the relationships to climatic conditions, usually the stalactites, stalagmites and calcareous pillars with larger sizes were deposited under damp and hot or warm and moist conditions; but the plate-shaped speleothems were mostly producted in nice and cool condition or cold condition. For example, the moonmilks in the Shifu Dong Cave in north China as silklike and honeycomb-shaped with porosities 50-80 % had been measured their chronologic age about 32.005± 1450 in upper cave and 22.120±440 in lower cave by ^{14}C, when the climate was under last cold stage of Quaternary. Some related results are expressed in Table 2, Table 3.

(6)Distributions of Karst Cavernes in China

The distributions of typical caves developed in different soluble rocks are expressing in Fig. 5, which legends are:

A. Pure karst caves, 3. typical cave in carbonate rock, 2 typical ground river system, 3. typical fissure cave; 4. cave in the salt rock; 5. cave in the gypsum, 6. ice cave (ice up in carbonate rock cave in summer or all the year); B. similar karst caves: 7. typical cave in red bed or other clastic bed, 8. earths cave, 9. cave in ingenous rock, 10. sea erotion cave, 11, glacial cave; C.

CLIMATIC CONDITIONS AND SPOROPOLLEN ANALYSES FROM SOME CAVES DEPOSITS IN CHINA Table 2

REGION AND PLACE			KINDS AND CONTENTS OF SPORO-POLLENS				CLIMATIC CONDITION
			Arbor	Bush	Herb	Pteridophyte	
			20 40 60 80	20 40 60 80	20 40 60 80	20 40 60 80	
GUIZHOU	TONGZI	A					Temperate nice and cold
		B					Warm-moist or damp-hot
		C					
		D					
		E					Warm-dry
	WUJIANGDU	F					Warm-dry
GUANGXI	LIUZHOU						Warm-dry
	GUILIN	A					Damp-hot
		B					Warm-dry
FUJIAN	LONGYAN	A					Damp-hot
		B					
		C					
		D					Warm-dry
		E					
	YONGAN	A					Damp-hot
		B					Warm-dry
JIANGXI	PENGZE						Warm-dry(?)
HEILONGJIANG	YICHUN						Nice and cold

COMPARISON OF CLIMATIC CHANGES AND SPELEOTHEMS IN SOME TYPICAL CAVES OF CHINA Table 3

Geological age	Before 10^3a	Changes of Climate in Quaternary	Known Main Stages of Cave Speleothems Before 10^3a	Unearthed Fossils of Ancient men in some cave		Feature of society
Holocene				Recent men	New stone age	Slave Sociity (4700a B.C - 21st C.B.C)
	7-8	After glacial stage	5-6			
Q_4	10-12			Neolithic man		Primitive Society
Late pleisto-cene	60-70±	5th cold or glacial stage	11-16 (to warm) 23-25 30-36 40-50 (with warm)	Homo sapiens	Qld Stone age	
	110±	4th warm-hot interglaciation	100-110			
Q_3	150±	4th cold or glacial stage				
Middle pleisto-cene	200±	3th warm-hot interglaciation	170-190	Age-Men		
	400±	3th cold or glacial stage	210-230 240-260 300-330 (with warm)			
	500-600±	2th warm-hot interglaciation	400-500			
Q_2	730±	2th cold or glacial stage				
Early pleisto-cene	1420(?)	with 1th warm-hot interglaciation				
Q_1	1800(?)	with 1th cold or glacial stage				

cave in halides and sulphates zones: 12. bare halides cave, 13. bare sulphates cave, 14. bare compound cave, 15. subsurface halides cave, 16. subsurface sulphates cave, 17. subsurface compound cave; D.Karst collapses: 18. compound collapsed collumn; E. caves with fossils of ancient man and vertebrates: 19. with fossils of early Pleistocene, 20. with A pe-men fossils of middle Pleistocene, 21. with Homo sapiens fossils of late Pleistocene, 22. with Neolithic man of early Holocene, 23. with cultural and historic remains; F. others: 24. salt lakes'zone.

This paper is only introduced simple circumstances of caves' developments in China in limited contents.

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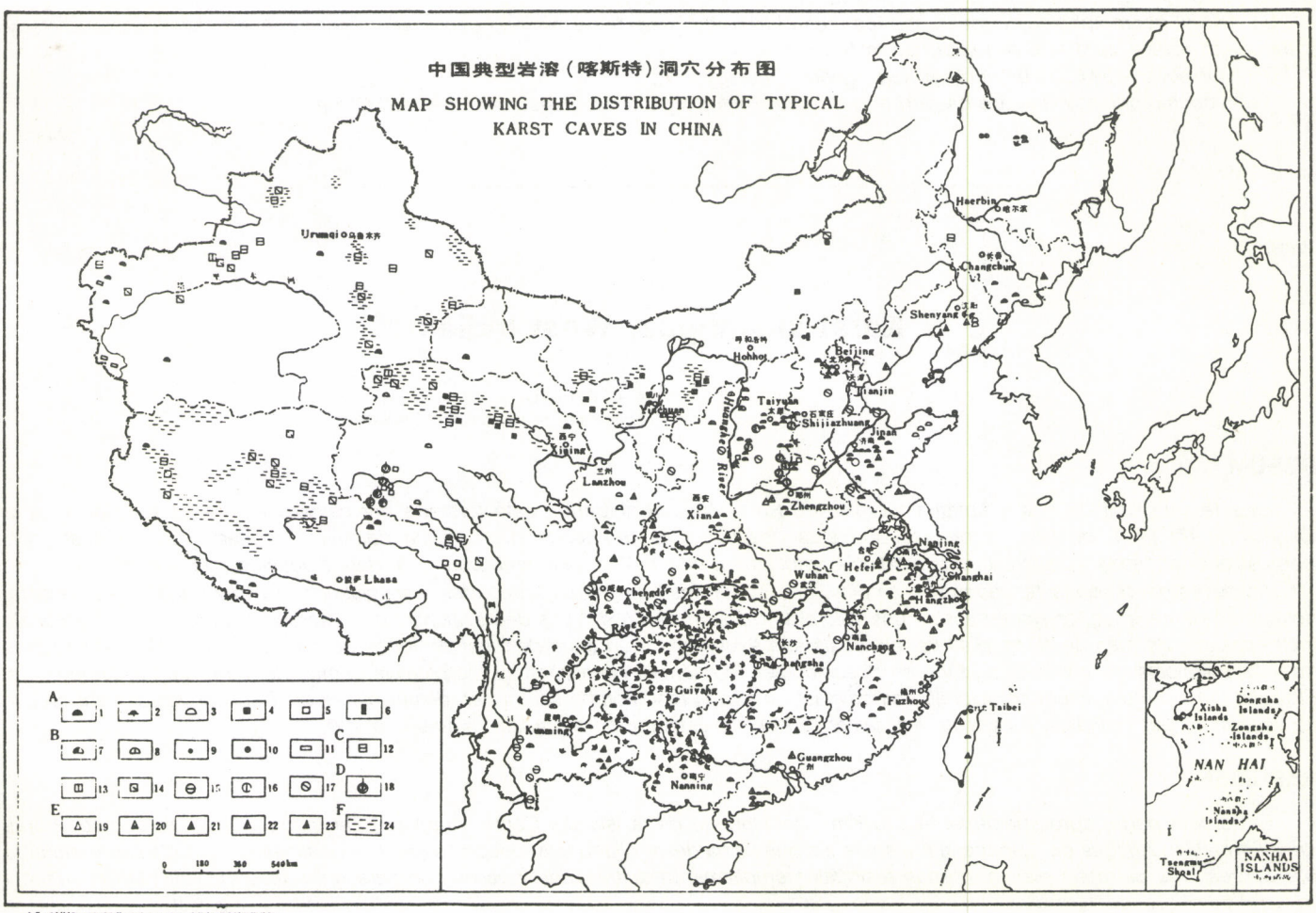

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Karst Geomorphology in the Eastern China

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RESUM

Les roques carbonatades es troben escampades en la petita àrea constitüida per les províncies de Jiangxi, Anhui, Jiangsu i Fujian. Segons la influència i control de la regionalització del bioclima i la no regionalització d'estructures geològiques i litològiques, les característiques geomorfològiques del carst són les següents:

1.– Entre la zona subtropical meridional i la zona temperada o càlida del nord, la geomorfologia càrstica desenvolupa «Fengkong» i «fenglin» semblants turons-pics i turons càrstics, respectivament.

2.– La geomorfologia del carst presenta unes característiques de transició entre el «fengkong» i el «fenglin» semblants a la geomorfologia subtropical al sud dels turons càrstics de la zona temperada del nord.

3.– La diferència regional òbvia de la geomorfologia càrstica.

La geomorfologia del carst es pot dividir en tres regions (incloses 6 sub-regions) a la Xina Oriental

RESUMEN

Las rocas carbonatadas están dispersas en la pequeña área de las provincias de Jiangxi, Anhui, Jiangsu, Zhejiang y Fujian. En la influencia y control de la regionalización de bioclima y la no regionalización de estructuras geológicas y litológicas, las características de la geomorfología del karst son las siguientes:

1.– De la zona subtropical en la zona Sur hasta la zona templada cálida en el Norte, la geomorfología kárstica desarrolla fengkong y fenglin* similares colinas-picos y colinas kársticas, respectivamente.*

2.– La geomorfología del karst muestra las características de la transición desde el fengkong y fenglin similares de la geomorfología subtropical en el Sur de las colinas kársticas de la zona templada del Norte.

3.– Diferencia regional obvia de la geomorfología kárstica

La geomorfología del karst puede estar dividida en 3 regiones incluyendo 6 subregiones en la China oriental.

SUMMARY

The carbonate rocks disperse in the small area of Jiangxi, Anhui, Jiangsu, Zhejiang and Fujian Provinces. In the influence and control of regionalization of bio-climate and non-regionalization of geologic structures and lithology, the characteristics of karst geomorphology are as follows:

1.– From the subtropical zone in the south area to the warm temperate zone in the north, the karst geomorphology develops the similar fengcong and fenglin, peak-hill and karst hills, responsiblly;

2.– Karst geomorphology appears the features of transition from the similiar-fengcong and fenglin of subtropical geomorphology in the south to the karst hills of temperate in the north.

3.– Obvious regional difference of karst geomorphology.

Karst geomorphology may be divided into 3 regios including 6 subregions in the eastern China

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Karst in Antigua, West Indies

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RESUM

Una tercera part de l'illa d'Antigua (aprox. 110 Km.^{2}) situada al Caribe està formada per calcàris no massa purs de l'época Oligocínica (?) (N.O. de l'illa), sobre les que s'ha desenvolupat una topografía càrstica dominant, formada essencialment, per depressions tancades i planes, turons residuals àmpliament distribuïts i valls amb cursos fluvials d'activitat intermitent.

Aquestes depressions tancades són amples, poc profundes i es troben agrupades, especialment a l'àrea central i sud-oriental del cinturó de càcaries, on poden assolir uns valors de densitat de 7/Km.^{2} Les depressions estan intercalades entre turons residuals molt espaiats, de més de 40 m. d'altura, els quals són exponents d'un tipus de carst de torres poc desenvolupat. Quatre sistemes de valls principals travessen la calcària en direcció N.O., drenant la zona càrstica i la planície central de materials no carbonatats. El règim hídric és clarament estacional. Les cavitats no són ni molt nombroses ni ben desenvolupades. El desenvolupament càrstic es veu limitat per l'escassa puresa de les calcàries i per l'existència d'un gradient hidràulic limitat.

RESUMEN

La tercera parte, aproximadamente 110 Km.^{2} del Noreste de la isla del Caribe Antigua, está formada por calizas poco puras de la Formación Antigua del Oligoceno (?), sobre las que se ha desarrollado una topografía kárstica dominante, formada esencialmente por depresiones cerradas planas, colinas residuales ámpliamente distribuidas y valles con cursos fluviales de actividad intermitente.

Estas depresiones cerradas son anchas, poco profundas y agrupadas, especialmente en el área central y Sudoriental del cinturón de caliza donde alcanzan densidades de 7/Km.^{2} Las depresiones están intercaladas con colinas residuales muy espaciadas, de más de 40 m. de altura; éstas representan un tipo de karst de torres poco desarrollado. Cuatro sistemas de valles principales atraviesan la caliza en dirección Noroeste. Ellos drenan tanto la zona kárstica como la llanura central de materiales no carbonatados. El régimen hídrico es claramente estacional. Las cavidades no son numerosas ni bien desarrolladas. El desarrollo kárstico está frenado por la baja pureza de las calizas y por un gradiente hidráulico limitado.

SUMMARY

The northeastern third, approximately 110 Km^2, of the Caribbean island of Antigua is underlain by impure limestones of the Oligocene (?) Antigua Formation, upon which has developed a subdued karst topography consisting essentially of shallow exclosed depressions, widely-scattered residual hills and intermittently-active stream valleys.

The scattered exclosed depressions are broad, shallow and clustered, especially in the central and southeastern sections of the limestone belt where they attain densities of 7/Km.^{2} The depressions are interspersed with widely-spaced residual hills up to 40 m in height; these represent a poorly-developed form of karst tower. Four main valley systems traverse the limestone in a northeast (downdip) direction. They drain both the karst area and the non-carbonate central plain. Their flow regime is highly seasonal. Caves are not numerous or well-developed. Karst development is constrained by the low purity of the limestones and by a limited hydraulic gradient.

Introduction

Karst in the Lesser Antilles has been little studied yet it is widespread, diverse and of significance in island development. This is exemplified in Antigua, area 280 km^2. Mean annual temperature in Antigua is 26 °C and mean annual rainfall is 1,251 mm (Blume, 1974) with a wide range from 648 mm in 1930 to 1,868 mm in 1889 (Martin-Kaye, 1959). A marked dry season extends from January to May, a wet season from about August to November.

Geology and Soils

The karst in Antigua is developed on the Antigua Formation, which is composed of limestones and marls plus occasional volcanic intrusives, calcareous sandstones and clays (Martin-Kaye, 1959). The Antigua Formation attains a thickness of 500 and dips to the northeast at generally less than 5°. Its age has been disputed but it is ascribed to the Oligocene by both Warneford (1949) and Martin-Kaye (1959).

Limestones within the formation are variable, both in terms of purity and strength. A series of insoluble residue determiantions (Day, 1978) showed a range of calcium carbonate contents from 62 % to 96.15 % and a mean insoluble residue content of 18.0 % (s = 10.65, N = 10). Surface strenght values, determined by the Schmidt Hammer test of compressive strength (see Day, 1980), vary from 12 to 36 ($\bar{x}$= 33.3) for fresh sections and from 27 to 41 ($\bar{x}$= 37.8) for indurated surfaces. Petrographically the limestones are biomicrites, often highly fossiliferous and with small amounts of quartz (Day, 1978). Coral limestones are common and algal limestones have been reported (Martin-Kaye, 1959).

Soils are dominantly calcareous (up to 74 % calcium carbonate), extremely shallow (less than 0.3 m deep) and stoney (Hill, 1966). They are extremely well-drained and characterised by grass or scrub vegetation (see Beard, 1948).

The Karst

Karst landforms are developed primarily where the Antigua Formation outcrops in the northeastern third of the island (Figure 1). The dominant features are enclosed depressions, intermittently-active valleys and residual hills. Two small caves have been described by Gurnee (1961). The karst is delimited by an escarpment, 60 to 80 m high, which trends approximately northwest to southeast from Wetherills Point to Willoughby Bay (Figure 1). This escarpment is breached in some locations by dry and seasonally-active valleys. Surface flow is intermittent or ephemeral and only four valleys attain significant length or demonstrate any consistent flow (Figure 1, Table 1).

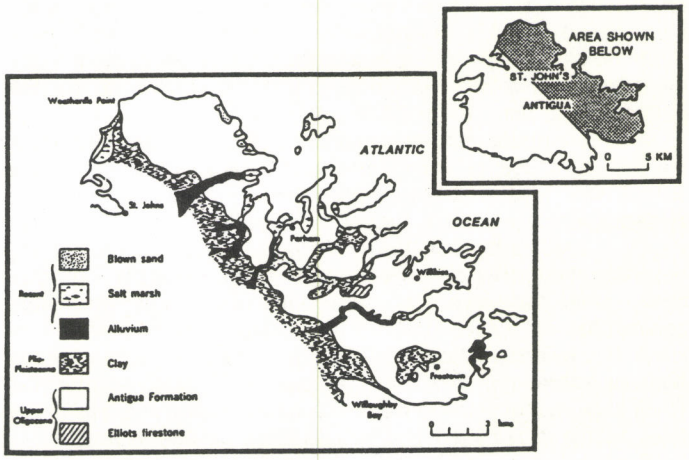

Table 1. Major Valleys in the Antigua Limestone Region

Name	Length (km)	Location	Catchment area (km^2)
Carrs Gut	3.6	Limestone region only	10.5
North Sound Stream	6.0	Central Plain and limestone region	11.0
Fitches Creek Stream	5.2	As above	15.6
Tomlinson's Stream	4.7	As above	13.7

Depression density is very low (Table 2). In an area of 110 Km^2 45 depressions were located and surveyed in the field (Day, 1978). Table 2 summarises the morphometric properties of these

Table 2. Morphometric properties of enclosed depressions, Antigua (N = 45)

	$\bar{x}$	s	Range
Depth (m)	1.96	1.85	0.2 to 12.0
Diameter (m)	101.67	91.48	17.5 to 525.0
Depth/diameter ratio	0.03	0.014	0.01 to 0.08
Density (/km^2)	0.39		
Depression area (km^2/km^2)	0.0058		
Index of pitting	172.41		
Planimetric shape (R_{wl})	0.69	0.155	0.35 to 0.99

depressions. In the north depressions are rare and subdued positive topography is dominant. Depressions are most dense in the centre and southeast; the most striking examples occur in the vicinity of Freetown (Figure 1). Depression area per km^2 is very low, the index of pitting correspondingly high (Table 2).

Depressions are shallow, generally less than 5 m deep ($\bar{x}$= 1.96 m, s = 1.85 m, N = 45). Only the large depressions near Freetown exceed this depth. Diameters are much greater than depths ($\bar{x}$= 101.67 m, s = 91.48 m, N = 45) and depth/diameter ratios range from 0.01 to 0.08 ($\bar{x}$, s = 0.03, s = 0.014, N = 45).

Planimetric shapes are variable ($\bar{x}$= 0.69, s = 0.155, N = 45). Small depresssions tend towards circularity but larger ones indicate definite elongation. Long axis orientations are concentrated in three directions: 31-40° (approximately southwest-northeast), 81-90° (near east-west) and 351-360° (near north-south). Since regional dip is towards the northeast and since Martin-Kaye (1959) reports three dominant jointing directions in the Antigua Formation in the segments 10-40°, 50-80° and 280-300° these orientations might be suggestive of broad structural control. However correspondence with jointing is poor and the preferred orientations are not statistically significant as determined by Tanner's (1955) test.

Depresion distribution, measured by the single nearest neighbour statistic, is clustered with $\bar{L}a/\bar{L}e$ = 0.533. Depressions are most dense in the southeast with densities up to 7/km.^{2}. Here depression development is promoted by a steep hydraulic gradient and there is little «competition» from dry valley systems (see Fermor, 1972; Day, 1978, 1983).

Also in northeastern Antigua occur isolated residual hills which Martin-Kaye (1959, p.1) describes succinctly as «scattered rather abrupt hills». Most of these hills rise from a surrounding limestone surface but some are surrounded by Plio/Pleistocene clays (Martin-Kaye, 1959) or by recent alluvial deposits. Typically the surface deposits occur only peripherally and do not separate individual hills. Locally the clays produce surface runoff which may abut against the hill bases, but no basal depressions, channels or sinks are evident. They also act as a reservoir for rainwater, perhaps promoting dissolution at the clay/limestone interface. The exact relationship between the deposits and the hills is unclear but the role of the deposits in hill formation seems limited.

Survey in a 4 km.^{2} area 2 km. southeast of Parham (Figure 1) (Day, 1978) documented 17 residual hills with a density of 4.25/km.^{2}. Densities in other areas are lower; four randomly-located 1 km.^{2} quadrats exhibited densities of 1, 1, 2 and 4/km.^{2} ($\bar{x}$= 2/km.^{2}, s = 1.225, N = 4). Residual hill heights range from 9 m to 40 m with a mean of 19 m (s = 11.8 m, N = 17) and median 16 m. Diameters range from 75 m to 520 m with a mean of 175 m (s = 121 m, N = 17) and median 140 m. Height/diameter rations range from 0.06 to 0.17 with a mean of 0.12 (s = 0.029, N = 17) and median 0.11. A strong relationship exists between residual hill height and diameter (Spearman Rank Correlation Coefficient r_s = 0.85, significant at the 0.01 level).

Width/length ratios (R_{wl}) range from 0.46 to 0.75 with a mean of 0.61 (s = 0.083, N = 17) and median 0.06. 12 of the hills (71 % of the measured population) have ratios between 0.51 and 0.70. The hills exhibit two preferred long axis orientations which are statistically significant as determined by tanner's (1955) test. These are in the classes 1-10° and 341-350°, both approximately north-south. This is similar to the orientations of some of the depressions and may reflect dip direction or jointing influence. Application of the single nearest neighbour technique (Williams, 1972) shows that the 17 sampled hills, as represented by points located at their summits, exhibit a distribution similar to that which might result from a uniformly acting process. $\bar{L}a$ is 0.340 km (s = 0.118, N = 17) and $\bar{L}e$ is 0.236 km. The ratio $\bar{L}a/\bar{L}e$ = 1.441, which is signifcantly different from random ($\bar{L}a/\bar{L}e$ = 1.0) at the 0.05 level. Throughout the entire limestone area, however, residual hills are markedly clustered; the preceding analysis deals with but one of these clusters.

Concluding Remarks

This study of the Antigua karst is preliminary and there is considerable potential for further work. Additional studies of the limestone are needed. Development of the valley systems is poorly understood and their contemporary hydrology deserves some attention. More information is needed about the relationship between the limestones and the more recent deposits, especially as the latter may influence near-surface hydrology and landform development. Overall the terrain is intermediate between types which have been described elsewhere in the Caribbean and Central America (e.g. Day, 1978). The residual hills represent a subdued form of karst tower and their development, along with that of the depressions, warrants further study.

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Karst and Landuse in Central Belize

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RESUM

El carst de Belize central, entre Belmopan i la capçalera de la vall de Stann Creek, consisteix en un fluviocarst de «cockpit», creuat per tres sistemes de valls d'alineació dominant nord-est: Caves Branch, el Sibun i Dry Creek, on s'hi ha desenvolupat una utilització del terreny variada i «entrepreneurial», com a reflex d'aquesta diversitat.

Caves Branch es troba condicionada per una plantació de cacao abandonada i per la ramaderia. Al Sibun hi ha plantacions de cacao i cítrics, juntament amb el bestiar. Dry Creek es caracteritza per posseir un tipus d'agricultura mixta, a petita escala. El carst de «cockpits» es troba sotmès a una forta influència per part dels ramaders de Milpa, en sa major part refugiats de El Salvador i Guatemala. Una agricultura alternant a petita escala condiciona el fluviocarst, si bé s'està endegant un nou projecte de plantació de cacao al sud-est de Caves Branch.

Els problemes inherents a la utilització del terreny de les valls fluvials són causa d'inundacions i de canvis ràpids del drenatge. El subministrament d'aigua planteja greus problemes al carst de «cockpit» i hi ha un risc creixent d'erosió accelerada del sòl dels vessants de les muntanyes.

RESUMEN

El karst de Belize Central, entre Belmopan y la cabecera del Valle de Stann Creek consiste en un fluviokarst de «cockpit», atravesado por tres sistemas de valles de alineación dominante Noreste – Caves Branch, el Sibun y Dry Creek. Se ha desarrollado un tipo de «landuse» variado y «entrepeneurial» como reflejo de esta diversidad.

Caves Branch está condicionada por una plantación de cacao abandonada y por ranchos de ganado. En el Sibun hay plantaciones de cacao y cítricos junto con el ganado. Dry Creek se caracteriza por la agricultura nómada a pequeña escala. El karst de cockpits está bajo una fuerte presión de los granjeros de Milpa, en su mayor parte refugiados del Salvador y Guatemala. Una agricultura alternante a pequeña escala condiciona el fluviokarst, aunque se está desarrollando un nuevo proyecto de plantación de cacao al Sud-este de Caves Branch.

Los problemas de la utilización del terreno en los valles fluviales incluyen inundaciones y cambios rápidos del drenaje. El suministro de agua plantea graves problemas en el karst de cockpit y hay un creciente peligro de erosión acelerada del suelo en las laderas montañosas.

SUMMARY

The karst of central Belize, between Belmopan and the head of the Stann Creek Valley, consists of cockpit fluviokarst traversed by three major Northeast-trending valley systems – Caves Branch, the Sibun and Dry Creek. A varied and entrepeneurial landuse pattern has developed in reflection of this diversity.

Caves Branch is dominated by an abandoned cacao plantation and by cattle ranching. In the Sibun are cacao and citrus plantations together with cattle ranching. In the Sibun are cacao and citrus plantations together cattle ranching. Dry Creek is characterized by mixed small-scale agriculture. The cockpit karst is under increasing pressure from milpa *farming, largely by Salvador and Guatemala refugees. Mixed small-scale shifting agriculture dominates the fluviokarst, although a new cacao project is being developed southeast of Caves Branch.*

Landuse problems in the river valleys include flooding and rapid channel shifting. Water supply poses serious problems in the cockpit karst and there is increasing danger of accelerated soil erosion on hillslopes.

Introduction

The karst of central Belize, southeast of the capital of Belmopan, is developed on a broad limestone plateau which rises southward toward the Maya Mountains and which is dissected by three northeast-trending river valleys –Caves Branch, the Sibun and Dry Creek (Figure 1). The karst consists of broad depressions, residual hills and abandoned valley systems.

Hillslopes are rugged, soil distribution is patchy and soil depths are greatest in depression bottoms. Surface water is uncommon in the dry season (January to May) but the landscape is transformed in the wet season (June to November) when there is extensive but short-lived runoff.

Steep ramparts and isolated limestone peaks flank the river valleys and extensive cave systems are developed in the valley sides (Miller, 1981). In the valleys themselves rivers with marked seasonal variations in discharge carry load derived from the metamorphosed sediments of the Maya Mountains. Valley floors are flat and llauviated with braided channels in which, at low flow, extensive gravel bars are exposed. Wet season flooding, often accompanied by rapid channel migration, disrupts the valley floors. The valleys broaden northward and lead eventually into a low coastal plain. Along its sothern edge the limestone abuts against the metasediments of the Maya Mountains.

The limestone is Cretaceous (the Campur Formation) and dips at less than 5° to the northeast (Miller, 1981) or at less than 10° to the northwest (Wright et al, 1959). To the north it is overlain by younger sedimentary rocks and by the sediments of the Belize River Valley. To the south the Northern Boundary Fault, represented by a 700-800m escarpment, separates the limestones from the metarmophic rocks of the Maya Mountains (Bateson and Hall, 1977). Thickness of the limestone ranges from 900m adjacent to the Maya Mountains to 2000m further north. The limestones are often massively-bedded and sometines dolomitised. They are variable petrographically, many are biomicritic but micrites occur locally and brecciated limestones are common. Many are considerably altered (Day, 1978; Ireland,1982, McDonald, 1979; Miller, 1981). Their purities, porosities, water absorption capacities and mechanical strenghts are also variable (Day, 1978; Ireland, 1982). Jointing in the limestones trends southwest to northeast, echoing that of the Maya Mountains.

Soils on the limestones are patchy, well-drained red-brown calcareous rendzinas or vertisols derived from the limestones (Furley and Newey, 1979). Depth and moisture content increase downslope to depression and valley bases. Alluvial soils in the main valleys are variable but many are red-brown acidic clays. Drainage conditions vary considerably with site location. Vegetation is mostly secondary growth mixed broadleaved deciduous

seasonal forest. It contains a wide variety of species including several associated with the calcareous soils (Furley and Newey, 1979).

Mean annual rainfall is between 2000 and 2400mm with a marked dry season fluctuating around January to May. Much rain falls in intense storms and there are marked local differences, for example between Belmopan, Roaring River and Caves Branch (Figure 1) (Walker, 1973; Furley and Newey, 1979; National Hydrometeorological Service Records). Mean annual temperature is around 25°C.

The karst

The karst contains several different components, some widespread, others localised. Among these are cockpit depressions enclosed by residual hills, isolated cones and towers, incompletelyenclosed, ill-defined broad depressions, poorly-integrated valley systems, valley ramparts and the main valleys themselves.

South of Belmopan are isolated outlying residuals hills which grade southward into an area of generally distinct cone separated either by narrow (<100m wide) discontinuous valleys or by broad (up to 500m) depressions. Most cones are less than 40m high but some rise up to 120m above adjacent valleys. Compared to other areas cone slopes are relatively uniform. Fully enclosed depressions (cockpits) are uncommon between Belmopan and Deep Valley (on the west side of Caves Branch) and overall the karst here is open relatively integrated, suggesting paleodrainage north and west toward Roaring Creek and the Belize River Valley. There is much contemporary ephemeral drainage and one east bank tributary of Roaring Creek maintains flow up to 6km through the karst, representing an important local water supply.

Deep Valley is an eastward trending paleodrainage triburtary of the Caves Branch system (Miller, 1981). Total lenght is about 4km, width is almost 1km and depth is about 80m. The valley floor is discontinuous and interrupted by karstic depressions. West of Caves Branch the valley breaches a 120m high rampart, a serrated ridge of residual hills rising up to 100m above intervening dry hanging valleys resulting from incision of the Caves Branch Valley. East of Caves Branch another large dry valley leads into an area of mixed cockpit and fluviokarst (Miller, 1981). Depressions and residual hills both vary in size and shape but depressions are commonly 40-80m deep and often exhibit southwest-northeast orientations (Day, 1978). Between the Sibun and Dry Creek the karst is composed largely of scattered cones and broad depressions grading northward into tower karst (Mc Donald, 1979). Serrated ramparts flank the valleys and some towers are developed close to the Hummingbird Highway (Figure 1) where they have been isolated by drainage off the adjacent metamorphics.

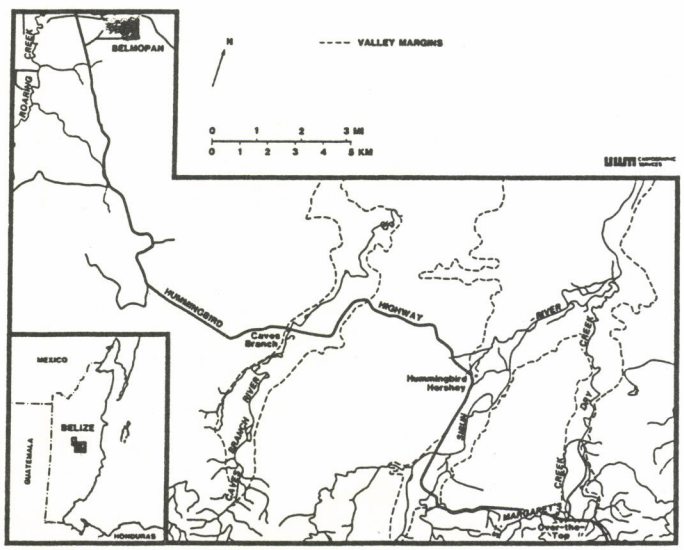

Figure 1. Major rivers and roads of central Belize.

The valleys of Caves Branch, the Sibun and Dry Creek are very different from the adjacent cockipt, tower and fluviokarst. The valleys are flat-floored, alluviated and have more or less distinct margins. They trend toward the northeast and are fault guided (Wright et al, 1959). All three rivers are allogenic, rising in the Maya Mountains. The Caves Branchr valley is an open valley polje which extends some 8.5km through the karst, attains a width of 1-2km and is bordered by ramparts 80 to 160m high. Channels are cut up to 10m into the alluvium, which is a mixture of reddish clays and sands, derived from the metamorphics, and local limestone cobbles which are often cemented. Shallow surface depressions act as catchments and sinks for dainage off the alluvium. Channels are braided, gravel bars and undercut limestone cliffs are common. Wet season discharge of the Caves Branch River may exceed $50m^3\ sec^{-1}$, but dry season discharge is often negligible. Considerable discharge is pirated by cave systems flanking the valley (Miller, 1981, 1983) and the remaining flow sinks into a ponor at the north end of the valley before resurging to join the Sibun.

The Sibun Valley, about 8km long and 1-2km wide through the karst, is similar in many respects to Caves Branch. Karst hills and depressions border the valley but there is some authigenic drainage from within the limestone. The west edge of the valley is less abrupt and a marked set of terrace occupy the western part of the valley adjacent to the Hummingbird Highway. The Sibun too has a very variable discharge and has the reputation as the most floodprone river in Belize (Wright et al, 1959).

The Dry Creek Valley is the smallest of the three, extending some 5.5km through the karst before joing the Sibun and with a width of generally less than 1km. Dry Creek and its major tributary, St. Margaret's Creek also have highly variable discharges and have fills and undercut flanking hillslopes. Channels are floored largely by limestone and metamorphic cobbles.

Landuse

Reflecting the varied karst terrain there has developed a complex and rapidly changing mosaic of landuses. Three broadly different categories of agricultura landuse are associated with, respectively, the cockpit karst. the fluviokarst and the major river valleys. The cockpit and irregular interior karst has been little used agriculturally until recently. Within the last decade however Salvadoran and Guatemalan immigrants have established settlements along the Humminbird Highway, particulary between Balmopan and Caves Branch, and have initiated mixed small-sacale farming usually employing the *milpa* system of forest clarence, cultivation for 2 to 4 years the abandonment. In 1957 *milpa* acreage was negligible but by 1985 approximately 300ha was either actively in use or recently abandoned and this total is increasing as *milpas* are established further from the road. Depression and valley bases are used initially but hillsloper are bing cultivated increasingly. Contemporany *milpa* activity is mostly west of Caves Branchs and east of the Sibun since much of the area between Caves Branch and the Sibun is protected government forest preserve.

The fluviokarst valleys, particularly Deep Valley and the tributaries of Roaring Creek, have been used agriculturally in modern times since at least the 1950's and,. in the case of Deep Valley probably by the pre-Hispanic Maya who occupied there a site which has been dated to 700-900AD (Davis, 1980). Much of the former *milpa* land is currently abandoned. In the major valley east of Caves Branch a major cooperative cacao projected was initiated in 1985. This porject, involving local farmers, the Hershey Corporation. The Pan-American Development Foundation, U.S.A.I.D and the Belize Goivernment, will cover about 400ha.

Abriculture in the tree main valleys is the most varied and sophisticated. Seaton Development Ltd. of Canada own a total of some 25,000ha including most of the Caves Branch where they operate a cattle ranching operation invilving about 100 head and some 80ha of grazing land. Much of Caves Branch has been logged or cleared and there is an abandoned 120ha cacao plantation for merly operated by Sharpes of Jamaica. Seaton employees

cultivate personal *milpa* plots both in the valley and west along the Hummingbird Higway.

The U.S. Hershey Corporation, through its subsidiary Humming bird Hershey, operates a cacao and citrus plantation totalling some 730ha in the Sibun Valley. Currently some 245ha of the valley bottom is in cacao and about 40ha on the higher terrace is in citrus. Independent farmers in the Sibun cultivate about 30ha of citrus and about 40ha is used for cattle grazing. Agriculture in the Dry Creek Valley is very mixed but is dominated by small to medium sized (<50ha) private farms owned and operated by Belizeans and foreigners. Farming techniques are variable and crops are mixed, although citrus is becoming increasingly important. Livestock numbers are low but, as on other private farms in the area, chicken, cattle and pigs may be important to individual farmers.

Landuse Problems

Outside the main valleys water supply is a significant dry season problem necessitating the use of springs, wells and tanker supplies. Coverselay, intense wet season rains produce flooding in depression and valley bottoms and cause severe soil erosion on steeper cultivated slopes. In the main valleys wet season flooding is a major problem especially since it is often accompanied by severe erosion of alluvial fills and dramatic channel shifting. Dry season flows, although low are usually reliable, although Hershey maintains and uses a 30m well.

Acknowledgements

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On Paleoenvironment of Karst Development and Plate Tectonics

RESUM

La carstificació constitueix un tipus de procés geològic exogenètic íntimament relacionat amb la zonació climàtica. El paleoclima ve determinat per la paleolatitud, com a conseqüència de la deriva continental i resta registrat en els sediments dins la història geològica.

Aquest treball tracta de les relacions entre el desenvolupament del carst i la zonació climàtica, els indicis de paleoambients tropicals i subtropicals en desenvolupaments càrstics favorables, els canvis del medi ambient i el desenvolupament del carst en períodes geològics diferents.

Es demostra que el paleoambient favorable per a la formació del carst comença al Paleozoic, d'acord amb els mapes de reconstrucció continental i la posició de la placa xinesa. Constitueixen importants períodes paleocàrstics el període comprès entre l'Ordovicià Mitjà i el Carbonífer antic del nord de Xina, el comprès entre el Pèrmic antic i el més recent a la Xina meridional i els períodes intermitjos i recents del Cenozoic.

RESUMEN

El Karst es un tipo de proceso geológico exogenético íntimamente relacionado con la zonalidad climática. El paleoclima queda determinado por la paleo-latitud, como resultado de la deriva continental y queda registrado en los sedimentos en la historia geológica.

Este trabajo trata de las relaciones entre el desarrollo del karst y la zonalidad climática, las indicaciones de paleoambientes tropicales y subtropicales, en desarrollos kársticos favorables, los cambios del medio ambiente y el desarrollo del karst en períodos geológicos distintos.

Se demuestra el paleo-ambiente favorable para el karst desde el Paleozoico, de acuerdo con los mapas de reconstrucción de los continentes y la posición de la placa China. El Ordoviciense medio hasta el Carbonífero antiguo en el Norte de China, entre el Pérmico antiguo y reciente en China meridional y los períodos medios y recientes del Cenozoico, constituyen importantes períodos paleokársticos.

SUMMARY

Karst is a kind of exogenetic geological process closely related to the climatic zonality. The paleoclimate is controlled by the changing paleolatitude as a result of continental drift and is recorded by the sediments in the geological history.

The relations between karst development and climatic zonality, the indications of tropic and subtropic paleoenvironments on favourable karst development, the environmental changes and karst development in different geological periods are discussed in this paper.

According to the maps of continental reconstruction and the position of China plate, the favourable paleoenvironment on karst since Paleozoic is demonstrated. The Middle Ordovician to Early Carboniferous in North China, between Early and Late Permian in South China and since Middle and Late periods in Cenozoic are important paleokarstic periods.

Introduction

Karst is a kind of exogenetic geological process closely related to the climatic zonality. The development of karst is controlled by the climatic factors in a certain sense.

Paleokarst is an interstratal karst as a synonym buried karst which is covered by post-karst rock or sediment and there is normally a disconformity or unconformity. The term paleokarst in China is commonly used in a narrow sense that developed during the Precenozoic time.

The development of karst may be evaluated and predicted in quality by the study of paleonvironment on paleogeology, paleogeography and paleoclimate.

The paleoclimate is controlled by the changing paleolatitude as a result of continental drift and is recorded by the sediments in the geological history.

The carbonate rocks, coral reefs, laterite and bauxite are the signs of paleoclimate and paleolatitude in tropics and subtropics. Karst landforms may also provide the information of paleoclimate and paleolatitude.

The relationships between karst and climatic zonality

For the present, four climate belts are recognized. They are warm-wet, warm-arid, cool-wet and cold-dry.

Climatic differentiation of karst is inherent in the subject since the extent and rates of carbonate rock solution are affected by the amount of water available and that passing through the rock. Thus karst development is at its greatest in belts of warm-wet and cool-wet climates–temperate, tropical and subtropical. Figure 1 shows the karstic solutional erosion in relation to precipitation.

Temperature is of importance for karst development. The organic activity in soil and the rate of reaction for the processes of solution are controlled by the temperature. The CO_2 in soil air is conditioned by the temperature and water balance. This is shown in the diagram in fig. 2, which shows the predicted global pattern of mean growing-season soil log (PCO_2). The area of log (PCO_2) in soil air above −2.20 is mostly located in belts of warm-wet climates–both subtropical and tropical.

According to climatic factors, karst features in China can be divided into four karst regions. Each karst region is a climatic zone with a special aridity.

Paleoenvironmental indication in climatic belts for favourable karst development

Climate plays an important role in determining the nature and composition of sediments in a given area.

The carbonate rocks, coral reefs, laterite, bauxite, evaporite and red beds are important paleoenvironmental indication of warm, wet and arid climatic belts in relation to karst development on continantal plate.

The distribution of the different climatic belts in the history of the earth mobile due to the changes the earth's pole position and probably because of the drift of continents.

Paleokarst forms which formed under different climatic conditions from those of the present are important paleoenvironmental indications as well.

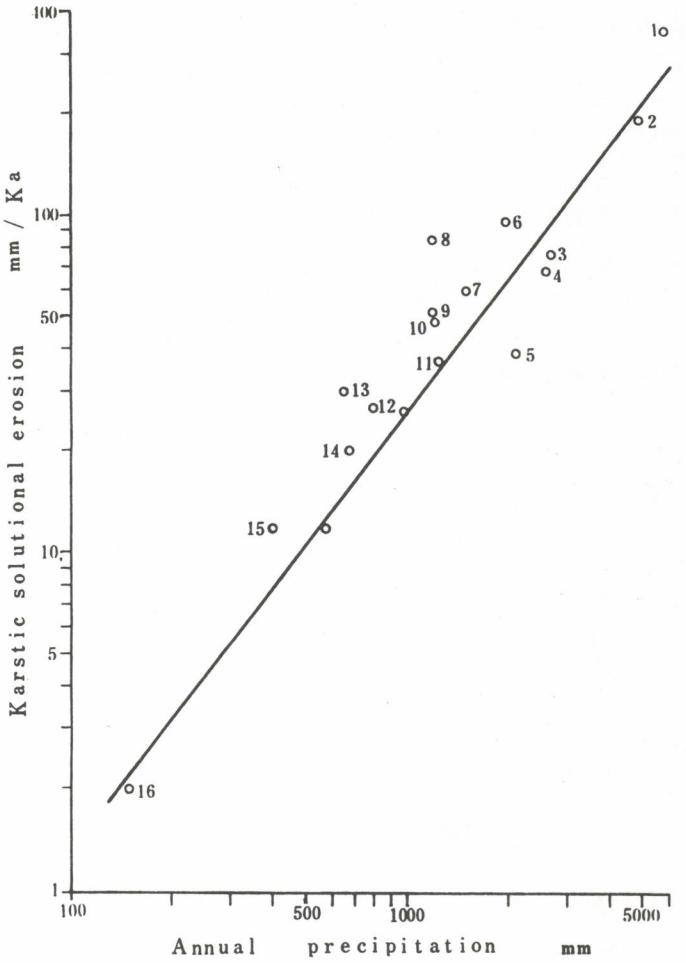


Fig. 1. The relationships between the karstic denudation and precipitation in different countries of the world (after Lang, 1977; Sweeting, 1980 and author's calculated).
1. New Britain; 2. Sarawak; 3. Philippines;
4. Ocean Is.; 5. Japan; 6. Indonesia;
7. Slovenia; 8. Hubei, China; 9. Yunnan, China;
10. Neretva River; 11. Guizhou, China; 12. Poland;
13. Shandong, China; 14. Hungary; 15. Shanxi, China;
16. Nullarbor Plain.

Karst geomorphological forms have been buried by more recent sediments after their formation. They are karstic plain, tower karst-karstic plain, wavy karstic plain which consists of hilly and uvala, karstic mountain land and karstic reef mass. Except the karstic plain and karstic mountain land, others are only originated in temperate, subtropical and tropical belts.

After the paleolatitude of the buried paleokarst landforms in Europe, North America and China are resumed in the maps of continantal reconstruction, you will notice the identity in the distribution of paleokarstic phenomena with the climates–subtropical and tropical. Paleokarstic phenomena and its paleolatitude are listed as follows:

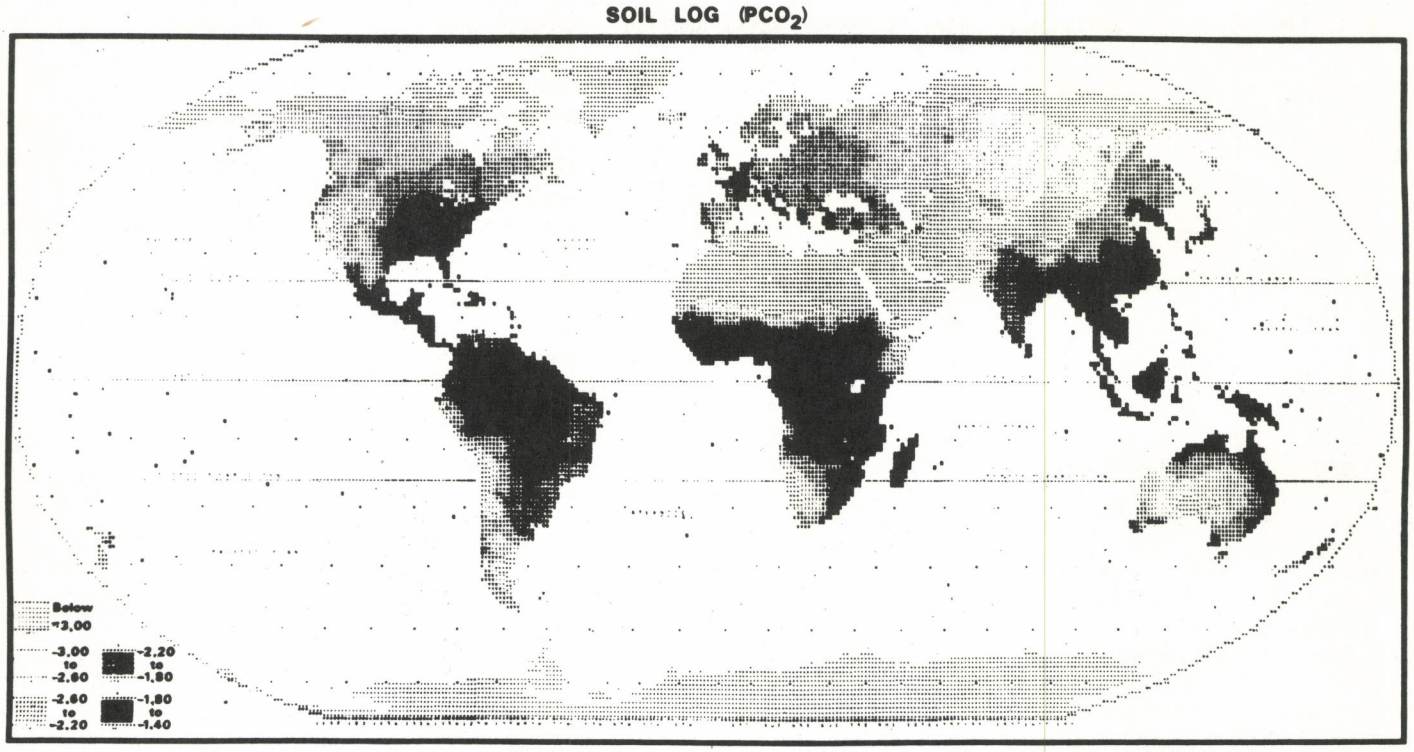


Fig. 2. The predicted global pattern of mean growing-season soil log (PCO_2) (after Brook, 1983).

Paleoenvironmental changes in geological periods and karst development

Paleomagnetism shows that the continents have changed their positions in relation to the earth's magnetic field by thousands of kilometers since Precambrian time. These movements are revealed in two ways–by polar wandering and by continental drift.

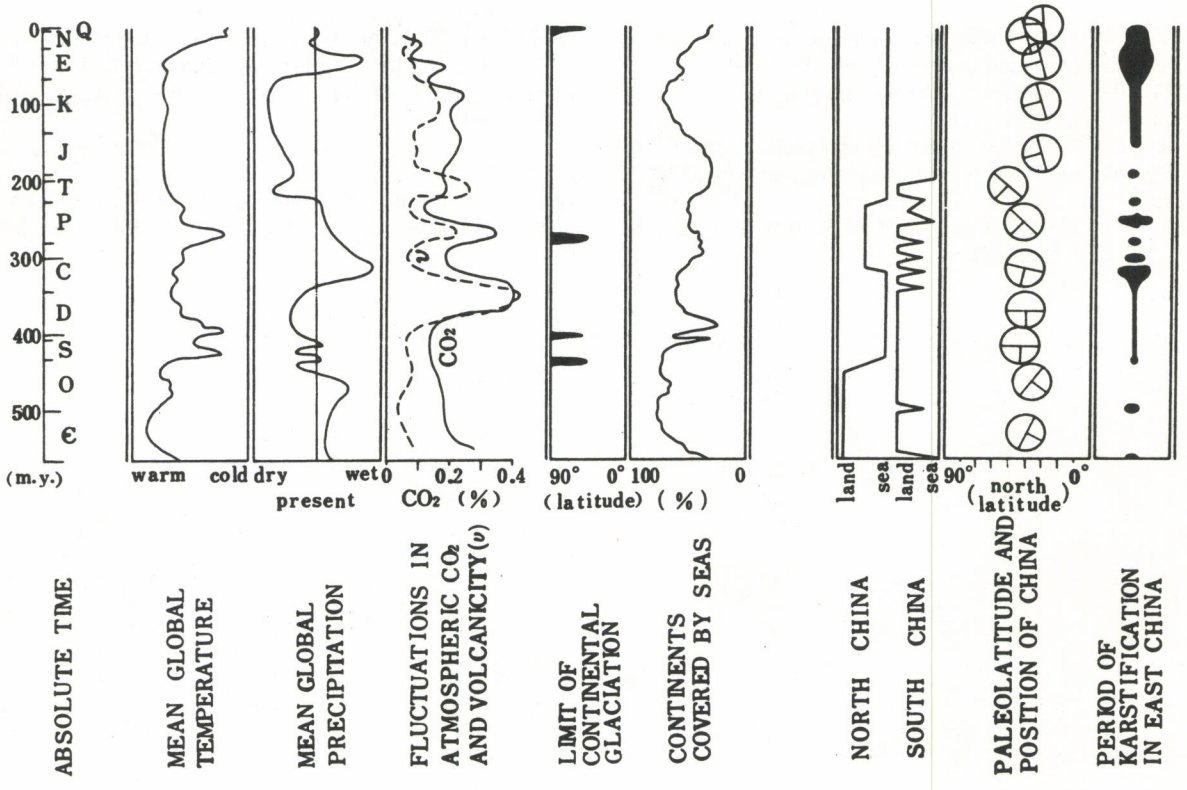
Continental drift and the phenomena connected with it affected climates of the past, such as the paleogeographic factors, latitude changes, mountain building, sea level changes, configuration and orientation of continental masses and ensuing changes in ocean current and wind patterns.

The changes in the composition of the earth's atmosphere especially CO_2 and astronomical factors are not connected with continental drift, they affected climates of the past too.

The karstification is a rapid geological process. Its time scale may be considered as from 100,000 to 10,0000,000 years when the karst landscape may be changed obviously. The factors which affected climatic changes below 100,000 years may not be considered for karstification.

The maps of continental reconstruction have been compiled by geologists. The position of China plate is similar in these maps in geological periods. According to Seyfert's maps the paleolatitude of karst development in China is discussed.

Fig. 3. Generalized global fluctuations in some influential factors of karstification and the paleolatitude, karst periods in China since Paleozoic era (part of the data after Seyfert and Sirkin, 1979; Frakes, 1979; Budyko, 1982).



Areas of Paleokarst	Present Latitude	Ages of Carbonate Rocks	Ages of Karstification	Paleokarst Forms	Paleolatitude
Yugoslavia	N41-47	T2	T	dolines	N15-21
		K	K-Tr	intensive karstification	N24-30
Italy	N36-47	K	K	dolines, shafts and bauxites	N16-24
France	N43-51	C	P-T	peneplainization,	N24-30
		K	K	shafts & bauxites	N27-33
		Tr	Tr	highly evolved karst, dolines & erosion valleys	N34-40
Poland	N50-54	C	C-T	isolated, steep-walled hills, often more than 100 m high	N15-21(P) and N30-36(T)
		T	T	dolines, uvalas and poljes	N30-36
		K	K	dolines & shafts	N31-36
Rumania	N44-48	T	T	corrosion and erosion relief	N30
		J,K	K	peneplain and bauxites	N25-30
Hungary	N46-48	T	K	bauxites, uvalas,	N30
		J	E	tower & cone karst	N35
U.S.A.					
Kansas	N37-40	C	C	hilly and uvalas	equator
Michigan	N42-45	D	D	tower karst	S15
Texas	N30-33	P	P	tower karst	N5-10
U.S.S.R					
Tartary	N55	D	D	tower karst	N10
China					
North China	N33-43	O	O-C	dolines, karstic plain & bauxites	N40-50
Eastern Yunnan	N25	P	P	karstic mountain land	N35

The factors of influence for karstification such as mean global temperature, mean global precipitation, fluctuations of CO_2 in atmosphere and volcanicity, limit of continental glaciation and continents covered by seas are shown in the fig. 3. The distributions of land and sea in North and South China, the paleolatitude and position of China plate and periods of karstification in East China are shown in this figure as well. From Middle Ordovician to Early Carboniferous in North China, between Early and Late Permian in South China and since Middle and Late periods of Mesozoic are important paleokarstic periods.

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To the problem of the soviet Tyan-Shan vertical karst belting

V. n. Mikchailov

RESUM

El Tyan-Shan soviètic cobreix tota la part occidental del sistema muntanyenc del mateix nom. La discreció de les regions de formacions carbonatades situen llurs posicions en diferents cinturons climàtics que porten a diferent intensitat dels processos de formacions kàrstiques dels massisos calcaris.

La combinació favorable de la precipitació efectiva, l'aspror del relleu, la quantitat anual de diòxid de carboni extret de l'estrat vegetal es dóna en el cinturó muntanyenc mig que posseix la major denudació kàrstica. El mínim de formació kàrstica es troba en el cinturó de muntanyes baixes, en zona semiàrida i paissatge desèrtic. Entre els valors de la denudació kàrstica i l'elevació de la massa s'observa força connexió que es descriu amb l'ajut de l'equació $Y = A + Bx$. En el intèrval de 1.300-4.000 m. el coeficient de correlació és de 0,88.

La disposició de la majoria de cavitats kàrstiques en el cinturó muntanyenc mig, s'explica també per la superposició de cavitats contemporànies amb relictes pre-neogènics, que estan preservats gràcies a la petita amplitud dels moviments neotectònics, que estan preservats gràcies a la petita amplitud dels moviments neotectònics d'alguns territoris. El cinturó de muntanyes altes és una zona de relleu kàrstic contemporani de relleu residual, que ha estat destruït per una poderosa erosió neogen-quaternària. El cinturó de muntanyes baixes és una zona principalment amb relleu subterrani residual.

RESUMEN

El Tyan-Shan soviético cubre la parte occidental del sistema montañoso del mismo nombre. La discreción de la regiones de formaciones carbonatadas situan sus posiciones en varios cinturones climáticos que llevan a diferente intensidad de los procesos de formaciones kársticas de los macizos calizos.

La combinación favorable de la precipitación efectiva, la aspereza del relieve, la cantidad anual de dióxido de carbono extraido del estrato vegetal se da en el cinturón montañoso medio que posee el mayor valor de denudación kárstica. El mínimo de formación kárstica se encuentra en el cinturón de montañas bajas, en zona semiárida y paisaje desértico. Entre los valores de la denudación kárstica y la elevación de la masa se observa bastante conexión que se describe con la ayuda de la ecuación $Y = A + Bx$. En el intérvalo de 1.300-1.4000 m. el coeficiente de correlación es de 0,88.

La disposición de la mayoría de cavidades kársticas en el cinturón montañoso medio, se explica también por la superposición de cavidades contemporáneas con relictos pre-neogénicos, que están preservados gracias a la pequeña amplitud de los movimientos neotectónicos de algunos territorios. El cinturón de montañas altas es una zona de relieve kárstico contemporáneo y relieve residual, que ha sido destruido por una poderosa erosión neógeno-cuaternaria. El cinturón de montañas bajas es una zona principalmente con relieve subterráneo residual.

SUMMARY

The Soviet Tyan-Shan covers the western part the of the mountain system of the same title. The discretion of region's carbonaceous formations stipulates their positions in several climatic belts, that brings to different intensity of the karst formation process of the limestone's massifs.

Favourable combination of the effective precipitation, ruggedness of relief and quantity of extracted soil-plant leyer's carbon dioxide falls on the middle mountain belt that has the greatest value of karst denudation. Minimun of karst-formation is marked at the low-mountain belt, at semiarid zone and desert landscape. Between values karst denudation and height of the massive is observed rather a connection that is described with a help of equation $Y = A + Bx$. At the interval 1300-4000 metres correlation coefficient is 0,88.

The disposition of majority karst caves at middle mountain belt is explained also by superposition of contemporary cavities on relict pre-neogenic, whick are preserved thank to small amplitudes of neotectonic motions of some territories. High mountain belt is a zone of contemporary karst relief and relict relief, which has been destroyed with powerfull neogen-quaternary erosion. Low-mountain belt is a zone of priority relict underground relief.

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Experimental studies of the intensity of surface corrosion in the karst regions of Yugoslavia

Dusăn Gavrilović

RESUM

Durant un període de varis anys, es va mesurar la corrosió superficial d'onze localitats de diverses altituds i de diferent clima, mitjançant la utilització d'un mètode de «taules estàndart». La intensitat mitjana de corrosió va des de 2,2 $m^3./Km^2./any$, a les muntanyes Càrpato-Balcàniques, fins a 6,1 $m^3./Km^2./any$, a les muntanyes litorals de Montenegro.

La corrosió és més enèrgica sota el recobriment del sòl, que a la superfície de la roca nua i depèn més de la humitat del sòl que no pas de la quantitat de precipitacions. La influència indirecta de la temperatura de l'aire és més efectiva que la influència directa de la precipitació.

L'estimació de la corrosió superficial amb taules estàndart, combinada amb la mesura de la duresa de l'aigua, ens permet d'observar la intensitat de la corrosió subterrània. La relació entre la corrosió superficial i la del subsòl és, aproximadament, de 1 : 8 i la relació entre la corrosió superficial i la marginal del 1 : 4.

RESUMEN

La medida de la corrosión superficial en once localidades, durante un período de varios años, fué llevado a cabo mediante la utilización de un método de «tablas standard» en varias altitudes y en diferentes climas. La intensidad de corrosión promedia va desde 2,2 $m^3./km^2./año$, en los montes Cárpato-Balcánicos, hasta 6,1 m^3 $km^2./año$, en los Montes litorales de Montenegro.

La corrosión es más enérgica bajo el recubrimiento del suelo que en la superficie de roca desnuda, y depende más de la humedad del suelo que de la cantida de precipitación. La influencia indirecta de la temperatura del aire es más efectiva que la influencia directa de la precipitación.

La medición de la corrosión superficial con tablas standard, combinada con la medición de la dureza del agua nos permite observar la intensidad de la corrosión subterránea. La relación entre la corrosión superficial y la del subsuelo es aproximadamente de 1 : 8 y la relación entre la corrosión superficial y la marginal de 1 : 4.

SUMMARY

The measuring of surface corrosion, on eleven localities, during a several years period, was carried out by using a method of «standard tablets» on various heights and in different climates. The average corrosion intensity is from 2,2 $m^3/km^2/year$, in the Carpatho-Balkanian Mountains, to 6,1 $m^3/km^2/year$, in litoral mountains of Montenegro.

The corrosion is more intensive under the soil cover than on the bear rock surface, and is more dependant on humidity of the soil than the quantity of precipitation. The indirect influence of air-temperature is more distinct than direct influence of precipitation.

The measuring of surface corrosion with standard tablets combined with measuring of water-hardness enables us to observe the intensity of underground corrosion. The relation between the surface and underground corrosion is approximatively 1 : 8, and relation between surface and marginal corrosion 1 : 4.

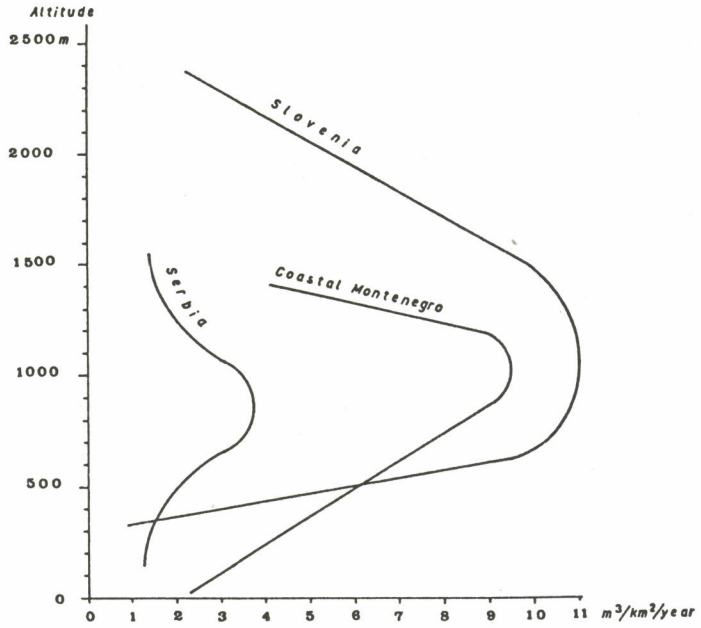
1. Introduction

At the 7th International Speleological Congress in Sheffield, in 1977, the Commission for Karst Denudation adopted the research program of the intensity of corrosion by the application of «standard tablets». The main objective of the investigations was to establish quantitative values of surface corrosion in different climatic zones, resp. the climatic variability of the karst process. The management of this project was entrusted to the academician Dr. Ivan Gams of Ljubljana. Though the project has been dealt with for eight years already and over 30 searchers from 16 countries of the world have been engaged in its realization, the published results of investigations are comparatively scarce, so that it is still impossible to evaluate the importance of the experiment. Nevertheless, in the meantime there have been gained precious experiences.

Between 1978 and 1983 in Serbia were carried out, in seven localities (situated in the region of Šumadija and in the Carpatho-Balkan mountains) the measurements of the intensity of surface corrosion by the application of «standard tablets» (D. Gavrilović, 1984). Determined results have been obtained, but it was impossible to draw a conclusion as to the influence of the climate on this process. The only explanation was that the climate in that part of Serbia where observations were made, is not sufficiently differentiated to exert an essential influence on the differences in the speed of corrosion. It is, besides, quite understandable if one has in view the fact that the differences in the annual quantity of precipitations between individual localities where measurements had been taken were less than 300 mm.

After the experiences acquired in Serbia, in 1984 and 1985 were effected the measurements in 4 localities on the seaside mountains of Montenegro (D. Gavrilovíc, 1986). This area was chosen for several reasons. First, on the mountains Orjen and Lovćen are the amounts of precipitations the greatest not only

in Yugoslavia, but in Europe, too. Second, at the foot of these mountains is very pronounced a typical Mediterranean climate, and, third, by carrying out this experiment is obtained a complete profile, with the transition from the moderate continental, through the mountainous, to the Mediterranean climate. The working assumption was that markedly high quantities of precipitations on the mountains Orjen and Lovćen will necessarily have to reflect themselves on the intensity of corrosion.



Relation between the altitude and the intensity of surface corrosion.
Dušan Gavrilović

2. Experimental part

The measurements were effected with the «standard tablets» from the Upper Cretaceous limestone from Lipica near Triest, which is, from the chemical point of view almost pure calcium carbonate (I. Gams, 1981), or the prototype of rocks of classical Karst. The tablets have the shape of round plates: diameter 41 mm, thickness 3-4 mm, surface 29-30 sq cm and mass 10-17 g.

The tablets were exposed, for at least one year, to the influence of atmospheric factors in an open space (they were lying on the surface or dug into the soil), and after that was verified the diminution of their mass and on the basis of this were calculated various parameters of the intensity of corrosion.

Before the experiment had been initiated, the limestone tablets were numbered, heated up to 25° C, held for 2 hours in the desiccator and after that their mass was weighed with the precision of six decimals of a gram. The same procedure was repeated after the end of the experiment, the mechanical impurities having been previously removed by a strong air jet.

3. Results of measurements

In elaborating the obtained data there was first noticed the great deviation of the results from Ralja, where the intensity of corrosion was 4,4 times greater in an average (in a case even up to 7,2 times) than in all other localities in Serbia. The explanation offered itself. Only the basis was not here a calcareous one and only in this locality was expressed a superficial draining of water. Consequently, the soil here was on the whole considerably more humid than it is as a rule in the karst. The results obtained in this locality were therefore singled out as atypical. Still, they are of a scientific value, too, for they point out the great importance of the humidity in the soil for the dissolving of carbonate rocks and explain the essence of the action of marginal corrosion, to which, otherwise, is attributed in the karst a determined morphogenic importance.

The experiment at Ralja has shown that the dissolution of limestone is more dependent of humidity in the soil than on the amount of precipitations. This was corroborated also by the measurings effected in other localities of Serbia. The intensity of corrosion in the covered karst, under the pedologic layer, is greater by at least 40-50 p.c. than the corrosion on the bare calcareous surfaces.

In contrast to Serbia, where it was impossible to establish the mutual dependence between the quantity of precipitations and the corrosion, in the Montenegrin Littoral the intensity of corrosion grew in the absolute amount with the increase of precipitations. However, when the amounts of dissolved limestone were directly compared with the quantity of precipitations, a litre of atmospheric water at Ulcinj proved to dissolve 71 p.c. of limestone more than on the mountain Lovćen, 35 p.c. more than on the mountain Orjen and 48 p.c. more than on the bare calcareous areas in Serbia. Considerably higher solvability of limestones along the seaside could have been influenced by the mild Mediterranean climate only, i.e. by higher temperatures of air and of water. This observation is in accordance with one of the fundamental theoretical assumptions of the karst process – that the warm water dissolves the limestone quicker than the cold one.

Considering the surface corrosion as a morphogenic factor, it has been calculated that the bare calcareous surface on the Orjen mountain lowers by 8,90 mm, on the Lovćen mountain by 4,99 mm, near Ulcinj by 3,67 mm and in Serbia by 2 mm only in

The average intensity of the surface corrosion

Location (Nr. of tabs.)	Altitude m	Precipi– tation mm	Position cm	10^{-6} g/cm² day	Corrosion m³/km² year	mm/1.000 years	mg/l year
Serbia							
Sremčica (2)	160	701	– 5	0,98692	1,30	1,31	11,75
Ralja (1)	208	739	–2	5,18098	7,00	8,05	65,77
Ralja (4)	208	739	–20	8,01566	10,83	11,04	96,18
Rajac (2)	848	916	–15	2,74482	3,71	3,69	25,48
Zagubica (1)	440	647	–20	2,68760	3,63	3,69	43,64
Veliki Krš (1)	1.140	915	0	1,96886	2,66	2,71	18,35
Veliki Krš (1)	1.140	915	–20	0,75640	1,02	1,02	7,05
Rtanj (1)	1.226	1.000	0	1,78209	2,41	2,72	14,39
Rtanj (2)	1.566	1.000	–2	1,04212	1,40	1,46	8,31
Smilovci (2)	713	674	–5	1,84896	2,50	2,66	25,76
Montenegro:							
Orjen (4)	1.231	3.909	0	6,12400	8,28	8,90	13,91
Lovcen (7)	1.380	2.741	0	3,55279	4,80	4,99	11,01
Ulcinj (6)	40	1.135	0	2,55721	3,46	3,67	18,84
Budva (1)	50	1.211	0	0,89696	1,21	1,36	6,22

a period of thousand years. In the hilly and mountainous regions of Serbia, the average lowering of the surface of the relief, under the influence of erosive processes, amounts to 160 mm in a thousand years (R. Lazarević, 1983), i.e. it is 66 times quicker than the lowering of the calcareous surface under the influence of corrosion. From the theoretical point of view, with an erosive plateau, cut into the carbonate and non-carbonate rocks, after a million of years already, there would originate, under the influence of selective erosion, a fold in the relief, 158 mm high! These quantitative indicators, regardless of the fact that they are very generalized, should be taken into consideration in determining the age of karst pleateaus and of the folds in the contact karst.

The measurements effected with a larger number of tablets in the same locality have shown that there frequently exists a considerable dispersion of results (maximum being 31 p.c.), that is to say that the limestone corrosion is in its essence a very variable process.

A special problem is the relation between the surface corrosion and the underground corrosion. The intensity of the underground corrosion can be calculated in this way only if from the total corrosion, which manifests itself through the hardness of water from karst sources, be subtracted the value of the surface corrosion. On the basis of the available data on the hardness of source water and of the measurements carried out with «standard tablets» (Only the values obtained on the bare calcareous areas were taken into consideration), there results that the ratio between the surface corrosion and the underground corrosion on the mountain Orjen and in the Julian Alps amounts to 1:13, on the Lovćen mountain to 1:17, in Serbia to 1:15 and near Ulcinj to 1:9. From this could be deduced that the subterranean corrosion is more intensive under the conditions of the continental and mountainous climates, than under the influences of the maritime Mediterranean climate. It is thought, of course, of the effect of one litre of water only.

With the increase of the altitude, there grows also the amount of precipitations and the air temperature decreases, both these climatic elements having an approximately rectilinear course. In contrast to them, the intensity of surface corrosion grows with the increase of the altitude, but to a determined limit only, and after that continues to decline. In the Montenegrin Litoral, in Serbia and in Slovenia, this limit lies between 900 and 1.100 m of altitude. The reason for the discrepancy which, at a determined altitude, occurs between the amount of precipitations and the intensity of corrosion, ought to be looked for in the spread of the forest cover and its indirect influence on the temperature as a negative factor of corrosion. On the upper limit of the forest the air temperature falls abruptly, and, on account of this, independently of the further increase of precipitations, the intensity of corrosion decreases with the height.

The vertical zonation of the corrosive process, observed on bare calcareous ous areas, too, is still more marked under the forest and pedologic covers. The forest reduces, by its retentive property, the direct effect of precipitations, but, owing to biochemical processes in the forest soil, the real intensity of corrosion still increases, so that it exceeds the values of surface corrosion on the bare calcareous areas in the same altitude zone (D. Gabrilović, 1984). Consequently, the man, by his activity, reducing or increasing the areas under forests, can exert a considerable influence on the intensity of corrosion. It has been believed for a long time, that the clearing of forests gives rise to the revival of the karst process. In the last years, however, there are more and more searchers who affirm that the effect is precisely the opposite one. After the clearing of the forest and the destruction of the pedologic layer only comes to light what the corrosion had already created before. The extremest opinions in this direction were stated by L. Jakucs (1983), who asserted that the karst was a product of biological processes.

The results obtained by experimental investigations under natural conditions as well as the measurements of the hardness of water compel us to start thinking in a different way than the one we had so far followed. It is obvious that the climate, as a modifier of the karst process, has a far less importance than the other natural factors, and by this very fact also than the activity of man in a determined space.

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Temporal variations in soil carbon dioxide at pigeon Mountain, Georgia, 1985

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RESUM

Estimacions efectuades en intervals de dues setmanes, han aportat una sèrie de dades sobre els factors ambientals responsables de les variacions temporals del contingut de CO_2 del sòl i de la denudació per dissolució, durant un període de 12 mesos, els anys 1985-1986. El contingut de CO_2 del sòl es va mesurar en 10 llocs diferents mitjançant perforacions amb un tub d'acer inoxidable de 3mm. de diàmetre interior. A cada lloc, una perforació controlava el nivell de CO_2 a 30 cm. de profunditat, mentre que una altra ho feia de la base dels sediments. També es varen analitzar mostres de l'aire present en el sòl, mostres que es varen recollir amb una xeringa hermètica, mitjançant un cromatògraf de gasos HP 5840. Les variacions mes importants del contigut de CO_2 (0,114 % el febrer i 0,533 % l'agost) indiquen canvis de tempertatura del terreny (3,1°C el febrer i 21,6°C l'agost) i, en menor grau, del seu contingut d'humitat. Les variacions periòdiques del quimisme de les aigües de les sorgències (el pH va baixar de 7,4 a 6,7 i la duresa va passar de 80 a 124 ppm. entre el febrer i l'agost) i de la denudació per dissolució assenyalen variacions estacionals de la descàrrega d'aigua dels terrenys i del contingut de CO_2 del sòl.

RESUMEN

Mediciones efectuadas con intérvalos de dos semanas han aportado datos sobre los factores ambientales responsables de variaciones temporales del contenido de CO_2 en el suelo y la denudación por disolución durante un período de 12 meses en 1985-86. El contenido de CO_2 del suelo se midió en 10 lugares mediante perforaciones con tubo de acero inoxidable de 3mm. de diámetro interior. En cada lugar una perforación controlaba el nivel de CO_2 a 30 cm. de profundidad, mientras que otra lo hacía en la base de los sedimentos. También se analizaron muestras del aire contenido en el suelo, recogidas con una jeringa hermética, mediante un cromatógrafo de gas HP 5840. Las más importantes variaciones en el contenido de CO_2 (0,114 % en Febrero y 0,533 % en Agosto) reflejan cambios en la temperatura del terreno (3,1°C. en Febrero, 21,6°C. en Agosto) y en menor medida en su contenido de humedad. Las variaciones periódicas en el quimismo de las aguas de las surgencias (el pH bajo de 7,4 a 6,7 y la dureza pasó de 80 a 124 p.p.m. entre Febrero y agosto) y en la denudación por disolución, reflejan variaciones estacionales en la descarga de agua de los terrenos y en el contenido de CO_2 del suelo.

SUMMARY

Measurements at two-week intervals have provided data on the environmental factors responsible for temporal variations in soil CO_2 and solutional denudation during a 12-month period 1985-1986. Soil CO_2 was measured at 10 sites using 3 mm internal diameter stainless steel wells. At each site one well monitored CO_2 levels at 30 cm depth, a second well monitored CO_2 at the base of the soil layer. Soil air samples, collected using a 10 ml gas-tight syringe, were analyzed using a HP 5840 gas chromatograph. Marked seasonal variations in soil CO_2 (0.114 % in February, 0.533 % in August, 1985) reflect changes in soil temperature (3.1°C in February, 21.6°C in August) and to a lesser extent changes in soil moisture. Seasonal variations in spring water chemistry (pH dropped from 7.4 to 6.7, total hardness increased from 80 to 124 p.p.m. February to August) and in solutional denudation, reflect seasonal variations in ground water discharge and soil CO_2 levels..

Introduction

Although the percent of CO_2 produced in the soil that is lost to ground water may be small, levels of CO_2 in ground waters play a major role in determining limestone denudation rates. Field measurements by several workers have demonstrated that soil PCO_2 is largely dependent on soil temperature. Using carbonate spring water chemistry data, Drake and Wigley (1975) deduced a mean annual PCO_2 variation given by:

$\log(PCO_2) = -1.97 + 0.04T$,

where PCO_2 is in atmospheres and T is the mean annual temperature in °C. Although soil PCO_2 is clearly dependent upon soil temperature, there is also a large body of evidence to suggest that it is also dependent on soil moisture. For example, Tamm and Krzysch (1963) found that 50 % of the variation in soil CO_2 was due to temperature and 20 % to moisture. The objective of the present study was to establish relationships between soil PCO_2, soil temperature, and soil moisture at two Mixed Deciduous Forest sites in northwest Georgia.

The Study Areas

Variations in soil CO_2 were studied at two localities ––the Pocket and Anderson Cove–– on the northwest side of Pigeon Mountain in Walker County, northwest Georgia. The climate of the area is humid subtropical (Köppen Cfa) with somewhat continental characteristics due to elevation (340-350 m). The average annual temperature is 15°C, average annual precipitation is 1,370 mm. Both localities are Wildlife Refuge Areas with a natural vegetation of Mixed Deciduous Forest. The topographic slope in the Pocket study area (elev. 340 m) averages 5°, at Anderson Cove (elev.350 m) it averages 17°. Measurements of soil CO_2 in both areas were made in soils resting on Mississippian-age Bangor limestones.

Methodology

In each of the two study areas five soil CO_2 measurement sites were established. Soil CO_2, soil temperature, and soil moisture were monitored at 14-day intervals from January to December, 1985 (Table 1). Two stainless steel wells with an outside diameter of 6.3 mm were installed at each site. One well was inserted to a depth of 30 cm, the other to the bottom of the soil layer. The wells were sealed at the top by a rubber septum. Gas samples were obtained by inserting a hypodermic needle through the septum and drawing 5 ml of air into a gas-tight syringe. The samples were transferred immediately into evacuated blood collection tubes (vacutainers). In the laboratory the gas samples were injected into a Hewlett-Packard Model 5840 gas chromatograph equipped with two columns. They were analyzed using the thermal conductivity method (Mills 1984). To calibrate the instrument, oxygen, nitrogen, and carbon dioxide standards of 99.999 % purity and precision were injected and the resultant area counts were entered into a polynomial regression to predict the detector response to injected samples. In addition, injections of air accompanied each run and consistently yielded values between 0.035 % and 0.04 % CO_2 (the atmospheric level) thus providing a simple means of verification. The accuracy and reproducibility of the measurements is believed to be $\leq$ 0.01 % PCO_2.

Table 1. *Measurement Schedule*

Measurement Number	*Date*	*Measurement Number*	*Date*
1	Jan 18, 1985	13	Jul 06, 1985
2	Feb 03, 1985	14	Jul 20, 1985
3	Feb 15, 1985	15	Aug 06, 1985
4	Mar 02, 1985	16	Aug 19, 1985
5	Mar 16, 1985	17	Sep 01, 1985
6	Mar 29, 1985	18	Sep 15, 1985
7	Apr 14, 1985	19	Sep 28, 1985
8	Apr 30, 1985	20	Oct 12, 1985
9	May 11, 1985	21	Oct 26, 1985
10	May 25, 1985	22	Nov 09, 1985
11	Jun 08, 1985	23	Nov 24, 1985
12	Jun 23, 1985	24	Dec 07, 1985
		25	Dec 21, 1985

Soil temperatures at the ten sites were measured at a depth of 30 cm using a Cole-Parmer digital soil thermometer. Soil moisture was determined by collecting soil samples at 10 cm depth from points close to the wells. The samples were weighed in the laboratory and then were dried for five days at 70° C and weighed again. Soil moisture was calculated using the formula:

$$\% \text{ moisture} = \frac{(\text{weight of wet soil} - \text{weight of dry soil})}{\text{weitht of dry soil}} \times 100$$

Precipitation was monitored daily at a gauge installed 5 Km north of the Pocket.

Variations in Soil CO_2

Variations in precipitation, soil temperature, soil moisture and soil CO_2 at the Pocket and at Anderson Cove during 1985 are shown in Fig. 1. The average soil CO_2 value for the measurement period

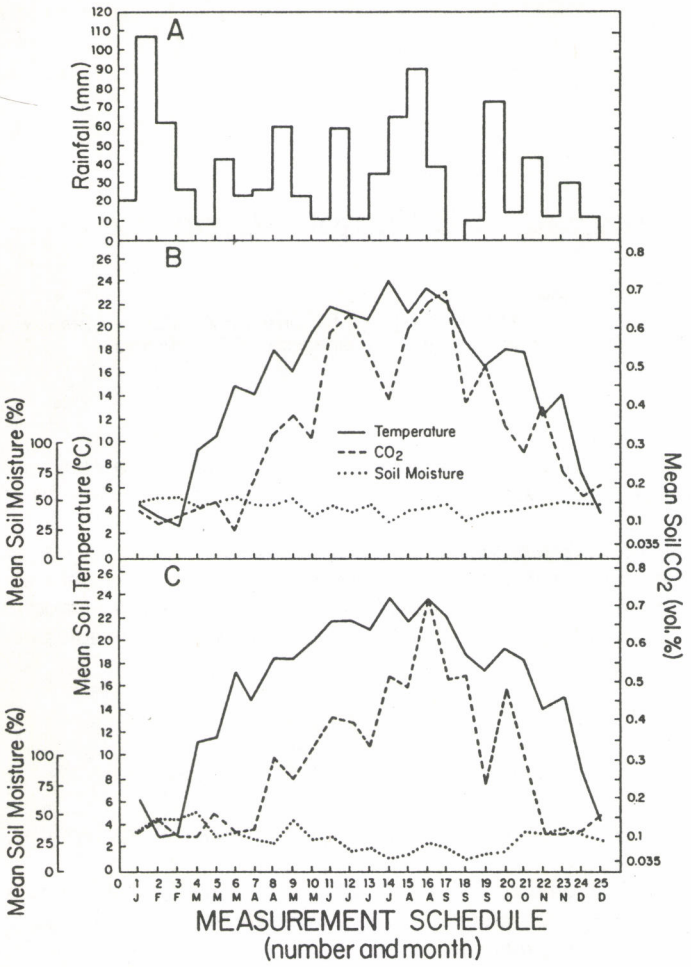

Fig. 1. Precipitation, Soil Carbon Dioxide, Temperature, and Moisture Variations at the Pocket (B) and Anderson Cove (C), Pigeon Mountain, Georgia, January to December, 1985.

was 0.31 % or some ten times the atmospheric level. Marked seasonal fluctuations are apparent in all four variables. Mean soil CO_2 at the Pocket was lowest (0.09 %) on February 3 and highest (0.69 %) on September 1. At Anderson Cove the lowest value (0.09 %) occurred on February 15 and March 2, and the highest value (0.71 %) on August 19. Mean soil temperatures at the Pocket reached a minimum (2.7° C) on February 15 and a maximum (24.0° C) on June 20, comparable values at Anderson Cove were 2.9° C on February 3 and 23.9° C on August 19. Mean soil moisture at the Pocket ranged from 31.0 % on June 20 to 53.1 % on February 15 and at Anderson Cove from 11.4 % on June 20 to 51.7 % on March 2. In general, the data indicate minimum soil CO_2, minimum soil temperature, and maximum soil moisture in late winter (February-March), and maximum soil CO_2, maximum soil temperature, and minimum soil moisture in late summer (July-August). As precipitation is well distributed throughout the year, lower soil moisture levels in the summer months reflect higher soil temperatures and evapotranspiration rates.

Carbon dioxide in individual wells at the Pocket ranged from 0.04 % on February 3 and 15 to 1.22 % on September 1, and at Anderson Cove from 0.05 % on February 3 to 2.28 % on September 15. At the Pocket measured soil temperatures ranged from −3.5° C on February 3 to 29.6° C on July 20 and soil moisture from 17.6 % on November 24 to 100 % on February 3. At Anderson Cove temperatures varied from −2.0° C on February 3 to 29.8° C on July 20 and moisture from 5.5 % on September 15 to 79.5 % on May 25.

To investigate relationships between soil CO_2, soil temperature, and soil moisture at each site, multiple linear regression analysis was carried out with soil CO_2 as the dependent variable. Regressions were perfomed using mean soil CO_2 values (averages of values for the 10 wells), mean soil temperatures (averages of 5 values) and mean soil moisture percentages (averages of 5 values) at each site on each measurement date. Soil PCO_2 values in atmospheres were converted to $\log_{10}$ (PCO_2) values to more closely linearize relationships between the dependent and independent variables. Results revealed a very strong positive relationship between soil CO_2 and soil temperature (Table 2 models 1 and 3). At the Pocket soil temperature accounted for 67 % of the variance in soil CO_2 and at Anderson Cove it accounted for 64 % of the variance.

Only at Anderson Cove did soil moisture appear to influence soil CO_2 in a statistically significant way. In model 4 soil temperature and soil moisture together explained 73 % of the variance in soil CO_2 values, the MOIST parameter being significant at the 0.01 level (Tabla 2). An important implication of this relationship is that at Anderson Cove increases in soil moisture caused reductions in soil CO_2. In model 2 the MOIST parameter is not statistically significant but it is interesting that the MOIST coefficient is also negative.

Tabla 2. *Regression Relationships Between Soil CO_2 and Soil Temperature and Moisture, Pigeon Mountain, Georgia**

Location and Model Number	Model Parameters	Parameter Values	Significance of Parameters (Prob. > F)	R^2
Pocket	INTERCEPT	−3.11	0.0001	
1	TEMP	0.04	0.0001	0.67
The Pocket	INTERCEPT	−2.84	0.0612	
2	TEMP	0.03	0.0001	0.68
	MOIST	−0.005	0.5108	
Anderson Cove	INTERCEPT	−3.24	0.0001	
3	TEMP	0.04	0.0001	0.64
Anderson Cove	INTERCEPT	−2.76	0.0010	
4	TEMP	0.03	0.0006	0.73
	MOIST	−0.01	0.0153	

* The dependent variable was log (PCO_2). All models were significant at the 0.001 level.

Conclusions

Soil Co_2 levels at the Pocket and at Anderson Cove during 1985 were strongly and positively influenced by variations in soil temperature. A temperature coefficient of 0.04 is suggested by models 1 and 3 in Table 2 and also by the studies of Drake and Wigley (1975). Only at Anderson Cove was soil moisture an important factor in determining soil CO_2 levels. Differences in soil moisture drainage rates at the two sites may help to explain this result. At the Pocket, where the topographic slope is 5°, drainage is slow. The average soil moisture during 1985 was 44.2 % and the standard deviation of moisture values only 5.8 % At Anderson Cove the topographic slope is 17°, as a result, soil moisture drainage occurs much more rapidly. In 1985 the average of soil moisture values was only 29.3 % and the standard deviation 10.8 %. The negative correlation between soil CO_2 and soil moisture at both sites studied suggests that during and after precipitation CO_2 is flushed from the soil ––the flushing being more marked at Anderson Cove where soil water percolation is more rapid.

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K PRO-leme izučemija karstovoj demudacii V Gorazych Stramach

К проъleme изучения карстовой денудации В Гораых Странах

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RESUM

L'estimació de valor de denunciació kàrstica (D_K) és de gran importancia per l'estudi de les regions kàrstiques. Fa que sigui possible comparar la intensitat dels processos kàrstics de vàries zones climàtiques i franges altitudinals, així com pot determinar una zonació kàrstica, etc

Els diversos mètodes que existeixen d'estimació de D (Kruber, Labtew, Radionow, Coebel, Grumm, Williams, Gans, Pulina, et al) donen valors que varien inclús en las mateixes regions kàrstiques. Sota el nostre punt de vista això és degut a la falta de coincidència dels límits de les conques topogràfiques i hidrogràfiques en las zones kàrstiques. Sobre aquesta base hem introduït les fórmules per determinació de denunciació kàrstica de superfície (D_{K1}) i sota terra (D_{K2}) que han estat publicades a les actes del VII Internacional Congress of Speleology en Sheffiled, 1977

$D_{K1} = 0.63 \cdot M_1 \Delta H_1$ (1)

$D_{K1} = 0.63 \cdot M_2 \Delta H_2$ (2)

on M_1 y M_2 són constants de «run-off» subaeri i subterrani en 1/seg. Km2; H_1 y H_2 la dureza total de les aigües epigees y subterrànies, mg - equiv/1

Durant molts anys d'estudi del karst de muntanya les tendències de D_k augmenten amb el creixement del run-off (c) i el descens de la temperatura de l'aigua (t) fóren tan clarament determinats que poden ser considerats com una regularitat comú de les regions kàrstiques de països muntanyosos Hem expresat aquesta relació amb un model matemàtic:

$D_K = 43.8 - 3.17 + 0.0495\ C + 0.00182_t C$ (3)

Aquesta equació s'ha utilizat per formar un model geomètric. Ambdues equacions permeten determinar amb facilitat el valor de D_k amb dos paràmetres (run-off i temperatura). No obstant en casos particulars aconsellem utilitzar la fòrmula (1) i (2)

RESUMEN

La estimación del valor de denunciación kárstica (D_k) es de gran importancia para el estudio de las regiones kársticas. Hace que sea posible comparar la intensidad de los procesos kársticos de varias zonas climáticas y franjas altitudinales, así como puede determinar una zonación kárstica, etc.

Los diversos métodos que existen de estimación de D_k (Kruber, Labtew, Radionow, Coebel, Grumm, Williams, Gans, Pulina, et al) dan valores que varían incluso en las mismas regiones kársticas. bajo nuestro punto de vista ello es debido a la falta de coincidencia de los límites de las cuencas topográficas e hidrográficas en las zonas kársticas. Sobre esta base hemos introducido las fórmulas para la determinación de denunciación kárstica de superficie (D_{k1}) y bajo la tierra (D_{k2}) que han sido publicadas en las actas del VII Internacional Congress of Speleology en Scheffiled, 1977

$D_{K1} = 0.63 \cdot M_1 \Delta H_1$ (1)

$D_{K1} = 0.63 \cdot M_2 \Delta H_2$ (2)

en donde M_1 y M_2 son constantes de «run-off» subaéreo y subterráneo en 1/seg. Km2.; H_1 y H_2 la dureza total de las aguas epígeas y subterráneas, mg - equiv/l.

Durante muchos años de estudio del karst de montaña las tendencias de D_k aumentan con el crecimiento del run-off (c) y el descenso de la temperatura del agua (t) fueron tan claramente determinados que pueden ser considerados como una regularidad común de las regiones kársticas de países montañosos. Hemos expresado esta relación con un modelo matemático;

$D_K = 43.8 - 3.17 + 0.0495\ C + 0.00182_t C$ (3)

Esta ecuación se ha utilizado para formar un modelo geométrico. Ambas ecuaciones permiten determinar con facilidad el valor de D_k con dos parámetros (run-off y temperatura). No obstante en casos particulares aconsejamos utilizar la fórmula (1) y (2).

SUMMARY

The estimation of karst denudation value (D_k) is of great significance under study of karst regions. It makes it possible to compan the intensity of karst processes at various climate zones and altitude belts as well as to make karst zoning, etc.

The various existing methods of D_k estimation (Kruber, Laptev, Radionov, Korbel, Grum, Williams, Gams, Pulina, et al) give the variable values even in the same karst regions. From our point of view it is due to the lack of convergence of boundaries of topographic and hydrogeological basins in karst areas. On this basis we have introdused the formulae for determination of surface (D_{k1}) and undergroud (D_{k2}) karst denudation which were published in the proceedings of the VII International Congress of speleology in Sheffield, 1977

$$D_{K1} = 0.63 \cdot M_1 \Delta H_1 \quad (1)$$
$$D_{K1} = 0.63 \cdot M_2 \Delta H_2 \quad (2)$$

where M_1 and M_2 are the moduli of subaerial and subterranean run-off 1/sec. km^2; H_1 and H_2 –total hardness of surface and undergroud waters. mg– equiv/l.

During many years study of the mountainous karst the trends of D_k grouwth with the rise of run-off (c) and the fall of water temperature (t) were clearly determined that can be considered as a common regularity for karst regions of mountainous countries. We have expressed this relation by mathematical model

$$D_K = 43.8 - 3.17 + 0.0495\ C + 0.00182_t C \quad (3)$$

The above equation has been used to form the geometric pattern. the both of them make it easy to determine the value of D_k by two parameters (run-off and temperature). However. in particular cases we suggest to use the formulae (1) and (2).

Проблема изучения карстовой денудации (D_K) занимает важное место в карстологических исследованиях. Она позволяет сравнивать активность карстовых процессов в различных климатических зонах и высотных поясах, устанавливать связи между D_K и морфологией карстовых форм, проводить районирование карста и т.д. Для определения величины D_K используют различные объемные, гидрохимические, климатические, балансовые методы, авторами которых являются: А.А. Крубер (1915), Ф.Ф. Лаптев (1939), Н.В. Родионов (1949), Г.А. Максимович (1963), Ж. Корбель (Corbel, 1959), Г. Грум (Groom, 1965); Г. Грум и П. Вильямс (1965), И. Гамо (Gams, 1968), П. Хабич (Habich, 1968), М. Пулина (Pulina, 1974), А.Г. Чикишев (1973), М.П. Маринин и М.Н. Абышев (1977), Д.Ш. Габечава (1977). D_K разные исследователи выражают в м^3/км^2·год, мм/1000 лет, мк/год. Несмотря на то, что почти для всех формул, предложенных вышеотмеченными исследователями являются производными от давно известной в гидрологии формулы ионного стока и отличаются друг от друга размерностями отдельных членов, по ним, часто для одних и тех же регионов получаются разные результаты. Основной причиной этого разнобоя мы считаем недооценку факта несовпадения границ топографических и гидрогеологических водосборов, в особенности в условиях горного карста.

Исходя из вышесказанного нами еще в 1977 г. были предложены формулы для раздельной оценки поверхностной и подземной (Kiknadze, 1977; Кикнадзе, 1979; Дублянский, Кикнадзе, 1984). Эти формулы имеют следующий вид:

$$D_{K_1} = 0{,}63 \cdot M_1 \cdot \Delta H_1 \quad (1)$$

$$D_{K_2}\ 0{,}63 \cdot M_2 \cdot \Delta H_2 \quad (2)$$

где: D_{K_1} – поверхностная и D_{K_2} – подземная карстовая денудация в м^3/км^2·год; M_1 – модуль поверхностного и M_2 – модуль подземного стока, л/с·км^2; ΔH_1 – жесткость поверхностных и ΔH_2 – жесткость подземных вод, мг-экв/л. Для выведения этих формул использованы следующие размерности: площади поверхностного (S_1) и подземного (S_2) водосборов, км^2; объемы поверхностного (Q_1) и подземного (Q_2) стока, м^3/год; общая жесткость атмосферных осадков (H_x), общая жесткость поверхностных вод, включающая и общую жесткость атмосферных осадков (H_y), общая жесткость подземных вод, включающая общую жесткость атмосферных осадков и поверхностных вод (H_z), мг-экв/л.

Будем иметь следующие зависимости:

$$\Delta H_1 = H_y - H_z \quad (3); \qquad \Delta H_2 = H_z - H_y \quad (4)$$

$$Q_1 = 31{,}5 \cdot M_1 \cdot S_1 \cdot 10^3\ м^3/год \quad (5)$$

$$Q_2 = 31{,}5 \cdot M_2 \cdot S_2 \cdot 10^3\ м^3/год \quad (6)$$

Следовательно:

$$D_{K_1} = \frac{Q_1 \cdot 20 \cdot \Delta H_1}{S_1 \cdot 10^6} \quad (7)$$

$$D_{K_2} = \frac{Q_2 \cdot 20 \cdot \Delta H_2}{S_2 \cdot 10^6} \quad (8)$$

Вставив в формулы (7) и (8) соответствующие значения (Q_1) и (Q_2) будем иметь:

$$D_{K_1} = \frac{31{,}5 \cdot M_1 \cdot S_1 \cdot 10^3 \cdot 20 \cdot \Delta H_1}{S_1 \cdot 10^6} \quad (9)$$

$$D_{K_2} = \frac{31{,}5 \cdot M_2 \cdot S_2 \cdot 10^3 \cdot 20 \cdot \Delta H_2}{S_2 \cdot 10^6} \quad (10)$$

После соответствующих сокращений получим конечные формулы (1) и (2).

Полученные по этим формулам результаты позволили сравнить интенсивность карстовых процессов на Большом Кавказе с таковыми других известных карстовых регионов Европы (рис. 1). Диаграмма в конечном счете отображает комплекс факторов, принимающих участие в сложных процессах карстогенеза. Замечается четко выраженная тенденция роста величины D_K по мере увеличения стока и уменьшения температуры воды, что следует считать одной из общих закономерностей для горных карстовых регионов. Увеличение с высотой количества атмосферных осадков и уменьшение испарения определяет большую инфильтрацию и инфлюацию атмосферных вод в высокогорье (в особенности в условиях голого карста, чем в средне- и низкогорье. Вместе с тем с высотой уменьшается температура вод. Эти два фактора наряду с другими равными факторами в значительной мере определяют более интенсивное развитие карстовых процессов в горах, результаты которого выражены в обилии поверхностных и подземных форм карста.

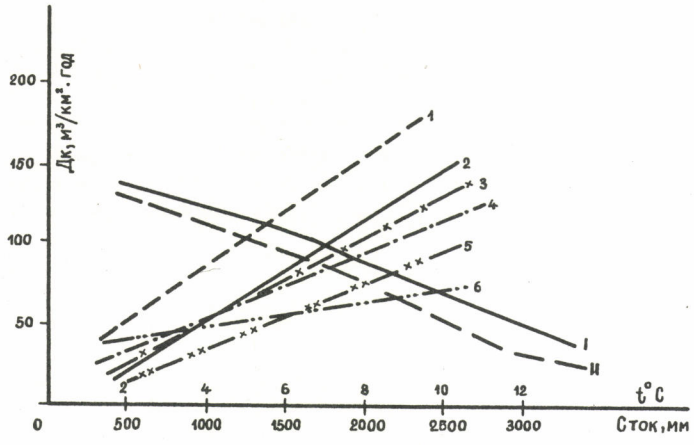

Рис. I. Диаграмма зависимости карстовой денудации от температуры воды (I, II) и стока (I-6) в горном карсте Большого Кавказа и Европы. I-Южный склон Большого Кавказа; II-Европа. I-Французские Альпы; 2-Южный склон Большого Кавказа; 3-Польские Татры; 4-Триглав (Югославия); 5-Пирин (Болгария); 6-Северный склон Большого Кавказа.

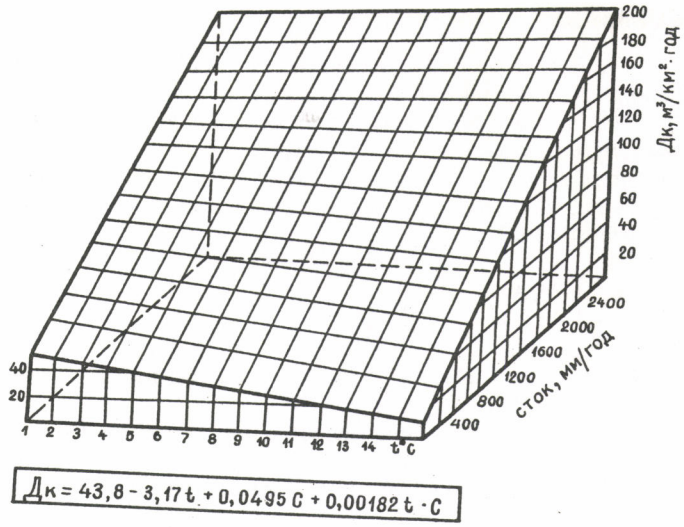

Рис. 2. Математическая модель зависимости величины карстовой денудации (Дк) от стока (C) и температуры воды ( ) и ее графическое изображение.

Зависимости между Dк , стоком и температурой воды выражаются линейным законом:

$$Dк = x + yt \qquad (II)$$

$$Dк = x + yC \qquad (I2)$$

где: Dк - карстовая денудация, $м^3/км^2 \cdot год$; t - средняя температура воды, C° ; C - сток, мм/год.

В координатной системе Dк и t (рис. 2) нанесены точки для карстовых районов Большого Кавказа и Альп. Аппроксимируем эти точки линейным законом (уравнение II). Для определения неизвестных параметров x и y используем метод наименьших квадратов (Длин, 1958). Учитывая координаты точек ($Dк_i$, t_i) и их количество (i = I,2....I0), будем иметь I0 уравнений

$$Dк_i = x + yt_i \qquad (I3)$$

с двумя неизвестными x и y . Обозначим сумму квадратов отклонения между фактическими расположениями точек и искомым уравнением (II) через η , т.е.

$$\eta = \sum_{i=1}^{10} \left[Dк_i - (x + yt_i)\right]^2 \qquad (I2)$$

Подберем x и y так, чтобы η была бы минимальной. С этой целью определим первое производное η по x и y и приравним к нулю:

$$\frac{\partial \eta}{\partial x} = 0; \quad \frac{\partial \eta}{\partial y} = 0 \qquad (I3)$$

Так как

$$\frac{\partial \eta}{\partial x} = -2\sum_{i=1}^{10} \left[Dк_i - x - yt_i\right] \qquad (I4)$$

и

$$\frac{\partial \eta}{\partial y} = -2\sum_{i=1}^{10} \left[Dк_i - x - yt_i\right] \cdot t_i \qquad (I5)$$

С учетом (I4) и (I5) система (I3) примет вид:

$$\begin{cases} \sum_{i=1}^{10} Dк_i = 10x + y \cdot \sum_{i=1}^{10} t_i^2 \\ \sum_{i=1}^{10} Dк_i t_i = x\sum_{i=1}^{10} t_i + y\sum_{i=1}^{10} t_i^2 \end{cases} \qquad (I6)$$

Таким образом получим систему двух уравнений с двумя неизвестными x и y . Из (I6) x и y имеют значение:

$$x = \frac{\sum_{i=1}^{10} Dк_i \sum_{i=1}^{10} t_i^2 - \sum_{i=1}^{10} Dк_i t_i \cdot \sum_{i=1}^{10} t_i}{10\sum_{i=1}^{10} t_i^2 - \left(\sum_{i=1}^{10} t_i\right)^2} \qquad (I7)$$

$$y = \frac{10\sum_{i=1}^{10} Dк_i t_i - \sum_{i=1}^{10} t_i \cdot \sum_{i=1}^{10} Dк_i}{10\sum_{i=1}^{10} t_i^2 - \left(\sum_{i=1}^{10} t_i\right)^2} \qquad (I8)$$

Зная координаты точек ($Dк_i$; t_i)i =I,2...I0, с помощью формул (I7) и (I8) легко можно определить координаты точек x и y . Определяя величины x и y по формуле (II), после некоторых преобразований получим:

$$Dк = 160 - 10t \qquad (I9)$$

Зная температуру воды (t), с помощью формулы (I9) можно определить среднее значение Dк для любого карстового региона горных стран. Применение эмпирической формулы (I9) ограничено тем, что при t =I6°C Dк получается отрицательной. Следовательно, ее можно использовать в горных карстовых регионах, где температура карстовых вод варьирует в пределах I-I3°C (карстовые регионы Альпийской складчатой области). Очевидно, при относительно высоких температурах функциональная зависимость между Dк и t не подчиняется линейному закону.

Для определения неизвестных параметров x и y в уравнении (I2) поступаем аналогично уравнению (II). В результате получается уравнение например для Южного склона Большого Кавказа (зависимость между Dк и стоком):

$$Dк = 21,2 + 0,047C \qquad (20)$$

В общей сложности по стоковым и температурным данным можно определить величину Dк приближенно, и, в случае необходимости сравнить с полученными по формулам (I) и (2) данными. Зависимость между Dк , стоком (C) и температурой воды (t) отображает математическая модель:

$$Dк = 43,8 - 3,17t + 0,0495C + 0,00182tC \qquad (2I)$$

Составленное по данному уравнению геометрическое изображение модели (рис. 2) легко можно применять для карстовых регионов, где температура воды не превышает I5°C.

Интенсивность карстовой денудации изменяется во времени и зависит от сезона года, продолжительности определенного вида питания (инфильтрационно-инфлюационного, конденсационно-инфильтрационного), паводков) Поэтому по возможности следует прибегать к дифференциальному анализу гидрохимических данных. Такой подход к оп-

ределению величины карстовой денудации позволяет прийти к важным выводам о происхождении карстовых вод и изменениях их минерализации в различные сезоны, для чего необходима постановка стационарных гидрогеологических и гидрохимических исследований (Дублянский, Кикнадзе, 1984).

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L'influence des saisons de l'année sur la dénudation karstique

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RESUM

En el període comprès entre 1981 i 1985 hem estudiat la influència de les estacions de l'any en la taxa d'intensitat de corrosió del carst de Demänova al Baix Tatras (Carpats Occidentals, Txecoslovàquia).

RESUMEN

En 1981-1985 hemos estudiado la influencia de las estaciones del año en la tasa de intensidad de corrosión en el karst de Demänova en el Bajo Tatras (Cárpatos Occidentales) Checoslovaquia.

SUMMARY

ABSTRACT. The influence of the Season on the Karst Denudation. In 1981-1985 we have studied the influence of the season on the corrosion intensity rate in the Demänová karst of the Low Tatras /West Carpathians/, Czechoslovakia.

We used the standard Yougoslavian limestone tablets method. The obtained data were as follows:

1. In the Demänovka stream entering the karst with the water temperatur of 0,1°C-1,8°C, the corrosion intensity was 107-145 mm/1000 years in the winter half-year.
In the summer half-year with the water temperatur of 2,6°C-9,2°C the corrosion intensity reached 131-320 mm/1000 years.
2. In the Demänovka spring with the water temperature of 2,8° C-4,5°C and the capacity of the aggresive, CO_2 0,5-3,5 mg/l, the corrosion intensity was 12,5-26,8 mm/1000 years in the winter half-year. In the summer half-year at the water temperature 5°C-7,4°C, the corrosion intensity was 29,57 mm/1000 years.
3. In the Demänovka leaving the karst with the water temperature of 2,8°C-4,5°C and the capacity of the aggresive CO_2 0,8-3,7 mg/l, the corrosion intensity was 6,8-25,8 mm/1000 years in the winter half-year. In the summer half-year at the temperatur 5,2°C-8,6°C and the capacity of the aggresive CO_2 0,8-4,4 mg/l, the corrosion intensity was 18,3-38,9 mm/1000 years.
4. One meter above the karst terrain at the air temperatur −6°C, the corrosion intensity was 0,9-3,6 mm/1000 years in the winter half-year. In the summer half year at the air temperature 6,6°C-16,5°C, the corrosion intensity was 1,9-4,6 mm/1000 years.
5. On the limestone surface/the rainfall 63-123 mm/, the corrosion itensity was 2,7-7,3 mm/1000 years in the winter half-year. In the

summer half-year/the rainfall 92-112 mm/, the corrosion intensity was 4,7-9,1 mm/1000 years.

6. In the depth of 20 cm under the surface in the sil/rendzina/ at the soil temperatur −10°C till −1°C, the corrosion intensity was 4,7-9,1 mm/1000 years in the winter half-year. In the summer half-year at the soil temperature 5°C-10°C, the corrosion intensity was 2,1-4,5 mm/1000 years.

L'intensité de la dénudation karstique dépend nou seulement de la situation du karst dans les diverses régions climatiques, mains aussi des variatios suivant les saisons de l'année. Ce sont ces influences que nous avons étudiés pendant l'année 1981-1985 dans le karst de Demänova au Nord de la Basse Tatra en Tchécoslovaquie. Les resultats complets pour ces 5 années sont présentés dans ce rapport.

Le karst de Demänová est situé au nord de la Basse Tatra dans la zone de montagnes de moyenne altitude, c'est-à-dire jusqu'à la limite supérieure de la forêt/de 715 à 1500 m/. La crête centrale de cette montagne est formée d'un noyau cristallin/ granite/, tandis que la partie nord est constituée de roches sédimentaires parmi les quelles sont présents les calcaires du «Guttenstein» et des dolomies grises du Trias moyen. Les calcaires du Guttenstein sont nettement stratifiées, très fissurés et au point de vue chimique, assez purs: 92 à 96 % de $CaCO_3$.

La zone du karst de Demänová est drainée par la riviere Demänová et par ses affluents. Tous les cours d'eau prennent naissance dans le noyau granitique des Basses Tatras et ils s'écoulent en direction nord. Dès qu'ils sont en contact avec les calcaires, ces cours d'eau sont absorbés par des ponors. Ils sont drainés en profondeur et circulent au niveau inférieur des grottes de Demänová pour réapparaître par une grosse émergence, d'un débit de 300 à 1800 litres par seconde.

Le climat du karst de Demänová est caractérisé par une zone froide: température moyenne annuelles de 5° Celsius, la température la plus basse étant de −7°Celsius au mois de janvier, la plus haute de 14°Celsius en juillet. Les précipitations moyennes annuelles sont de 770 à 1500 millimètres, en janvier et février 50 millimètres, en juin et juillet 130 millimètres.

Pour déterminer les valeurs quantitatives de la corrosion, nous avons utilisé la méthode des plaquettes standard qui consiste à déterminer la perte de poids de plaquettes calcaires placées dans un terrain calcaire pendant un certain temps. Cette méthode est préconisée par la «Commission de Dénudation du Karst» de

Tableu 1.– Intensité de la corrosion dans le karst de Demänová pendant les années 1981 à 1985

Localisation	Précipitations en mm	Température en °C	Dates mesurées	Surface des plaquettes en cm²	Perte de poids en g		Corrosion en mm/1000 ans	
					hiver	été	hiver	été
Site n° 1 Dans le courant de la Demänovka, apres la sortie des terrains cristallins, altitude 1025 metres	382	−4,2	31.X.81 2.5.82	29,75 29,93	1,014 0.747		135,7 99,3	
	672	11,6	3.5.82 30.X.82	29,63 29,77		1,24 1,12		168,4 150,4
	739	−0.3	2.11.82 2.5.83	29,25 29,37	0.957 1,168		107,5 189,3	
	554	11,2	3.5.83 30.X.83	29,07 31,07		1,80 1,91		321,0 327,5
			1.11.83 23.4.84	28,37 30,00	0,770 0,982		128,9 138,9	
			24.4.84 31.X.84	31,28 29,73		2,799 2,377		346,7 320,8
			1.11.84 3.5.85	30,43 26,81	0,841 0,656		130,4 119,3	
			4.5.85 31.X.85	29,40 26,75		1,658 1,490		258,4 210,0
			1.11.85 30.4.86	29,10 26,45				
Site n° 2 Emergence de la Demänovka au milieu de la vallée karstique, altitude 787 metres	292	−3,1	31.X.81 2.5.82	30,54 30,50	0,138 0,082		17,8 12,1	
	545	13,5	3.5.82 30.X.82	30,46 30,40		0,278 0,292		45,47 43,49
	537	1,31	2.11.82 2.5.83	30,15 30,32	0,134 0,125		17,5 17,4	
	440	13,1	3.5.83 30.X.83	30,05 29,82		0,221 0,199		29,04 27,53
			1.11.83 23.4.84	30,00 29,51	0,167 0,137		23,6 19,9	
			24.4.84 31.X.84	29,90 29,40		0,413 0,360		57,86 52,22
			1.11.84 3.5.85	29,59 29,35	0,086 0,176		12,84 26,86	
			4.5.85 31.X.85	29,46 29,17		0,289 0,292		42,43 44,82
			1.11.85 30.4.86	29,35 29,25				

Continuation du tableau 1:

Localisation	Précipitations en mm	Température en °C	Dates mesurées	Surface des plaquettes en cm^2	Perte de poids en g		Corrosion en mm/1000 ans	
					hiver	été	hiver	été
Site n° 3 Dans le courant de la Demänovka à la sortie du terrain karstique altitude 715 mètres	201	−2,7	31.X.81 2.5.82	30,98 30,43	0,053 0,085		6,80 14,95	
	418	14,1	3.5.82 30.X.82	30,91 30,33		0,268 0,13		38,65 18,25
	335	1.8	1.11.82 2.5.83	30,80 30,21	0,265 0,197		34,35 25,80	
	325	13,8	3.5.83 30.X.83	30,75 perdu		0,177		23,00
			1.11.83 23.4.84	30,70	0,126		7,05	
			24.4.84 31.X.84	30,64 30,52		0,266 0,213		38,96 28,14
			1.11.84 3.5.85	30,50 30,44	0,062 0,049		8,65 7,55	
			4.5.85 31.X.85	30,25 30,06		0,065 0,090		9,08 11,63
			1.11.85 30.4.86	30,05 29,90				
Site n° 4 Sur la surface du calcarie, la partie supérieure du karst de Demänová altitude 860 mètres / 1 mètre au-dessus du calcaire	337	−3,4	31.X.81 2.5.82	30,55 30,50	0,008 0,028		0,98 1,68	
	608	12,8	3.5.82 30.X.82	30,50 30,50		0,032 0,020		1,96 1,59
	638	0,75	1.11.82 2.5.83	30,50 30,50	0,005 0,004		0,80 0,70	
	497	12,5	3.5.83 30.X.83	30,50 30,50		0,019 0,020		2,42 2,62
			1.11.83 23.4.84	30,40 30,50	0,016 perdu		2,17	
			24.4.84 31.X.84	30,65		0,035		4,60
			1.11.84 3.5.85	30,65	0,035		4,60	
			4.5.85 31.X.85	30,65		0,030		3,94
			1.11.85 30.4.86	30,60				

L'UIS sous la direction du Professeur I.Gams de Ljubljana/ Yugoslavie/.

Les plaquettes standard envoyées de yougoslavie sont de forme circulaire, de 4,15 centimètres de diamètre et 0,27 a 0,4 centimètres d'épaisseur, en calcaire Crétacé supérieur/Senonien/ de Lipica. La composition est la suivante: 57 % CaO, 0,21 % MgO, 0,1% SiO_2, 0,007 % Fe_2O_3, 0,05 % Al_2O_3.

En 1981 j'ai placé quatorze plaquettes calcaires dans cinq emplacements du Karst de Demänová:

1er emplacement: 2 plaquettes standard placées dans le courant de Demänová après sa sortie des terrains cristallins, à l'altitude 1025 mètres, à proximité du Karst.

2e emplacement: 2 plaquettes dans le lit de la Demänová à son émergence, altitude 787 mètres.

3e emplacement: 2 plaquettes placées dans le courant de la Demänová à l'embouchure du Karst de Demänová, altitude 715 mètres.

4e emplacement: 5 plaquettes placées sur la surface du calcaire au-desseus du lit desséché de la Demänová, altitude 860 mètres.

5e emplacement: 5 plaquettes sur surface du calcaire près de l'entrée dans la grotte de glace de Demänová, altitude 800 mètres.

A ces divers emplacements, l'intensité de la corrosion durant la période 1981 à 1985 s'avere très variable et dépend de la situation d'emplacement des plaquettes et des conditions atmosphériques, come indiqué au tableau n.I.

Les résultats de ces mesures ont montré que la corrosion la plus élevée est dans le courant de la Demänová à la sortie des terrains cristallins. Pendant les mois d'été/du 1er mai au 31. octobre/ elle atteint les valeurs de 131 à 320 mm pour 1.000 ans en fonction de la température de l'eau de 2,6 à 9,2°Celsius et de l'a bondance du CO_2 agressif de 2,8 à 6,6 mg par litre. Pendant les mois d'hiver/du 1er novembre au 30.avril/ elle atteint les valeurs de 107 à 145 mm pour 1.000 ans, avec une température de l'eau de 0,1 à 1,8° Celsius et une abondance du CO_2 agressif de 3,7 à 7,7 mg pour litre. Sans doute, le grand contenu de CO_2 agressif et la très faible mineralisation de l'eau de Demänovka i cause la grande agressivité qui s'est manifestée dans la formation des espaces souterrains des grottes de Demänová.

La corrosion dans la source de la Demänová atteint en hiver les valeurs de 12,8 à 26,8 mm par 1.000 ans, avec une temperature de l'eau de 3,2 à 4,8°Celsius et une abondance du CO_2 agressif de 1,3 à 3,9 mg pour litre, tandis qu'en été les valuers sont de

Continuacion du tableau 1:

Localisation	Précipitations en mm	Température en °C	Dates mesurées	Surface des plaquettes en cm^2	Perte de poids en g		Corrosion en mm/1000 ans	
					hiver	été	hiver	été
Site n° 4 Sur la surface du calcaire, la partie supérieure du karst de Demänová, altitude 860 mètres à 20 cm sous la surface, dans le sol sur la surface du calcaire	337	−3.4	31.X.81 2.5.82	30,96	0,009		1,19	
	608	12,8	3.5.82 30.X.82	30,94		0,024		3,16
	638	0,75	1.11.82 2.5.83	30,90	0,031		4,03	4,03
	497	12,5	3.5.83 30.X.83	30,87		0,018		2,32
			1.11.83 23.4.84	30,82	0,012		1,64	
			24.4.84 31.X.84	30,73		0,051		7,32
			1.11.84 3.5.85	30,70	0,020		3,05	
			4.5.85 31.X.85	30,58		0,019		2,74
			1.11.85 30.4.86	30,50				
	337	−3,4	31.X.81 2.5.82	32,07 30,09	0,039 0,025		4,35 3,42	
	608	12,8	3.5.82 30.X.82	32,07 30,01		0,022 0,033		2,67 4,58
	638	0,7	1.11.82 2.5.83	32,07 30,00	0,015 0,025		1,18 3,45	
	497	12,5	3.5.83 30.X.83	30,00 28,98		0,029 0,026		3,58 3,41
			1.11.83 23.4.84	30,00 28,50	0,018 0,014		2,45 1,90	
			24.4.84 31.X.84	29,90 28,00		0,015 0,019		2,16 3,10
			1.11.84 3.5.85	29,85 27,96	0,012 0,022		1,70 3,55	
			4.5.85 31.X.85	29,80 27,90		0,020 0,022		2,95 3,74
			1.11.85 30.4.86	29,75 27,85				

29 à 57 mm par 1.000 ans/ la température de l'eau de 5,0 à 7,4°Celsius et l'abondance du CO_2 agressif de 0,5 à 3,5 mg par litre/. Comme on le voit, l'agressivité des eaux de la Demänová dans la source n'est pas encore totalement éliminée et utilisée pour la dissolution du calcaire dans les ponors. Par curiosité le cours souterrain de la Demänová dissout par an 311 cm^3 du $CaCO_3$, calculé pour un coloir de 4.000 mètres de longueur, 4 mètres de largeur et 3 mètres de hauteur il se serait formé en 154.340 ans.

L'intensité de la corrosion dans le courant de la Demänová à la sortie des terrains calcaires atteint en été les valeurs de 18,3 à 38,9 mm pour 1.000 ans/la température de l'eau de 5,2 à 8,6°Celsius et le contenu du CO^2 agressif de 0,8 à 4,4 mg par litre, tandis qu'en hiver les valeurs de 6,8 à 25,8 mm pour 1.000 ans/la température de l'eau de 2,8 à 4,5°Celsius et l'abondance du CO_2 agressif de 0,8 à 3,7 mg pour litre/.Ces mesures ont montré que l'eau de la Demänovká à l'émergence et à la sortie des terrains calcaires est encore agressive et capable de dissoudre du calcaire.

Les autres valeurs de la corrosion ant été mesurées sur un terrain karstique où les plaquettes calcaires étaient exposées à la corrosion seulement pendant les périodes de précipitations sur les calcaires. Sur la site n° 4 et n° 5, les plaquettes localisées 1 metre au dessus du calcaire elle atteint en été les valeurs de 1,9 à 4,6 mm pour 1.000 ans/la temperature moyenne de l'air de 6,6 à 16,5°Celsius, tandis qu'en hiver les valeurs de 0,9 à 3,6 mm pour 1.000 ans/la température moyenne de l'air de −6 à 1,4°Celsius/. Pour les plaquettes localisées sur la surface du calcaire elle atteint en hiver les valeurs de 2,7 à 7,3 mm pour 1.000 ans et en été les valeurs de 4,7 à 9,1 mm pour 1.000 ans.

La vitesse de corrosion la plus petite a été mesurée sur les plaquettes localisées à 20 centimètres sous la surface, dans le sol de type rendzine, composé de 70 % humus et de 30 % de fragments calcaires. Ces plaquettes ont montré en été des valeurs de 2,1 à 4,5 mm par 1.000 ans/la température du sol étant de 10°Celsius/, tandis qu'en hiver les valeurs de 1,8 a 3,5 mm par 1.000 ans/la température du sol de −5°Celsius/.

La plus grande difference dans la corrosion karstique est expliquée par le fait que les calcaires dans lesquels s'ecoulent les eaux superficielles et souterraines subisent en permanence l'influence de la corrosion, tandis que les calcaires en surface subissent cette influence seulement pendant les periodes de précipitations atmosphériques. En hiver quand les calcaires sont recouverts de neige, ou en été durant les périodes sèches, la corrosion est pratiquement nulle.

Denudation measurements by the limestone-tablet-method in a sub-arctic area, Glomdalen, Northern Norway.

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RESUM

S'ha investigat la denudació de les calcàries d'un règim climàtic subàrtic durant dos anys hidrològics complets, des de l'agost del 1983 fins a l'agost de 1984. Es descriu el projecte científic complet en les tesis de l'autor: DENUDACIÓ D'UNA ÀREA CARSTIFICADA D'UNA ZONA CLIMÀTICA SUBÀRTICA, 1986, UNIVERSITAT D'OSLO.

Com a zona d'investigació es va escollir Glomdalen (Nordland, Noruega), zona fortament carstificada, amb moltes cavitats i formacions de superfície. La zona investigada abarca una àrea de 211 km^2., amb dues subàrees, encaixonades una dins de l'altra, el sistema Jordtulla de 26 km^2. i el sistema Storbekken de 4,6 Km^2.

La investigació efectuada inclou les característiques hidrològiques, químiques i morfològiques de la zona. S'han utilitzat mesuradors de descàrrega, dos en el sistema Storbekken, un en el sistema Jordtulla i un en el sistema Glåmagå.

Es varen efectuar anàlisis químiques de més de dues-centes mostres d'aigua.

El sistema calcària-brikkettes, també utilitzat per Trudgill, Goudie, Gans i d'altres, es va utilitzar des de mitjan agost 83 fins a mitjan agost 84, colocant-se plaquetes a l'aigua, al sòl i a l'aire en 18 micromedis diferents.

Els resultats científics revelen una visible variabilitat dels índexs de denudació de diferents medis.

En les anàlisis químiques es troba histeresi per a diversos paràmetres dels cursos.

La investigació carsto-hidrològica mostra una interessant variació i paral·lelismes significatius entre les tres zones encaixants.

RESUMEN

Se ha investigado la denudación de las calizas en un régimen climático subártico durante dos años hidrológicos completos, desde agosto 1983 hasta agosto 1984. Se describe el proyecto científico completo en las tesis del autor: DENUDACIÓN EN UN AREA KARSTIFICADA EN UNA ZONA CLIMATICA SUBARTICA, 1986, UNIVERSIDAD DE OSLO.

Se escogió Glomdalen, Nordland, Noruega como zona de investigación. Se encuentra fuertemente karstificada con muchas cavidades y formaciones de superficie. La zona investigada totaliza un área de 211 km^2., con dos subáreas como cajas colocadas una dentro de otra, el sistema Jordtulla de 26 km^2. y el sistema Storbekken de 4,6 km^2.

La investigación efectuada ha sido tanto hidrológica como química y morfológica. Se han utilizado medidores de descarga, dos en el Sistema Storbekken, uno en el sistema Jordtulla y uno en el sistema Glåmagå.

Se efectuaron análisis químicos de más de doscientas muestras de agua.

El sistema caliza-brikkettes, también utilizado por Trudgill, Goudie, Gans y otros, se usó desde mediados de Agosto 83 hasta mediados de Agosto 84, se colocaron plaquetas en el agua, suelo y aire en 18 micromedios diferentes.

Los resultados científicos muestran una marcada variación de las tasas de denudación en diferentes medios.

En los análisis químicos se encuentra histeresis para varios parámetros de los cursos.

La investigación karstohidrológica muestra una interesante variación y similitudes características entre las tres zonas «caja en caja».

SUMMARY

The denudation on limestone in a subartic klimatic regime has been investigated for two fully hidrological years from August 1983 to Aug. 84. The total scientific project is described in the Author's Theses: DENUDATION IN A KARSTIFIED AREA IN A SUBARCTIC KLIMA-ZONE, 1986, THE UNIVERSITY OF OSLO.

Glomdalen, Nordland, Norway is chosen as investigation –area. It is highly karstified with a lot of caves and surface features. The total hydrological investigated area is 211 km^2, with two sub-areas, like boxes put into one another, the Jordtulla-system which is 26 Km^2, and the Storbekken-system, which is 4.6 km^2.

The investigation is both hydrological, chemical and morfological. There has been four discharge-recorders in use, two at the Storbekken-system, one at the Jordtulla-systeme and one at the Glåmåga-system.

Chemical analyses is done for more than two hundred watersamples.

The limestone-brikkettes method also used by Trudgill, Goudie, Gams a. o. is used from medio August –83 to medio August –84. 82 tablets was placed in water, soil and air in 18 different micromilleues.

The scientific results show remakable variation on the denudation-rates in different surroundings.

In the chemical analyses there is found hysteresis by several of the parameters through flows.

The karsthydrological investigation shows interesting variation and characteristic similarities between the three «box in box» –areas.

84 tablets in 17 groups were placed in different surroundings in Glomdalen, Northern Norway from August 1983 to August -84. The three surroundings were WATER, SOIL and AIR. In each main surrounding there are some sub-surroundings to differenciate conditions like turbulence, agressivity, support of allogenetic water, different soils or exposure in open air. (fig. 1)

The result of the measurement show interesting variation between the main surroundings, but also, there are differences inside a main surrounding caused by the different local conditions. This is confirmed by the statistical treatment of the tablet–results. (fig. 2)

The results are shown in table A–1 to A–3. The histogram show the denudation in per cent and per mille. The values are found to be in average per 1.000 years: *Water* 185.0 ± 92.2 mm, *Soil* 0.35 ± mm, and *Air* 0.29 ± 0.17 mm in subarctic climatic conditions.

The tabltgroups are placed as follows:	category:
A: Bog-brooklet above treelevel.	
B: Stagnant bowater, Fjelllbuveimyra.	
C: Cave-inlet, Fossholet.	
D: Resurgence, Storbekkgrotta.	Water.
E: Ponor on the polje, Jordbekkvollan.	
F: Artesian resurgence, Juta.	
G: Jordtulla ponor at the outlet of Glomdalen lake.	
H: Cavelake, Mellomgrotta.	
I: Artesian spring, The Marble Spring.	
J: Peat.	Soil
K: Sand form chist.	or
P: Gravel from calsite and dolomite.	vegetation-cover
N, O: Vegetation-cover, moss.	
L: Air-exposed on dolomite above tree-limit.	Air-exposed
M: Air-exposed on grey calsite-marble in an open place.	
R: Air-exposed on grey calsite-marble in leaftreeforrest.	

(Map from Laurit 1980)

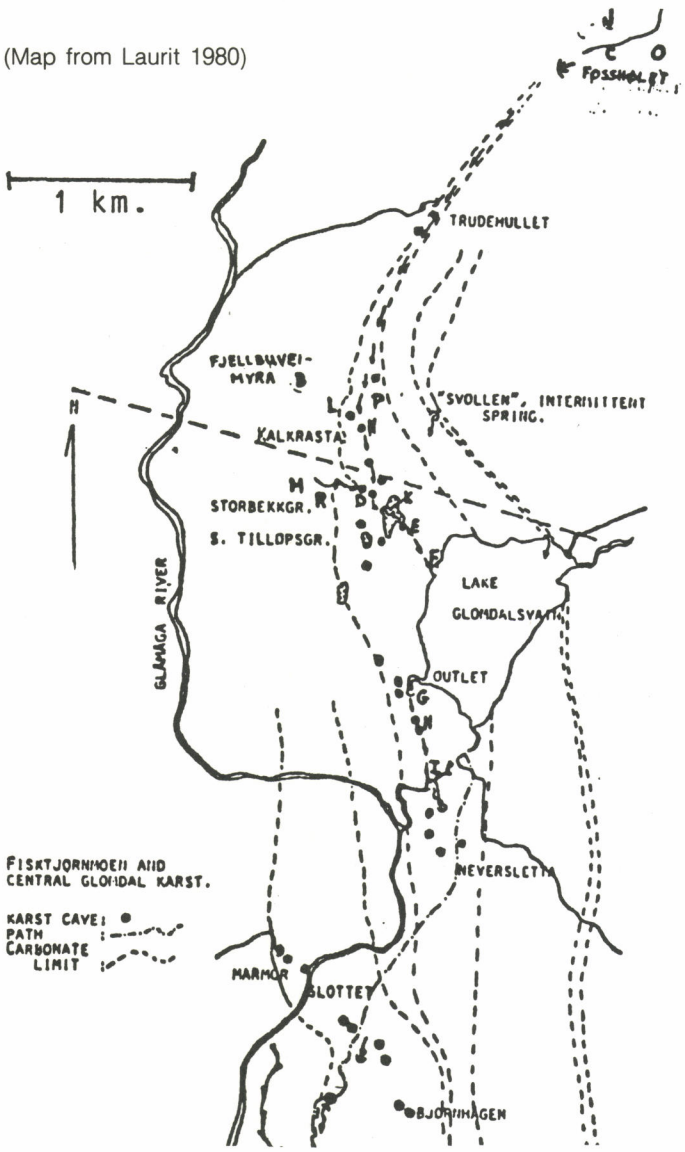


Fig. 1. The localisation of the measurement-stations of the tablets.

When investigating the influence of hidrological conditions, it is found a decrese in the denudation rate with time of the waters contact with limestone in the cave–system. This effect is shown in fig. 3 a/b

Scanning Electron Microscopy is done on the surface of the tablets. Fig. 6. show an example of the differences on the surface–denudation of Naxos–marble in $\times 550$ enlargement.

This method is discribed by Trudgill (1975,1977) and Goudie (1981) The main purpose of this experiment is to find that limestone looses weight in differt surroundings, due to the local physical and chemical conditions.

The experiment was based on the hypothesis that would be differences between the main surroundings, local variations in the same main surrounding and also inside each group. It was expected that turbulent water would give the highest denudation-rate, and that the denudation rate is some higher for covered limestone (under soil or vegetation) than in open air.

The denundation–results confirm this hypothesis. (fig. 2) Turbolent water is highly corrosiv and gives the largest rate of denudation, burried tablets shows little higher values than those exposed to air only.

A comparison between three series of tablets from measurements in Glomdalen has also been made.* The three series of tablets are made from different types of limestone, that is, The limestone is of different origin. The Glomdaltype is the local stone, the Skrim–type is from southern part of Norway, the Naxosstone is a Greek stone and the last one comes from Yougoslavia (Table 1).

When looking at the different types of stone used, it is discovered that there are denudation–differences due to this factor too. Table 2 show the variation of the chemical content in some of the tablets used. Also the shape and size of the tablets will influate on such measurement–results.

The reason for why different types of stone is used, is the result of trying out what sort of stone would be useful in such measurements and which wouldn't. It is found that a marble will be the best fitted. The Naxos–marble isn't very easily breaked as the Norwegian marble does, so the Naxos type is the one which is to be recomended.

When comparing the three Glomdalen–series, one has to take a little adjustment into account because of the different types of stone which is used.

*The practical part of the measurements with the 1979–80, 1980–81 series is done by S–E Lauritzen, the theoretical work of these two series and the 1983–84 serie is done by the author.

The scientists which have used this method before, have been using local stone in the measurements. Using the same type of tablets troughout the world in different climic zones, will most probably give very interesting results.** (last page.)

When taking the few measurements into account, it seems like the Yougoslavian stone is less resistant to denudation than the others. The Greek stone, Naxos, show higher D–rate thant the Norwegian stones. It is possible that imported stone will respond differently on the climatic conditions and therefore give a slightly different denudation rate than the one which should be correct on the local stone.

When using the same tablet–type everywhere, the denudation differences ought to be due to differences in climatic condition when the tablets are placed in equal denudation surroundings.

The field–area for the Glomdalen investigations is about 28 km.^{2} *** The different local surroundings in the tablet experiments has been a bog–broklet, a wet bog, three different ponors, three resugences, a cave–lake and a surface–lake. In the soil the differences has been sand, limestone–gravel, vegetation and soil from peat. The differences in the air–exposed surroundings is caused, by the local variations in wind exposure, airworn material and the support of precipitation.

The water–turbulens increase with increasing discharge, and more air is comming into the water. Then the absorbed CO_2 increases the waters agressivity.

The humic acids in the soil give a higher denudation–rate for this surroundings than the agences in the air; precipitation, eolitic material and temperatures below zero.

Analyses of the denudation results of the 1983–84–series. A kontra B:

When looking at the two groups A and B, which both are wet bog surroundings, the results show a very little difference in the weightlosses. A=4,16 %, B=4,00 %, the difference might be a coinscidence.

Table 1. Weightloss in % relatively to different types of stones

DENUDATIONSURROUND	REFERRENCE	% WEIGHTLOSS	TYPES OF STONE
hydrological	G	$\bar{x} = 8.52$	Naxos
»	G	$\bar{x} = 3.73$	Skrim
»	D	$\bar{x} = 2.66$	Naxos
»	D	$\bar{x} = 0.20$	Skrim
»	A	$\bar{x} = 4.16$	Naxos
»	A	$\bar{x} = 0.26$	Skrim
»	J	$\bar{x} = 0.074$	Naxos
»	J	$\bar{x} = 0.1545$	Glomdal
»	J	$\bar{x} = 0.370$	Jugoslavisk
under vegetation	N	$\bar{x} = 0.075$	Naxos
»	N	$\bar{x} = 0.3073$	Glomdal
»	O	$\bar{x} = 0.057$	Naxos
»	O	$\bar{x} = 0.3403$	Jugoslavisk
»	O	$\bar{x} = 0.0343$	Skrim
»	R	$\bar{x} = 0.115$	Naxos
»	R	$\bar{x} = 0.095$	Glomdal

Table 2. Chemical analyses on the Naxos stone and 3 of the local stone in Glomdalen

LOKALITET	MARMORTYPE	FARGE	Fe_2O_3	SiO^2	TiO_2	P	CaO	MgO	S
Pikhågan	Glomdalen	grå	0.15	1.12	0.05	0.05	31.2	20.6	0.005
Marmorslott. I	Glåmåga	hvit	0.16	0.88	0.07	spor	55.0	0.6	0.008
Marmorsl. II	Glåmåga	grå	0.09	0.12	0.04	spor	54.0	1.0	0.015
Gresk	Naxos	hvit	0.06	0.09	0.06	0.01	55.7	0.1	0.014

Fig. 2. Histogram of the three tablet-sereis which is used for denudatioon- measurements in Glomdalen.

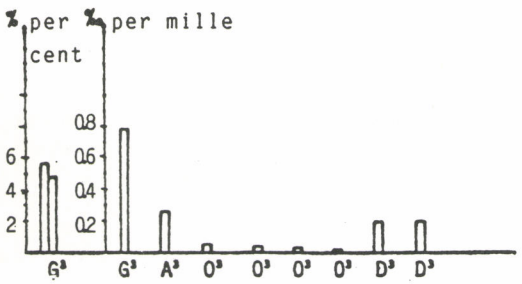


Fig. 2.a. The 1979-80-serie, type marble from Skrim.
The results is given in per cent for water surroundings, per mille for soil or air.

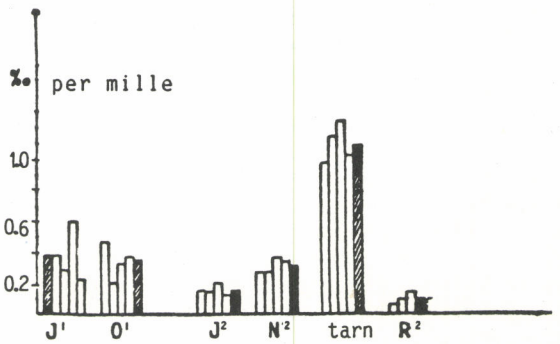
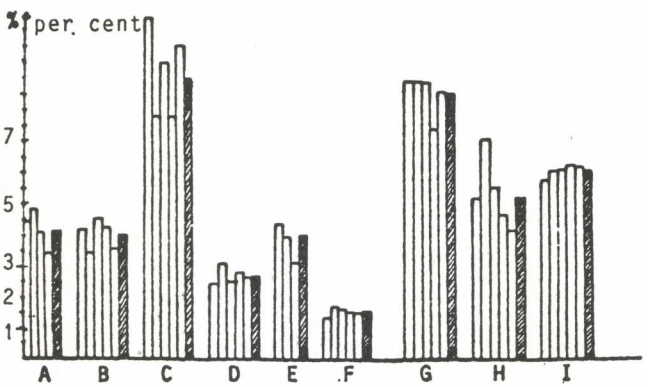


Fig. 2. b. The denudation of the 1980-81-serie, type Glomdalsmarble and Yougoslavian limestone.



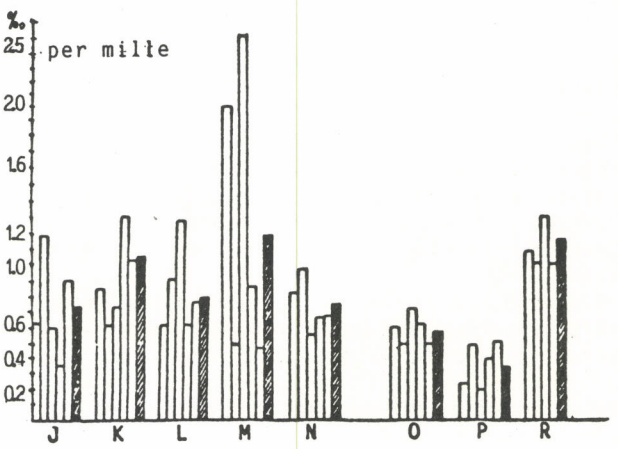


Fig. 2.c/d. The denudation of 1983-84 serie, type Greek marble (Naxos). The fig. 2.c. concern water-surroundings and the results is given in per cent. Fig. 2.d. shows the results in per mille for surroundings of soil and air.

Humic–acid is probably the main denudation agents in the corrotion. Mechanic weathering due to frost and thaw proesses has caused the corration.

Scaning Electron Microscopic Analyses (SEMA) shows that the surface of the tablets is rough with some humic cover and a little mechanical weathering.

Group C, D, &F:

When looking at the results for C, D, E and F, we find that the rate of denudation is as follows: C>>D<E>F. (fig. 2 & 3)

Fig. 3a, b show that there is some connection between the amount of discharge and the time of the waters residens – and the reaction time in the system. *The total time of reaction and residens is opposite propotional to the discharge, but the chemical reaction prosess decrease when the time of contact increase. As the time of contact between the water and the marble is a function of the water–way distance when the discharge is kept constant, is it possible to show the denudation in a vadose/freatic cave system relativly to the distance of the waterpath.*

Fig. 3a/b indicates a opposite relation between the waterpath–distance and the rate of denudation under constant conditions. The denudation rate is at its most when the contact between water and marble has been very little. If the conditions changes during the water running. ex. by absortion of CO_2 or support of allogenetic water, the denudation rate increase a little. When the conditions are back to stability the rate again decrease after same pattern as before.

Group G, H & I:

This denudation–surroundings is 98 % freatic, in contrast ot t he C, D, E, F–system where runs vadose in the caves mostly and also on the surface.

The result given in the histogram (Fig. 2) show that G>H<I. The rate of denudation is highest where the cave–system starts. The lake water has a high aggressivity. The denudation rate decreases through the freatic tubes, but increases a bit at the resurgence where water is highly turbulent due to artesian upwelling. It is possible that there exsist a support of allogenetic water at the distance between H and I which causes this increase in the denudation–rate in the Marblespring.

the difference between the two cave–systems, C, D, E, F and G, H, I is that the Storbekken–system (C, D, E, F) has a support of allogenetic water. This we know for sure because it is possible to watch on the surface. There is no certain proof of allogenetic water–supply in the freatic cave–system of Jordtulla (G, H, I), but because of the increasing aggressivity of the water this might be the most possible solution. Some absortion of CO_2 through karst–windows and cave–openings is also possible but increasing denudation rate caused by mixed corrosion is probably the main cause. (Bögli 1978.)

Conclusion: Valuation of the tablet–results for water–surroundings.

When looking at the results of the hydrological surroundings, the differences are clearly shown. The cave–systems show different results and the bog–results are unlike the cave results.

The average of the denudation in the hydrological surroundings is as weightloss of 4.99 %. (Bog = 4.08 %, (C, D, E, F)=4.23 %, (G, H, I)=6.26 %)

The difference of denudation of the two cave–systems might be due to difference in the length of the waterpath, the gradient of the systems, the discharge or the genesis of the cave–water.

The common thing between the two cave–systems is decreasing denudationrate relativly to the waters residence time, increasing denudation rate where there is creasing turbulens or support of allogenetic water.

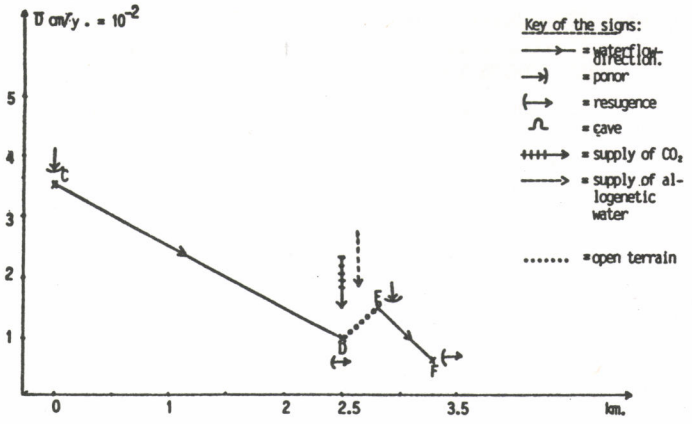


Fig. 3.a. The denudation rate as a function of the contact between water and limestone through the waterway-distance, and changes in the conditions along the path. The Storbekken-system is measured in km. The local places is C = Fosshølet, D = Storbekkgrotta cave-resurgence, E = Jordbekkvollen ponor at the polje, F = the resurgence of Juta.

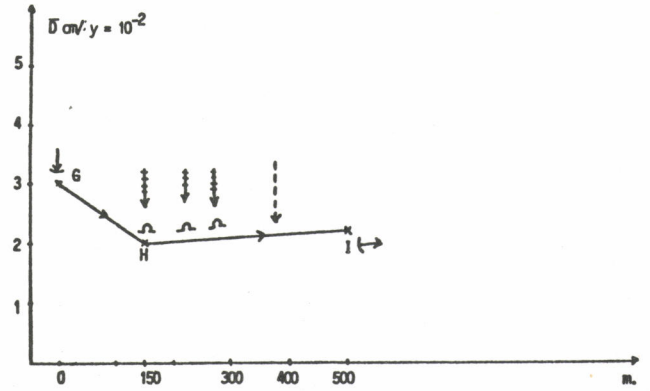


Fig. 3.b. The denudation rate as a function of the contact between water and limestone in the cave-system of Jordtulla. The distance is measured in meters. G = Jordtulla ponor/underground outlet of lake Glomdal, H = Mellomgrotta, a cave-lake, I = Marmokilden v/Fiskepøla, the final resurgence of the system of caves in Glomdalen.

Trend: There is a favourisation of denudation in hydrological surroundings on spots where the aggressivity, the discharge, the turbulences, or the support of allogenetic water is high.

As the discharge in Fosshølet is always less than the discharge in Jourdtulla, it seems likely to conclude that *the agressivity of the water is the main factor of its corrosiv effect.*

Group J, K, L, M, N:

When looking at the results of the denudation in the surroundings of soil or vegetation cover, the general picture is very much lower rate of denudation for this surroundings than for the hydrological. The weightloss is given in per mille. (Fig. 2)

The groups represent different soiltypes or vegetation. The variation between the local (microscale) surroundings is relativly high. In average the loss of weight in these surroundings is calculated to 0.087 % or 0.87 per mille. In per mille this means 0.97 for tablets covered by vegetation and 0.81 per mille in soil surroundings.

In the soil–surroundings the agenses are chemical like humic acid and water. There is also some mechanical weathering because of the low temperature in the soil for a very long season of freeze and thaw processes, in fact it might happen through all the months except for December, January and February.

Trend: The vegetation surroundings which cause humid stability directly on the marble, seems to contribute a lot during the karstification process. Observations from the nature itself confirms this hypothesis. Karren forms on steep walls of the marble–band beneath moss which nearly all the time is dripping. (Fig. 4) Another important factor is the altitude. The groups which were plased

below the treelimit, show a higher degree of denudation than those above. At the lower altitude the temperature is higher. More of the precipitation comes as rain, the richer vegetation allows more humic acids and the freeze and thaw prosess is prolonged.

Group O, P, R:

The results of the denudation in the air–exposed surroundings show a very low denudation rate. The variation between the groups and also inside one group is relatively high. The total average weightloss is 0.69 per mille, wich means 0.57 per mille for the group 0, 0.35 per mille for the P–group and 1.15 per mille for the group R.

In the air–exposed surroundings the agents are precipitation, wind & eolic material and temperatures below zero.

Trend: There is no differences due to the localisation of the tablets. Group P might be no. 1 because of a higher degree of humidity in the surroundings.

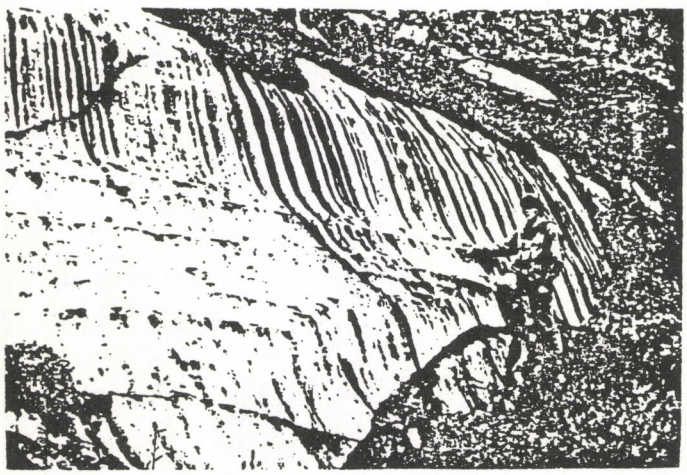


Fig. 4. Wandkarren water is nearly constant dripping from the moss above.

Comparison with the two other series:

Looking at the other series, the 1979–80 can't be statistical ranged or scientifically looked at because there are only 10 tablets all together in the measurement, which is far too few to draw conclusions from. The marble–type in this experiment was the Skrim marble.

The *trend* for these results indicates strongest denudation under hydrological conditions, some less in bog and very little denudation in air.

The measurement of the 1980–81–series is treated statistically. There has been three types of stone in this serie, Glomdals–marble and The Yougoslavian type made by I. Gams.

The *trend* is for this serie that the hydro–surroundings gives the highest rate, the soil the next highest and the air–exposed surroundings gives the very lowest result.

The statistical ranking test:

The denudation values is statistically treated to show weather the differences are significant or not. The method is discribed by Sverdrup 1980. The weightloss in per cent is used for ranking and comparison since the 1979–80 and 1980–81–series is only showing these results. The results is therefore possible to compare directly.

$\bar{Y}$ gives differences which are significant on the level of 5 % if the distance between the groups is more than or equal to 0.000523.

Conclusion: $\bar{Y}_F < \bar{Y}_D < \bar{Y}_B < \bar{Y}_H < \bar{Y}_I < \bar{Y}_G < \bar{Y}_C$ with a distance which is ≥ 0.000523. It is therefore possible to rank the average group values. The calculations show marcant differences in the measurement, higher than random differences would be. Therefore from a statistical point of view, *The differences in the result values are significant by the laws of statistics.*

Ranking of the results of the 1983-84 serie, group B-I, water.

Table 3. $\bar{Y}$ shows the average value of the groups

ØKENDE DENUDASJON	RANGORDNINGSNR.	$\bar{Y}^{I}_{B}$	GRUPPEREFERRANSE
	1	0.0058	F - kilden Juta
	2	0.0100	D - Storbekken meander
	3	0.0148	B - myr/tregrensen
	4	0.0200	H - Mellomgrotta
	5	0.0216	I - Fiskarpøla, Marmorkilden
↓	6	0.0304	G - JOrdtulla ponor
	7	0.0348	C - Fosshølet nedløp

Ranking of the results of the 1983–84 serie. group J-P, soil or air.

Table 4. $\bar{X}$ show the average values of the groups. If the distance between the groups is more than or equal to 0.3129×10^{-4} on the level of 5 %, the differences are significant.

ØKENDE DENUDASJON	RANGORDNINGSNR.	$\bar{X}^{P}_{J}$	GRUPPEREFERRANSE
	1	1.4316x10^{-4}	P - Kalkrasta, luft.
	2	2.3164xE	O - Fosshølet, luft
	3	2.8650xE	J - Fosshølet, torvjord
	4	2.9534xE	N - Kanalgrotta, vegetasjon
	5	3.2414xE	L - Kalkrasta, kalkgrus
↓	6	3.6296xE	K - Jordbekkvollan,skifersand
	7	4.9074xE	M - Storbekkgrotta,moseavrenning

Conclusion: $\bar{X}_P < \bar{X}_O < \bar{X}_J$ $(< \bar{X}_N)$ $< \bar{X}_L < \bar{X}_K < \bar{K}_M$ at a distance on $\geq 0.3129 \times 10^{-4}$ $\bar{X}_N$ is not possible to rank when using this test, but all the other groups are significant unequal, that is, *The differences in these results are significant by the law of statistics.*

Ranking of the results of the 1981-82-series, group J', 0'; X². N², J², soil, air, water. Table 5. $\bar{Z}$ shows the average values of the groups. The values are significant unequal on the 5 %-level when the distance is ≥ 0.2332.

ØKENDE DENUDASJON	RANGORDNINGSNR.	$\bar{Z}^{''}_{i}$	GRUPPEREFERRANSE
	1	0.1545	J''- Pikhågan, jord
	2	0.3073	N''- Søndre tilløpsgrotte
	3	0.3403	O' - Pikhågan, luft
	4	0.3700	J' - Pikhågan, jord
↓	5	1.0890	X''- Pikhågan, vann

Conclusion: $\bar{Z}^{J2} < \bar{Z}^{N2} < \bar{Z}^{O1} < \bar{Z}^{J1} < \bar{Z}^{X2}$ if the absolute values are ranked, but not when the group distance value is to be used. On the level of 5 %, the J^2 –group is significant unequal to the other groups by the distance of 0.2332.

When the testlevel of 10 % is used, there is also a significant difference between group J^2 and J^1. It is from this reason possible that the difference of weightloss and denudation in this series is caused by casualty, rather than differences in the denudation factors of the surroundings. *The differences in these results are not to be determined as significant by the law of statistics.*

Scanning Electron Microscopic analyses.

The surface of the tablets is analysed after a year of denudation and compared with one tablet which has been kept in the laboratory in room conditions. The surface study is related to the condition of denudation, the agents water, humic acids, eolitic material and variation in temperature.

Table 6. A surway of the tablets elected for analyses.

LOKALITET	NR.	MILJØ	FORSTØRRELSE	VEKTTAP i %	D cm²/år.
Fosshølet	109	turbulent, aggressivt, vann	x50, x550, x4800	10.85	0.039
tregrensen	108	myr, humussyrer	47,550,1500,4800	4.56	0.017
Kalkrasta	132	luft,eolisk materiale	75,550,4800,7200	0.02	0.856×10^{-4}
Laboratoriet	1	romfortòld,udenudert	60,540,1500,4800	-	-

Fig 5. show the surface of the tablets on the enlargement of x550.

Description of the surface of the tablets:

Tablet no. 109: the tablet has got clearly marcant, regularely limits of the crystal. There is stripes on the surface due to crystal-lamells. Some simple denudation pockets in the poreholes is also possible to observe.

Tablet no. 108: The crystal show unregulary shape of 5 to 8 planes. The limits are even more clearly shown due to the denudation process. The planes show sripes due to the lamelles, but also crossing stripes and fissures. Solution-pockets in the poreholes can be observed.

Tablet no. 132: The enlargement show the unregularity of the crystal shape. The number of planes varies from one crystal to another. The surface show lamell-stripes and crossing stripes and fissures. The solutionpockets are located along the lamelles.

Tablet no 1: The surface show that there different layers in the tablet. These are lamelles. There is some small pockets which is probably due to rough handling of the tablets when making them.

Conclusion

It seems like the limit of the crystal forms a zone of weakness, which is easily denudated. The number of unregularity of crystal-limit-sides is typical for $CaCO_3$. Because of the plane structure of the crystal, there are lamelles, on which the denudation takes place.

Crossing stripes and fissures are probably due to tension and compression, or might be due to mechanical erosion. These spots also form zones of weakness and the denudation goes on along them.

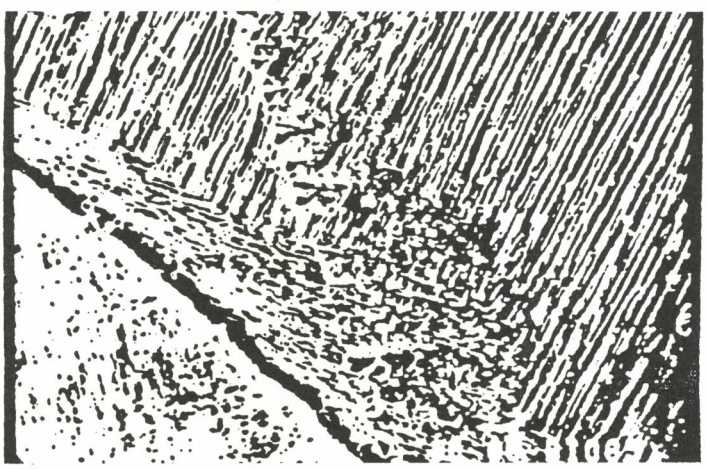
The pockets can be pore solution pockets or pockets because of substituted ions in the crystal-grid.

The cracks on the surface might be drying cracks of the humic surface layer or due to weathering.

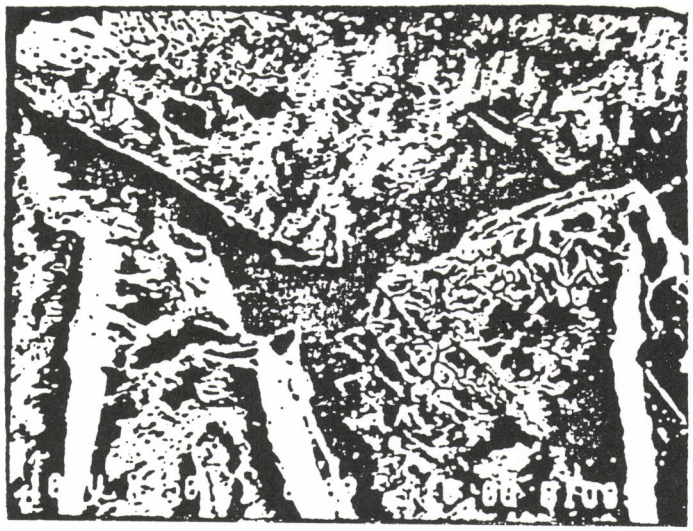
Of the surroundings represented *water* gives the highest denudation rate. The solution takes place along the lamelles. There isn't any pocket solution to take into account in turbulent water surroundings.

Bogwater show that denudation takes place along the crystal limits, cracks, lamelles and where there might be substitute-iones. The rate of denudation is the half of that in water.

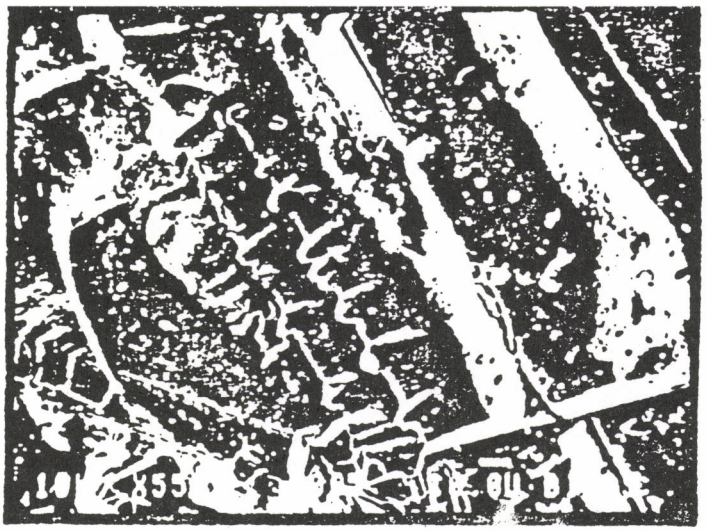
When the denudation surroundings is *air,* the poresolution seems to be favoured, but there is also some mechanical erosion due to frost and eolitic material.



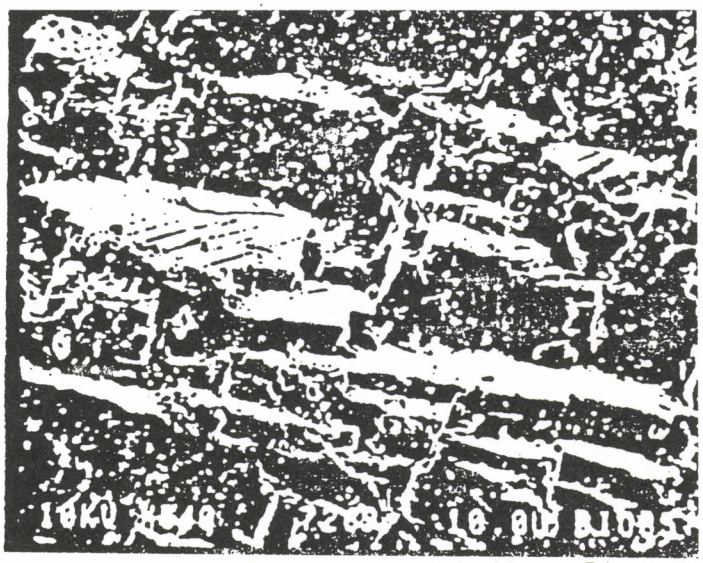
(Fig. A. 5. b) Tablett nr. 109 Surroundings: Turbulent, aggressiv water Lokality: Fossholet. Enlargement: : ×550.



Tablett nr. 108 (fig. A. 5. b) Surroundings: Bog. Lokality: Fjellbuveimyra Enlargement: ×550.



Tablett nr. 132. (fig. A. 5. j) Surroundings: Air. Lokality: Kalkrasta. Enlargement: ×540



Tablett nr. 1. (fig,. A. 5. n) Surroundings: room Lokality: laboratory Enlargement: ×540.

Acknowledgements:

I would like to thank Dr. Stein-Erik Lauritzen for is supervising and for lending me his unprepared results. This has been a great

Table 1.A. Denudationersults by the measurement of carbonate tablets. Glomdalen 1983-84

KATEGORY	REF.	LOCALITY	WEIGHTLOSS % min.	mid.	max.	$\bar{D}$ cm/y	± s	pr. 1.000 y i mm. ± s
WATER	A	FOSSHØLET;	3.42	4.16	4.87	0.016	± 0.002	160.0 ± 2.0
	B	FJELLBUVEIMYRA	3.45	4.00	4.56	0.015	± 0.001	150.0 ± 1.0
	C	FOSSHØLET;	7.72	8.93	10.85	0.035	± 0.005	350.0 ± 5.0
	D	STORBEKKGROTTA;	2.43	2.66	3.08	0.010	± 0.001	100.0 ± 1.0
	E	JORDBEKKVOLLEN; PONOR	3.15	3.80	4.35	0.015	± 0.002	150.0 ± 2.0
	F	JUTA;	1.32	1.52	1.69	0.006	± 0.001	60.0 ± 1.0
	G	JORDTULLA;	7.38	8.52	8.89	0.030	± 0.003	300.0 ± 3.0
	H	MELLOMGROTTA	4.18	5.24	7.08	0.020	± 0.003	200.0 ± 3.0
	I	FISKEPØLA;	5.78	6.09	6.26	0.022	± 0.001	222.0 ± 1.0
SOIL OR VEGETATION	J	FOSSHØLET;	0.036	0.074	0.119	1.43×10^{-4}	± 0.490	0.143 ± 0.5
	K	JORDBEKKVOLLEN; SAND	0.060	0.091	0.129	3.63 x E	± 1.140	0.363± 1.1
	L	KALKRASTA;	0.061	0.079	0.127	3.24 x E	± 0.880	0.324 ± 0.9
	M	SOTRBEKKGROTTA;	0.046	0.118	0.243	4.91 x E	± 3.480	0.491 ± 3.5
	N	KANALGROTTA;	0.055	0.075	0.097	2.95 x E	±0.780	0.295 ± 0.8
AIR-EXPOSED	O	FOSSHØLET;	0.049	0.057	0.072	2.32 x E	± 0.313	0.232 ± 0.3
	P	KALKRASTA;	0.020	0.035	0.051	1.43 x E	± 0.490	0.143 ± 0.5
	R	STORBEKKGROTTA;	0,099	0.115	0.117	4.64 x E	± 0.576	0.464 ± 0.6

Table A.2. Results of the denudationmeasurements with carbonate tablets, Glomdalen 1979-80, type Skrim

CATEGORY	REF.	LOCAL SURROUNDINGS	weightlossin % min.	mid.	max.	$\bar{D}$ cm/y ± s	pr. 1.000 y i mm. ± s
WATER	G[3]	JORDTULLA, TURBELENS	0.78	3.73	5.64		
	D[3]	STORBEKKGROTTA	0.20	0.20	0.20		
BOG	A[3]	PIKHÅGAN	–	0.26	–		
AIR	O[3]	PIKHÅGAN	0.022	0.0343	0.049		

Table A.3. Denudationresults from measurements with carbonate-tablets Glomdalen 1980-81, type Glomdal, Jugoslavisk

CATEGORY	REF.	LOCAL SURROUNDINGS	weightloss in % min.	mid.	max.	$\bar{D}$ cm/y ± s	pr. 1.000 y i mm. ± s
WATER	–	PIKHÅGAN ST. 1	0.971	1.089	1.230		
SOIL	J[2]	PIKHÅGAN	0.122	0.1545	0.200		
	N[2]	SØNDRE TILLØPSGROTTE	0.264	0.3073	0.359		
	J[1]	PINKHÅGAN	0.217	0.3700	0.601		
AIR	R[2]	KALKRASTA	0.057	0.0950	0.138		
	O[1]	PIKHÅGAN ST. 1.	0.201	0.3403	0.468		

help and inspiration in my work with my thesis and other studies on karst too.

Thanks is also directed to Statskraftverkene for ecconomical support and to several Hydrologists at NVE and the University for their friendly help.

Litterature

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SVERDRUP, ERLING: Lov og tilfeldighet, bind 2, s 143-147. Universitetsforlaget, 1964: Oslo

TRUDGILL, S. T: Rock weathering and climate, quantitative and experimental aspects, p. 59-110 in Geomorphplogy and Climate. Ed. E. Derbyshire, Wiley & sons, 1976: London

Remarks:** (p.4) These thoughts were discussed by my supervisor, S-E Lauritzen and myself with professor M. Pulina in Poland, february 1986 to see if it is possible to start a worldwide tablet-measurement programme to investigate the climatic influence on the differences of denudation.

*** The total investigation of the karst area of Glomdalen is written in the thesis «Denudation karst in subarctic climatic zone, Glomdalen, Northern Norway.» 1986. Department of Geography, the University of Oslo.

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Minimum duration for speleogenesis

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RESUM

L'examen dels conductes de dissolució d'àrees càrstiques que han sofert glaciacions, tant a Europa com a l'Alemanya del Nord, indica que molts dels conductes coincideixen amb paisatges influenciats per les glaciacions. Les dades indiquen que els conductes de dissolució de diàmetres superiors a 1 metre poden haver-se generat en el període comprès entre els 10.000 i els 15.000 anys des de l'última glaciació. Uns estudis de les illes Bahames han demostrat que conductes de dissolució d'1 m. de diametre, desenvolupants en antigues eolianites de fa 85.000 anys est van drenar i han romàs inactius des de fa 49.000 anys. Les dades sobre el nivell del mar de Plistocè recent no descarten l'existència d'una zona freàtica per al desenvolupament de galeries durant 5.000 anys, dins d'aquest període de 36.000 anys. Les dades de camp relatives al medi glacial i tropical donen suport als models de laboratori i als models teòrics de molts investigadors, que consideren que cal un mínim de 5.000 a 10.000 anys perquè puguin desenvolupar-se conductes de dissolució de l'ordre d'1 m. de diàmetre.

RESUMEN

El examen de conductos de disolución en áreas kàrsticas que han sufrido glaciaciones tanto en Europa como en Alemania del Norte, indica que muchos conductos coinciden con paisajes influidos por las glaciaciones. Los datos indican que los conductos de disolución con diámetros superiores a 1 metro pueden haberse formado en el período entre 10.000 y 15.000 desde la última glaciación. Los estudios en las islas Bahamas han hecho ver que conductos de disolución de 1 m. de diámetro, desarrollados en antiguas eolianitas de hace 85.000 años, y que los conductos se drenaron y permanecieron inactivos desde hace 49.000 años. Los datos sobre el nivel del mar del Pleistoceno reciente dan como posible la existencia de una zona freàtica para el desarrollo de galerías de sólo unos 5.000 años durante este período de tiempo de 36.000 años. Los datos de campo relativos al medio glacial y tropical dan un fuerte apoyo a los modelos de laboratorio y teóricos de muchos investigadores que dan un mínimo de 5.000 a 10.000 años para el desarrollo de los conductos de disolución del orden de 1 m. de diámetro.

SUMMARY

Examination of solution conduits in galciated karst areas of both Europe and North America shows that many conduits are concordant with the glacially deranged landscapes. The data suggest that solution conduits in excess of 1 m diameter can form in the 10.000 to 15.000 years since the last glaciation. Studies in the Bahama Islands have shown that 1 m diameter solution conduits developed in 85.000 year old eolianites, and that the conduits were drained and inactive by 49.000 years ago. Late Pleistocene sea level data would allow a freshwater lens in the proper position for conduit development for only about 5.000 years of this 36.000 year time span. This glacial and tropical field information strongly supports the laboratory and theoretical models of many other workers that yield a minimum of 5.000 to 10.000 years for development of solution conduits in the 1 m diameter range.

Introduction

A critical factor in the study of speleogenesis is the time required for solution conduits to form. In most areas of he world, caves are developed in Mesozoic or Paleozoic rocks many tens or hundreds of millions of years old. Cave systems being studied in those rocks may have had their origin far in the past under conditions vastly different from today. Even caves that are in apparent equilibrium with the present surficial environment may have begun their initial development long ago under another hydrologic setting.

Recent work by investigators such as A.N. Palmer (1984) and white (1978; 1985), among others, has produced equations, developed mostly from laboratory experiments, that demostrate that solution conduits of humanly passable dimensions ($r \approx 1$ m) can develop in approximately 10.000 years (depending upon conditions). This work implies that currently active cave systems may have developed in concert with the existing landscape and hydrologic regime. Applying the theoretical work to current field observations of caves in Paleozoic or Mesozoic rocks requires the assumption that all of the conduit development has occurred in the immediate geologic past, and not earlier in the history of the host rock. White (1985) has discussed the importance of the time involved in the initial enlargement of the original fracture or opening in the host rock. Caves that are in apparent equilibrium with the surficial environment may have completed their macroscopic enlargement relatively recently, as their geomorphic setting suggests, but the initiation of their development could be more proportional to the age of the enclosing rock.

To provide conclusive proof of the speleogenetic chronology

proposed by A.N. Palmer (1984) and White (1978, 1985), among others, has been an interesting challenge. Cave systems, when explored, often give a subjective feeling of great antiquity. Caves must certainly can be very old, in excess of 350.000 years, as paleontologic and radiometric data have amply shown. If it can be demostrated that cave systems mayt form rapidly ($\approx$ 10.000 years), then cave scientists will have, in the study of solution conduits, a data base that persists through time while being sensitive to local and tansient changes of environmental conditions during that time span. Complex cave systems may well represet a long-duration, hig resolution indicator of past surficial conditions.

Field Data Support for Rapid Conduit Development

To provide a field demostration of the laboratory and theoretical work, investigators have examined cave systems where the geomorphic setting makes it likely that the cave systems developed in the recent geologic past. Good field examples come from glaciated areas, where landscapes emerged from ice cover in the last 10.000 to 15.000 years. Cave systems found in these localities often appear perfectly adjusted to the recently deranged surficial landscape and hydrologic regime. This strongly suggests that the caves developed in the post-glacial time frame. Examples are common from around the world, and A.N. Palmer (1972), Mylroie (1977), Lauritzen (1981), and others have provided documented case histories. Glaciation both scours and mantles pre-existing ladscapes, and upon retreat a deranged drainage can occur. If a cave system consisting entirely of small, active passages can be found beneath such a landscape, with the cave's tributary passages arranged so as to collect water efficiently from the landscape, then the argument that the cave development is post-glacial is compelling. Despite this evidence, it can be argued that the initial fracture or flow path enlargement took place before or during glaciation. Data from the present (Ford, et. al., 1983) and the Late Pleistocene (Lauritzen, 1981) show that caves can be active beneath glaciers. Active caves beneath glaciers, by allowing water circulation, could control aspects of the ice/ground contact and help control the final nature of the surficial derangemente after ice withdrawal. After deglaciation, the resulting concordance of the solution conduits and the overlying deranged landscape could be interpreted as indicating the prior existence of conduits.

The data available in the Bahama Islands regarding the time necessary for speleogenesis are unique. The limestone is young, providing an upper limit on the age of any enclosed solution conduit. The host rock and deposits within the solution conduits can be dated quantitatively, thus providing a time window during which the cave must have formed. The data presented here were collected from San Salvador Island, Bahamas, which lies approximately 600 km east-southeast of the Florida Peninsula. The island consist almost entirely of Late Pleistocene and Holocene carbonate rocks (Carew and Mylroie, 1985), and it has a well developed karst topography that has been in part controlled by the glacially induced eustatic sea level fluctuations of the Pleistocene.

The data are summarized in Figure 1, a diagrammatic representation of the key features used to date the development of Lighthouse Cave, a major cave on the island. The initial data are from a Pleistocene fossil reef in Cockburn Town, on the west side of San Salvador. The reef contains fossil corals in growth position, and extends up to 4 m above current sea level. Because the island, like the rest of the Bahamas (Mullis and Lynts, 1977), is considered to be tectonically stable, and is underoing only slow isostatic subsidence, the fossil reef must represent an earlier, high stand of sea level. Corals dated at Lamont-Doherty Geological Observatory by Uranium/Thorium method yield an age of approximately 125.000 years before present (Carew, et. al., 1984). Specimens of the bivalve *Chione cancellata* recovered from the reef matrix were dated at approximately that same age by John Wehmiller at the University of Delaware using amino acid racemization techniques. The 125.000 year age in conjunction with the reef's +4 m elevation, indicate that the reef developed during the Oxigen isotope substage 5 e high sea level (Broecker and VanDonk, 1970; Emiliani, 1972) of the Late Pleistocene. The age determination also provided the basis for calibrating the amino acid racemization kinetics of *Chione cancellata,* allowing the amino acid racemization procedure to be applied to the terrestrial gastropod *Cerion* found in interior eolian calcarenites (carbonate dunes). In particular, the dates derived from *Cerion* in the eolian calcarenite wall rock of Lighthouse Cave were of importance.

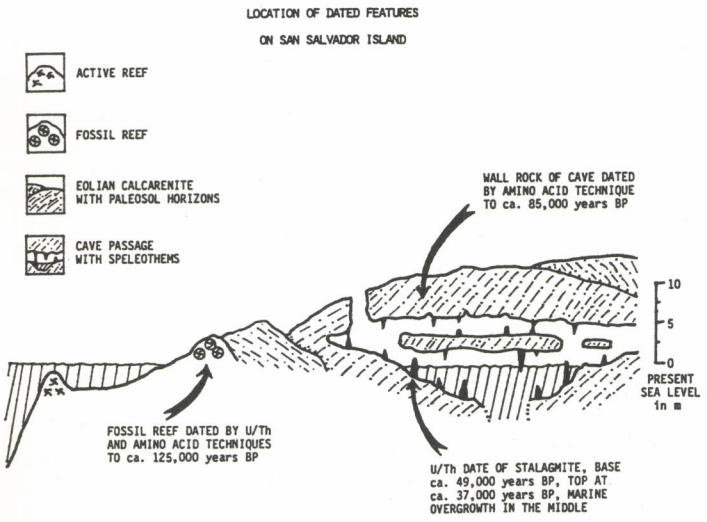
Lighthouse Cave is a large series of phreatic passages under Dixon Hill on the northeast side of the island. The cave has over 800 m of passage and several large chambers (Mylroie, 1983). The age of the rock determined from *Cerion* analysis was approximately 85.000 years (see Carew, et. al, 1984). Therefore the cave must be less than 85.000 years old. A stalagmite recovered at one meter below current sea level from within Lighthouse Cave was dated by Richard Lively and the Minnesota Geological Survey using Uranium/Thorium methods. The base of the stalagmite is 49.000 years old (Carew, et. al., 1984), therefore, the cave must have been developed and drained by then.

The data leaves a time window of not more than 36.000 years for the cave to form (between 85.000 and 49.000 years ago). This time window is already the proper order of magnitude to support the theoretical equations of A.N. Palmer (1984) and White (1985); however, the time window can be further narrowed significantly. The cave exteds, as currently explored, from -2 m to +7 m with respect to present sea level. The cave has limited breakdown development, and all surfaces within the -2 m to +7 m range have well developed phreatic (water filled conduit) solution features. Therefore, the cave develped in a brackish or freshwater phreatic zone that was solutionally aggressive and that extended to al least +7 m above present sea level. Work by Back and others (1984), A.N. Palmer and others (1977) and R. Palmer (1985) have demonstrated that solution in coastal limestone environments such as San Salvador may preferentially occur at the halocline, the boundary between intruding sea water and the overlying non-marine water. Even if both the sea water and the overlying non-marine waters are saturated with respect to calcite, mixing at the halocline will provide renewed aggressivity. While the halocline can be near or below sea level, formed by a fresh or brackish water Ghyben-Herzbug lens floating on underlying deuser sea water the halocline cannot be abrve sea level. The solution surfaces seen at +7 m in numerous locations throughout Lighthouse Cave suggest that either sea level was high enough at some time after 85.000 years ago to place the halocline at +7 m, or that the cave developed somewhere in a freshwater lens above the halocline. Observations indicate that San Salvador currently supports a Ghyben-Herzberg lens under portions of the island. The position of Lighthouse Cave in eolianites within a kilometer of the platform margin of San Salvador would support the argument that the elevation of the conduit is an approximate measure of sea level at the time of conduit formation (within 5 m or so), as a Ghyben-Herzberg lens would thin and pinch-out at sea level at the platform margin. Lighthouse Cave could not develop with phreatic solution features at +7 m unless sea level were at least at or near its present elevation during development. The time window for the development of Lighthouse Cave is therefore limited to the duration of a high sea level at or near its present elevation between 85.000 and 49.000 years ago.

Examination of the known Late Pleistocene sea level data (see Boardman, 1984) implies that the cave formed about 82.000 years ago, during a high sea level even that also formed the eolianites the cave is developed in. A marine transgression at that time would flood the San Salvador platform, producing the sediment that eventually formed the eolianites. Continued transgression would place the freshwater lens up into the eolianites, and the cave developed. The sea level rise discussed here lasted only a few thousand years, and indicates that the cave was abandoned before 75.000 years ago. In that case the cave was produced syngenetically as Jennings (1968) proposed for similar rocks in Australia. Assuming that the dating techniques used are at least moderately accurate, the Sant Salvador data suggest that the work of A.N. Palmer (1984), White (1985), and others, is essentially

correct. Lake Pleistocene eolian calcarenites are not exact analogues of Paleozoic or Mesozoic carbonates, but the data from the sea level curves would indicate that Lighthouse Cave, with its tubes, chambers, absence of breakdown, and sculptured walls, formed in only a few thousand years.

Further evidente of the speed with which karst processes can work is provided by the current relationship between Lighthouse Cave and the surrounding surficial environment. The cave has no apparent relationship with current topography, and is truncated by a hill slope. There is no apparent significant catchment for the cave, either laterally or vertically. Similar phenomena can be seen elsewhere on the island (e.g., Sandy Point Pits described in Mylroie, 1983), where surficial denundation has breached phreatic tubes and left large vadose shafts with no source of recharge at the crest of hills. Since all the rocks involved are less than 125.000 years old (Carew and Mylroie, 1985), this evidence argues for a rapid denudation, and therefore evolution, of the surficial karst landscape as well.



Cave development of San Salvador provides another useful piece of information bearing on the relationship of the «water table» to developing conduits. Because of the relationship of the water table or Ghyben-Herzberg lens, to sea level, caves such as Lighthouse Cave developed in the vicinity of sea level. As sea level is not known to have been more than a few meters above its present elevation during the last 85.000 years, the water table also must have been reasonably close to present ocean elevation (within +7 m) as the cave formed. Therefore, features seen in Lighthouse Cave such as sponge work, solution pillars, spans, pendants, and undulating tubes can develop under what are clearly shallow fresh or brackish water conditions, and a deep phreatic environment is not a prerequisite.

Conclusions

The data available strongly suggest that macroscopic solution conduits ($r \approx 1$ m) can develop in limestone in the time span of about 10.000 years. The theoretical equations, the laboratory experiments, and the field evidence are consistent. The field evidence is particularly critical, as it is the real-world representation rather than a theoretical model. The data from glaciated areas although compelling, is not conclusive. The Bahamian data is conclusive with regard to the time needed for conduit development. In addition, the Bahamian data has implications about the relationship of conduits to the water table, and about overall karst denudation rates.

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Karst in Mount Sedom

Giacomo Donini
Guido Rossi

RESUM

El Mont Sedom és un diapir (situat a la depressió del Mar Mort), que encara avui segueix enlairant-se (3-4 mm. per any), constituït per una potent massa de sal (Pliocè-Plistocè) recoberta d'un «cap-rock» semipermeable.

L'espeleogènesi, molt viva i ràpida (amb les cavitats més grans del món desenvolupades en sal: ICRC Cave, 4,5 km. Sedom Cave, 1,3 km. etc.) va lligada a la solubilitat, a l'estratificació i a la descompressió de la roca i a les variacions de nivell del Mar Mort i es troba condicionada per l'aridesa del clima (25-40 mm/any de precipitacions). Nosaltres analitzem, de forma especial, les morfologies singenètiques i paragenètiques esglaonades.

RESUMEN

El Monte Sedom es un diapiro (situado en la depresión del Mar Muerto) que todavía sigue elevándose (3-4 mm. por año), constituido por una potente masa de sal (Plioceno-Pleistoceno) recubierta por un «cap-rock» semipermeable.

La espeleogénesis, muy viva y rápida, (con las mayores cavidades del mundo desarrolladas en sal; ICRC Cave 4,5 Km. Sedom Cave 1,3 Km, etc.), va unida a solubilidad, estratificación, descompresión de la roca y a las variaciones de nivel del Mar Muerto y está condicionada por la aridez del clima (25-40 mm/año de precipitaciones). Se analizan especialmente las morfologías singenéticas y paragenéticas escalonadas.

RESUME

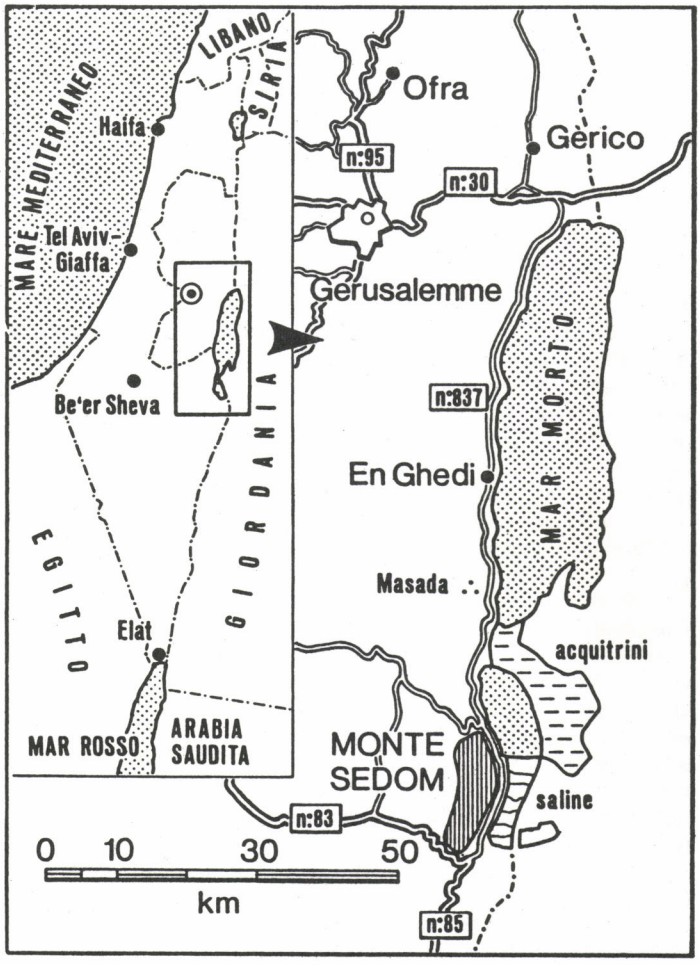
Le Mont Sedom est un dyapir (situé dans la dépression de la Mer Morte), encore en train de élèvement (3-4 mm par année), constitué d'une puissante masse de sel (Pliocène-Pleistocène) recouverte par un «cap-rock» demiperméable.

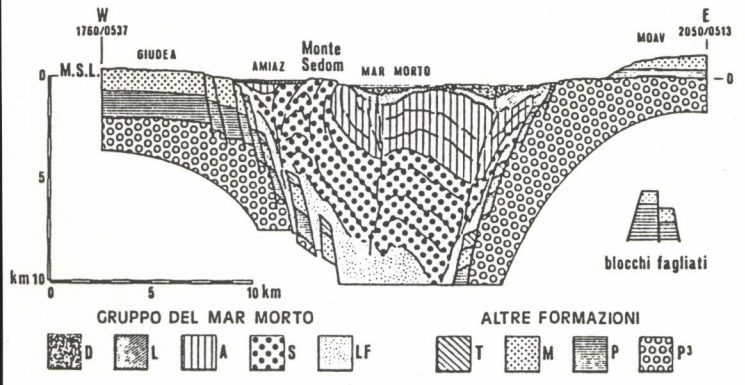
La spéléogénèse, fort vive et rapide (avec les plus grandes cavités du monde creusées dans le sel: ICRC Cave 4,5 km, Sedom Cave 1,3 km, etc.), est liée à solubilité, stratification, décompression de la roche et aux variations du niveau de la Mer Morte et est conditionnée par l'aridité du climat (25-40 mm/an de précipitacions). On analyse surtout les morphologies syngénetiques et paragénetiques étagées.

Geografic position

Mount Sedom is situated at 31°30' latitude north at 35°30' longitude west in the Israelian Territory. It rises up above the south shores of the Dead Sea from deepest depression of the Earth, as the Dead Sea Level is 400 m. under the medium level of the ocean. Mount Sedom covers a surface area of approximately 20 Km^2 and reaches an altitude of 198 m. above the sea level. This work expounds the results of the two expeditions organized by the «Gruppo Grotte Milano» during Easter 1983 and 1984 in the Dead Sea Depression, in cooperation with the Israel Caving Research Centre of the University of Jerusalem and with several people of the Speleological Group of Verona, Como, Imperia. The climate is most certainly desert, because it is surrounded by the Giuda desert on the north side and the Negev desert on the south side. Summer temperatures reach and sometimes exceed the 45°C found in the shade and consequently the rainfall is reduced: less then 50 mm. per year.

The precipitations in part effect the modelling of the relief as during the Karst phenomenon because only the strongest rainy events can lead to a superficial flowing, as opposed to whereas scarce precipitations that have no modelling effect because of the strong evapotranspiration of the diffuse rainfall and the dryness of the outcropping terrains. The Dead Sea Depression belongs to a system of a system of big lines that are fractures in the african rift, where big graben accentuate the tendency of the tectonic to strech. The Red Sea continues on towads the North west of this structure and to the North divides into the Suez Gulf and the Eilat/Aqaba Gulf without touching the triangular block of the chain of Sinai. The two Gulfs differ: the Suez is the continuation of the Red Sea structure and the Eilat/Aqaba belongs already to the fractures of the Dead Sea. Along the Dead Sea Depression the tectonic is no longer stret ched, but is compressed along a trascurrent fault, that is not rectilinear. In fact due to the counter clockwise rotation of the Arabian block there is a large left transcurrent fault with the Jordan territories that shifts to the North in respect to the Israelian Territories, with a speed that can reach up to centimetres per year. The transcurrent fault terminates in the North and is blocked by the Alpine-Hymalaian folds of the Turkish block. As the flow of the fault is not rectilinear, it produces a series of Graben like that of the Dead Bea. Locally even though in a compressed situation, the conditions produce a stretched effect that is favorable to the ascent of the saline diapirs, as seen with Mount Sedom. As you can see from the geologic section the diapir is overthrusting, due to the gravitational force

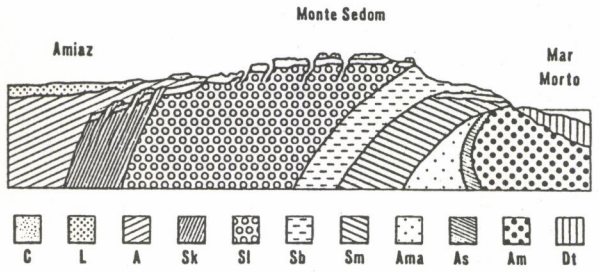




Sezione geologica della depressione del Mar Morto all'altezza del Monte Sedom.

Geologic section of Dead Sea depression including Mt Sedom.

Legenda: DEAD SEA GROUP: D = Dead Sea deposits, L = Lisan Formation, A = Amora Formation, S = Sedom Formation, LF = Pliocene Gulf deposits ("Lido Formation"). OLDER FORMATIONS: T = Tertiary, M = Mesozoic, P = Paleozoic, P^3 = Precambrians.



Sezione geologica del Monte Sedom.

Geologic section of Mt Sedom.

Legenda: C = "cap-rock", mainly anydrite, L = Lisan Formation, A = Amora Formation, Sk = Karbalet salt and shale, Sl = Lot salt, Sb = Benet Lot salt, Sm = Mearat Sedom salt, Amo = marl and anydrite, As = salt, Am = marl; marl, chalk and sandstone, Dt = superior part of "Terrace Deposit".

along the west side of the Dead Sea rift. The shape extends directionally North-South and this is due to the transcurrentmovement of the fault and to the consequent development of the stretched zones along the South-North axis.

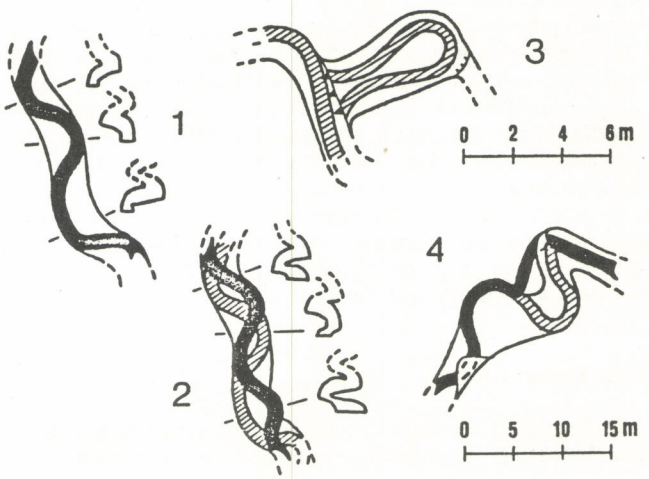
The other formations that Were over the halites have been fractured disarranged and brought up to the surface area by the ascent of the Sedom diapir to form the top side and the slopes of the Mount. The lithology that is present in the Sedom area is very differentiated and for convenience can be divided into two groups: the first group includes the lithotipes that form the diapir as a structural entity. The second group includes the formations that create the «cap-rock» that is to say the fractured rocks that have been crushed and dragged by the saltduring its ascent.

The salt oupcrops along some of the fault-mirror due to its strong solubility. The first group of lithotipes is composed of «Sedom Formation» and is divided into 5 members. They are mostly composed of rock-salt with some Anhydrite, leaving subordinate lithotipes like dolomites and marls. The «cap-rock» is composed of two formations: the Amora Formations and the Lissan Formation. The Amora Formation is composed of marls, gypsum, anhydrite, sandstone conglomerates and occasionally rock-salt. The Lisan Formation is predominately composed of chalk and marls. The Lisan Formation concludes the most recent sedimentary series of the Dead Sea.

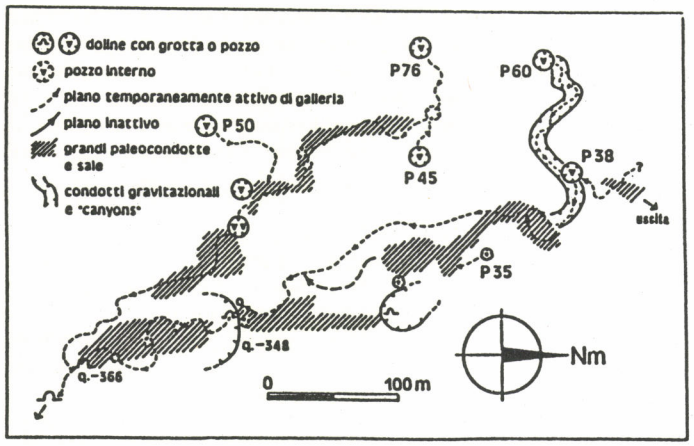
It has raised for the most part undisturbed by the diapir, While the Amora Formations has been strongly crushed during the ascent. Solution phenomena have produced impoverishment of the most soluble parts of the «cap-rock» and the formation of a salt-mirror at the top of the halite beds. The main tectonic lines that characterize Mt. Sedom taken from aerial pictures and then checked on the ground are the following: to the East there is a clear fault interpreted like a marginal fault of diapir that rises considerably at this part of the «dome» with respect to the surrounding terrains.

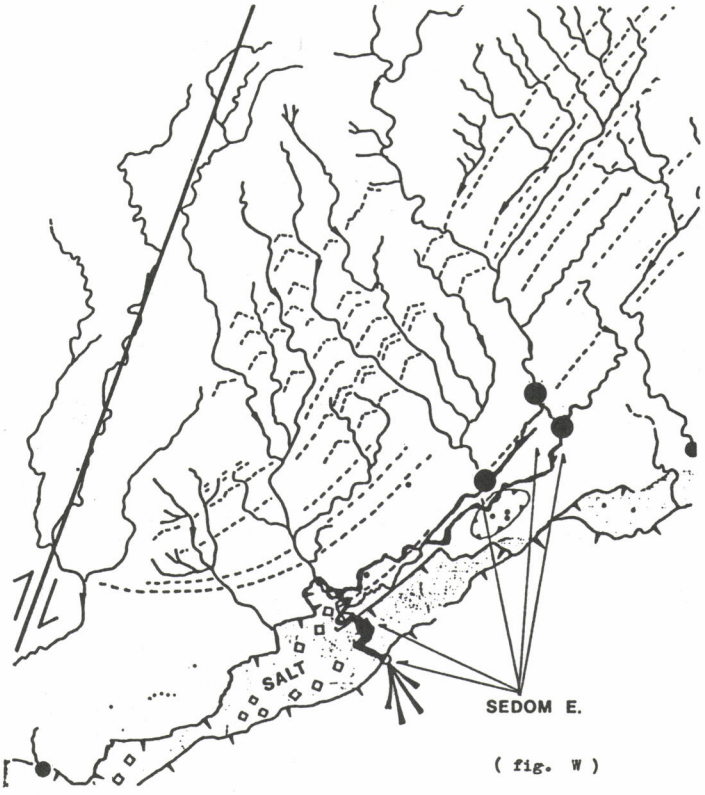
This is a very active fault and produces a fault slopes of 20-30 and sometimes even 40 metres with salt exposed lithotipes. Along the West side there are other subparallel faults that accentuate these areas; here the rising has been less intense and the overburden of the «cap-rock» and of the «Lisan Formation» is thicker so as to cover the slope of the main fault. To the North and South the structure of the margin of the diapir becomes complicated.

The «dome» has a very extended shape and consequently a series of radial faults in this sectors border the diapir crushing the various structural blocks. The radial faults are also intersected by a system of tangential faults that accentuate the diapir margin. The central part of the «dome» shows fractures with a North-South direction that repeat the motif of the two main hinges. At the same time they are intersected by a series of fractures and faults with an East-West and East-North East/West-North West direction. Locally this secondary system of faults is very important for the karst phenomenon. It's noticeable that the diapir to the Sedom is now rising approximately some mm. per year. This rising is more apparent in the center than over the flanks. The geologic section demonstrates how the «dome» has rised, showing the asymmetry between the East side, and the West side, the East side being more raised. This is due to the tectonic circumstance of the Dead Sea that with its consecutive subsidence of graben lined North-South, has favoured an asymmetric ascent of the salt along the West side of the depression. The source is situated at the base of the South-Eastern slope at q.-395 m, but the cavity presents another 14 entrances on the same slope. The scheme shows (fig. Y) the main morphological-functional characteristics of the cave where the following can be seen: two main branches active temporarily and confluent shortly before the source, that depend on the two shafts situated at 450 and 400 m from the source. They are the main alimentation points of the cavities. Some of paleogalleries and halls are situated at different heights in respect to the active level. A lot communicating shafts with the surface area and situated near the cavity axis. Inside the cave there are many different shapes. The most typical are: flat vault galleries, more or less deepened, cross sections for the possible evolution of «shelfs», winding movements with large loops of the conduit that show small and regular slope. Some parts of the gallery are partially or totally digged inside the alluvial filling that show a fossilization stage of the parts of the cave. In the palaeogalleries the sections are modified by clastic process. The structural or tectonic shapes are prevailing in some parts (faulted gallery, «squeezing» of rocky small blocks along the fractures). The most diffused deposits, in addition to the clastics, are the aeolian dusts, alluvions (the halite bottom of the galleries is never visible) and also the lithogenic deposits.



Evolution of a gallery due to the deepening and shifting of the loops in the river bed (fig. 1–2). Loops cutting (Malham and Cry Cave) (Fig. 3–4).





THE KEY IS THE SAME OF PAGE 7

Morfology

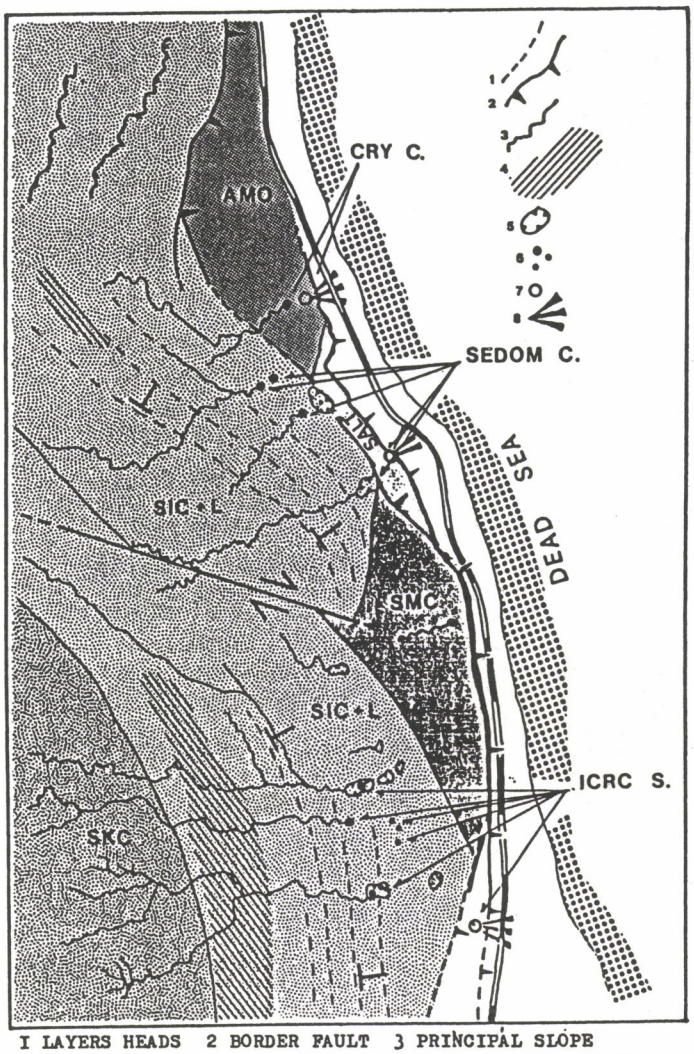
The M. Sedom morphology presents an high structural-lythologic control. The general shape of the diapir has a North-South orientation due to the ascent along one side of the graben of the Dead Sea. The morphostructural characters are very well preserved due to the dry climate. The modelling of the scenary is dominated by process of selective erosion, canyons and erosion furrows along the sides of the mount, whereas the top is subtabular with a series of absorbent fractures. Over the slopes develop the «bad-lands» and the rivers that have the tendency to move back to the diapir center. There are often capture phenomena due to the basins of restagnation-evaporation. These basins develop due to the differential erosion along some of the tectonic axis. Only the halites have karst potentiality during climatic conditions. The superficial karst shapes in the «cap-rock» are an effect of the speleogenetic below process. Therefore there is a tectonic origin, a collapse, an erosion and scarse solution for the superficial shapes.

Top Northern zone

This zone has two very steep slopes, that are cut by erosion furrows and has a level top. The basins of the rivers are very limited in the extension. The top has two lines of absorbent fractures with North-South direction along which open up many cavities of tectonic origin. They are crevasses part filled up with caved in cap-rock; sometimes they are connected with the solution shafts of the halites. The depth of these cavities is approximately 50/80 m. At the bottom of some of these cavities there is a trough with secondary saline crystallization. Only at the base of the «Liquid crystal cave» there is a lake of approximately 70 m^3. It has not possible to establish if the lake is due to the oscillations of the watertable level or to the accumulation of «fossil water». The longest subhorizontal cavity is the «Snake-cave» that captures a large superficial basin. The first part is tectonic and it is a meander. When the gallery reaches the halites there is a short shaft that is connected with a low, flat and sinuous gallery. In the North area there are some big shakeholes, and the biggest one is approximately of 70.000 m^3. At the bottom there is a large and low hall due to the collapse; with few morphologies of solution. Along the North slope of the diapir is very fractured, and there are many small cavities of tectonic origin.

South Eastern Area

To the South the diapir is larger and doesn't show a level top zone. To the S-E slope there are some of the N-S captured basins by the backing of the main grooves perpendicular to the structures. The catch basins are larger than to the North: some as much as thousands of m^2. The main incisions are blind and go into large shafts connected to the base of the temporarily active gallery planes with inactive levels. Here there is the Malham



I LAYERS HEADS 2 BORDER FAULT 3 PRINCIPAL SLOPE
4 COLLECTING BASINS 5 SOLUTION OR COLLAPSE SINKHOLES
6 SHAFTS 7 BASAL SOURCES 8 CAVITIES CONES

Cave or ICRC system that exceeds the 4 Km of lenght: the longest in the world digged in the halite. Another important cavity is the «Sedom Cave». The scheme (fig. W) demonstrates the relationship between the cavity and the tectonic structures. This cannot be verified in the morphology of the gallery. There are typical flat vaults, a lot of ceiling channels. The loops and the shelves on the slopes of the galleries are very well formed.

Genetic hypothesis

There are many factors that influence the karst genesis: Morphologic elements. The width of the drained basin is very important. Different stages can be seen: from simple tectonic cavity to the shafts of solution with circular/elliptical section, to the hydrogeologic tunnels and to the winding galleries. To the South the shafts cross completely the vadose zone whereas the galleries with a small slope develop near to the base level. ICRC, SEDOM, FELLAFEL, etc.

Structural elements.– It is clear that there is a very high structural control. If the shear is too intense, the collapses block potential conduits. The diapiric activity creates new draining ways and the destruction of the existent ways.

Lithologic elements.– The karst develops almost exclusively under the «cap-rock» (buried karst). The «cap-rock» thickness inhibits or enhances the speleogenetic process controlling the penetration of the waters. The insoluble debris cement to the bottom of the conduits delaying the solution of the bottom.

The long boiling time to dissolve the halitic cement of the sample, shows that it is very difficult to remove the deposits. A crust of sediments slightly erosible enhances the side erosion and the development of shelves by opposite loops. There are also longitudinal migrations of the loops with meander cuts. Due to the very high solubility of the salt there are not phreatic galleries on top of the base level. In the less active parts there are a lot of deposits of very fine dusts connected to the aeolian process and to the scarce humidity 48-63 % that inhibits the precipitation of the dust.

Climatic elements.– The aridity produces a selection over the absorbent areas. The collected waters the small basins will fill up the cavity and will enhance the cementation of the debris, while the largest basins will produce the excavation, the transportation and the distribution of the «cap-rock». The meteoric events are short but intense; they produce the development of the lateral loops due also to the kinetic energy of the waters.

This hypothesis justifies the strong convex shape of the surface of the shelves. The variations of the base level (Dead Sea) have produced at least one filling cycle of the eastern cavities. The fig. is a very symbolic picture of this phenomenon, it can be seen that the level variations due to the climatic differences are more important than those due to the tectonics effects.

Conclusion

The Mount Sedom existence is due to the balance between the tectonic force of the ascent and erosion.

The superficial lines are due to the selective denudation and erosion with a strong structural control. The karst is influenced by the drained waters that are quickly saturated, losing the solvent effect. Further information is required to understand totally this special karst.

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The Role of Sulfide Oxidation in the Genesis of Cesspool Cave, Virginia, USA

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RESUM

La cova de Cesspool és una cova de dimensions reduïdes, desenvolupada en travertins quaternaris dipositats per cursos d'aigua. Aquest dipòsit es troba situat al l'extrem oriental d'un sinclinal amb un nucli d'esquists negres als materials de la base de la paret de la falla St. Clair. La gènesi de la cova de Cesespool és el resultat de combinar la hidratació i l'oxidació del H_2S i la hidratació del CO_2. L'aigua saturada de calcita resultant conté 1,7 parts per milió (ppm.) de H_2S i 112 ppm. de SO_4^{2-}. Log PCO_2 és de –1,2, si bé va creixent endins la cova. Es van trobar també dos gèneres de bacteris oxidants de sulfurs, que actuaven oxidant el sulfur d'aquestes aigües. Un d'ells, Thiothrix, *es va observar a l'entrada de la cova; l'altre,* Beggiatoa, *fou localitzat aigües avall, associat a la interfase sediments/aigua de bassals i corrents d'aigua.*

RESUMEN

La Cueva de Cesspool es una pequeña cueva desarrollada en travertinos Cuaternarios depositados por cursos de agua. Este depósito está situado en el extremo oriental de un sinclinal con núcleo de esquistos negros en los materiales de la base de la pared de la falla de St. Clair. La génesis de la cueva Cesspool es el resultado de combinar la hidratación y oxidación H_2S y la hidratación CO_2. El agua saturada de calcita resultante contiene 1,7 partes por millón (ppm) H_2S, 112 ppm. SO_4^{2-} y las P_{C02} de–1,2 en donde crece dentro de la cueva. Se encontraron dos géneros de bacterias oxidantes de sulfuros que actuaban oxidando sulfuro en estas aguas. Se observó Thiothrix *ligado a la entrada de la surgencia, mientras que* Beggiatoa *fue encontrada aguas abajo, junto a la interfase de sedimento agua en los charcos y corriente.*

SUMMARY

Cesspool Cave is a small cave developed in stream-deposited Quaternary travertine. This deposit is situated on the east limb of a black shale-cored syncline in the footwall rocks of the St. Clair fault. The genesis of Cesspool cave is the combined result of H_2S hydration and oxidation and CO_2 hydration. The resultant calcite-saturated water contained 1.7 parts per million (ppm) H_2S, 112 ppm SO_4^{2-} and log PCO_2 of −1.2 where it rises into the cave. Two genera of sulfur-oxidizing bacteria were found to be actively oxidizing sulfide in these waters. Thiothrix *was observed attached to the spring opening, while* Beggiatoa *was found downstream near the sediment-water interface in the cave pools and stream.*

Introdution

Cesspool Cave is a small cave located in Alleghany County, Virginia (Figure 1). The cave has developed in one of four stream deposited Quaternary travertine buildups on Sweet Springs Creek. These buildups are the result of precipitation of calcium carbonate downstream from the carbonate-rich Sweet Springs and Sweet Chalybeate Springs. The first of the buildups occurs approximately 1.6 km downstream from Sweet Springs at Sweet Chalybeate Springs where Sweet Springs Creek crosses the contact between the Middle Ordovician limestones and the dolomites of the Beekmantown Formation of Lower Ordovician age (Butts, 1933). The second buildup occurs about 2.4 km farther downstream at the contact between Needmore Shale and the Ridgely Sandstone of Devonian age, on the overturned east limb of a black-shale-cored syncline in the footwall rocks of the St. Clair fault (Butts, 1933; T.M. Gathright, II, personal communication). This deposit, which is known as Sawmill Falls, contains Cesspool Cave. A third buildup approximately 0,8 Km farther downstreams is near the contact between the Brallier Shale and the Millboro Shale of Devonian age, (Butts, 1933) and is known as the Cascades. The final buildup is approximately 0,4 km farther downstream at the junction of Sweet Springs Creek and Dunlap Creek and is known as Beaverdam Falls.

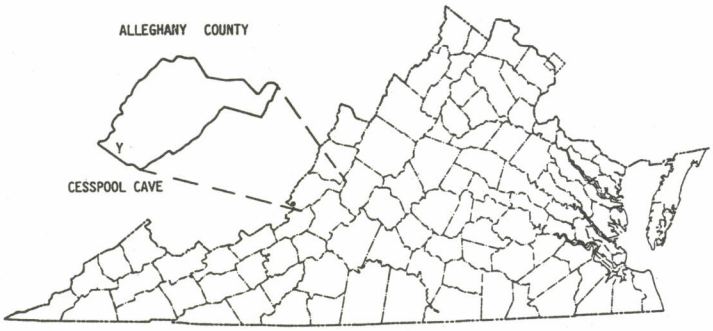

Figure 1. Location of Cesspool Cave in Virginia.

Cesspool Cave trends southward in the Sawmill Falls escarpment and has a maximum height of 6 m. The entrance to the cave is a stream-cut canyon approximately 3 m high and 1 to 2 m wide. This canyon has been partially obstructed by a soil slump as much as 2 m in height. The Cesspool stream flows out of the base of the east wall of the canyon approximately 4 meters from the dripline. Just inside the entrance is a room that contains a pool of water approximately 10 m in diameter and as much as 1 m deep. The ceiling of this room decreases in height to the west. Southward across the pool is a 6 m by 2 m fine gravel deposit. This deposit is a lag of carbonate and clastic pebble sediment wash off of a 12 m long by 3 m high hemidome of flowstone on the east wall. Water from the spring flows along the west margin of the gravel lag. The cave is approximately 3 m wide at the gravel bar. Southward the cave terminates across an 8 m diameter pool approximately o.5 m deep. The Cesspool spring occurs in the shadow of the flowstone dome. Circulation of the spring water is apparently in a clockwise direction around the terminal pool to the gravel channel.

The cave contains secondary flowstone travertine deposits typical of carbonate caves and primary travertine deposits of stream origin. In the terminal pool room, where flowstone deposition is not active, flowstone formations and walls are crusted with as much as 1 cm of gypsum. In the entrance pool room, corroded flowstone and primary travertine can be seen on upper ledges of the west wall and ceiling.

Hydrogen sulfide (H_2S) is found in the cave spring and its resulting stream. Oxidation of H_2S by chemical and biological processes appears to be important in the genesis of the cave. Biologic agents include representatives of three general of colorless sulfur bacteria: *Thiothrix, Beggiatoa,* and *Achromatium.*

Cesspool Cave appears to be a significant active example of contributory speleogenesis by H_2S hydration and oxidation. The processes occurring in this cave may be related to Hill's (1985) hypothesis of an H_2S-sulfuric acid speloeogenesis of the Guadalupe Mountain caves.

Methods

Three field trips for the collection of samples were made in February, April, and July 1985. Water samples were collected at three sites: Cesspool spring, the entrance pool and the outside stream aproximately 4 m downstream from the cave entrance.

At each site, samples for anion and cation analyses were collected in acid-washed 250-mL polyethylene bottles. Samples for alkalinity titration were collected in acid-washed 250-mL dissolved-oxygen bottles with ground glass stoppers. All samples were immediately placed on ice in coolers. Additionaly, a 100-mL sample was collected in an acid-washed polyethelene bottle for pH measurement.

Temperature and pH were determined in the field. Temperature was measured with a mercury-filled thermometer in the cave. The pH was measured for buffers and samples at air temperature at the mouth of the cave within 20 minutes of sample collection. An Orion model 211 portable pH meter and an Orion Ross combination electrode were used to measure pH (±0.02 units) after a two-point calibration.

Water samples for H_2S determination were collected using a glass syringe. The water was injected into serum bottles that had been previously evacuated with scrubbed nitrogen and sealed with butyl rubber stoppers. Samples of bacteria were collected in sterile containers from the cave stream in light and dark zones as well as downstream from the cave. Following the collection trip, bacteria were observed in the laboratory using a Zeiss standard model 14 microscope and phase contrast optics.

Immediately upon delivery to the laboratory, all samples for cation

Sample[1]	(HCO_3)	pH	T (°C	H_2S	Ca	Mg	Na	K	SO_4	NO_3	Cl
February 26, 1985											
C-1	464	6.81	12.4		179	15.3	5.6	5.1	123	0.12	11.2
Entr	459	6.75	11.3		171	14.8	5.4	5.1	126	0.15	10.8
C-2	450	6.78	10.9		181	15.0	5.2	5.0	127	0.15	11.0
April 8, 1985											
C-1	469	6.78	13.0		153	15.4	5.3	4.0	106	0.5	11.7
Entr	469	6.84	11.0		155	15.9	5.4	4.0	112	0.5	12.1
C-2	469	6.76	10.0		153	15.4	5.0	3.8	114	0.5	11.6
July 2, 1985											
C-1	390	6.96	12.5	1.70	166	16.6	5.4	4.6	112	0.5	10.3
Entr	392	6.98	13.0	1.53	168	16.5	5.3	4.6	112	0.5	10.7
C-2	391	6.97	13.0	0.17	166	16.6	5.7	4.4	115	0.5	10.5

[1]Sample locations: C-1: Cesspool spring, Entr: Entrance pool, C-2: aoutside stream; all units mg/L (ppm) unless otherwise noted.

Table 1. Chemical analyses of Cesspool Cave water samples.

and anion analysis were filtered through 0.45 μ m Millipore filters. A portion of the filtered sample was acidified with concentrated HNO_3. The acidified and unacidified samples were then refrigerated until chemical analyses could be performed. Duplicate alkalinity titrations were performed with 0.02 N Baker HCl on 50 mL of each sample within 24 hours of returning to the laboratory. Titration endpoints were taken to be the inflection points in the cumulative acid added vs. pH curve and were near pH = 4.3. Alkanity values were converted to HCO_3 which was assumed to be the only species contributing significantly to alkalinity.

The cations calcium, magnesium, sodium, and potassium were determined on the acidified samples by standard atomic absorption procedures using an Instrumentation Laboratories model 751 dual beam atomic absorption/atomic emission spectrophotometer. The anions sulfate, chloride, nitrate, and phosphate were determined by ion chromatography on a Dionex model 14 system. The H_2S concentrations were determined using Cline's (1969) colorimetric method. Chemical analyses were entered into a computerized equilibrium speciation model, and calculations of the saturation state of the water samples were completed.

Results

The results of the chemical analyses (Table 1) show that the groundwater is a Ca-HCo_3 type water with high SO_4^{-2} concentrations and near-neutral pHs. The three water samples taken along a flow path approximately 13 m long are quite similar in major ion chemistry for any given collection date. The only trends in the data are the slight increase in SO_4^{-2} concentration along the flow path for every trip and the order-of-magnitude decrease in H_2S concentration for the July trip (no H_2S analyses were performed on earlier samples).

	February			July				
	log P_{CO2}	SI_{cal}*	SI_{gyp}*	logP_{CO2}	SI_{cal}*	SI_{gyp}*	logP_{CO2}	SI_{cal}*	SI_{gyp}*
Cesspool spring	−1.25	−0.01	−1.20	−1.21	−0.08	−1.31	−1.47	0.04	−1.26
Entrance pool	−1.20	−0.11	−1.20	−1.28	−0.05	−1.28	−1.49	0.08	−1.26
Outside stream	−1.24	−0.07	−1.18	−1.20	−0.15	−1.27	−1.48	0.06	−1.25

$SI = \log \frac{\text{ion activity product}}{\text{equilibrium constant}}$

Table 2. Calculated results for water samples.

The results of the aqueous speciation calculations (Table 2) indicate whether the water is thermodynamically undersaturated (SI < 0) or supersaturated (SI > 0) with respect to various minerals. The February and April samples, taken when water flow was relatively high, are near equilibrium or slightly undersaturated with respect to calcite. The July samples, collected at low flow, were near equilibrium or slightly supersaturated with respect to calcite. All samples were significantly undersaturated with respect to gypsum. The calculated log PCO_2 values (Table 2) are all much greater than the normal atmospheric value −3.50.

Sulfur bacteria identified from samples included *Thiothrix* spp, *Beggiatoa* spp, and *Achromatium* spp. *Thiothrix* spp was found in the dark zone of the cave attached to travertine in the spring opening. *Beggiatoa* spp was found in the entrance pool and the stream outside the cave. *Achromatium* spp was also found in the entrance pool. *Beggiatoa* and Thiothrix *are filamentous gliding bacteria from one to more than 25 μm wide and form long sheaths that move by gliding.* Achromatium *is a large ovoid cell measuring from 5-100 μm.*

Discussion

The alkalinity and pH data in Table 1 indicate that carbonate mineral dissolution by CO_2-charged waters is occurring upstream from the spring. In fact, the degree of saturation in such that precipitation of calcium carbonate might be expected on outgassing of CO_2 in the cave if the high sulfate concentration were not inhibiting this process.

The H_2S concentrations measured in the spring indicate that the acidity upon dissociation of H_2S has a degree of importance in the dissolution of carbonate minerals upstream from the spring. Within Cesspool Cave three genera of colorless sulfur bacteria are actively oxidizing reduced sulfur species. As the bacteria oxidize H_2S, the pH of the water decreases, thus increasing the ability to dissolve travertine. This acidity may be responsible for the low-ceiling extension of the entrance pool room to the west. During the February and April visits white filamentous networks of colorless sulfur bacteria were abundant in both the terminal and entrance pools. The population of these organisms had declined during the July visit and consisted mainly of coatings on leaves and other debris in the entrance pool and outside stream. The H_2S concentrations showed that H_2S decreased by and order of magnitude from the entrance pool to the outside stream. The reason for the large fluxuations of bacterial populations is unknown but may be related to changes in the H_2S/O_2 gradient.

Cave atmospheric H_2S may be responsible for the uniforme degree of corrosion of flowstone and primary travertine observed in Cesspool Cave. In the terminal pool room the extensive crusts of gypsum could have been deposited by evaporation of sulfate rich waters at the solid-air interface, however gypsum crusts on flowstones are not commonly observed in other caves. A second hypothesis for the development of the gypsum crusts is that dew deposited on the cave walls and formations by variations in temperature and humidity could be absorbing H_2S. The resultant dissociation of H_2S is acidic, and dissolves the travertine and precipitates gypsum ($CaSO_4$) on evaporation.

The source of the H_2S is unknown. Possibilities include biological or chemical genesis by sulfate-reducing bacteria, dissolution of metastable iron-sulfide minerals, or degradation of organic matter. Sulfate concentrations are typically high in the region, e.g., Sweet Springs and Sweet Chalybeate Springs as well as Cesspool spring. Sulfate-reducing bacteria could be converting sulfate within the Cesspool spring aquifer. Dissolution of metastable iron-sulfides such as mackinawite (FeS) or greigite (Fe_3S_4) in black shales could produce H_2S. Black shales physically underlie the site due to folding. Migrating waters from the synclinal shale core could account for the H_2S. Organic compounds are found locally in the black shale units and the Helderberg limestone. Degradation of this organic material could also yield H_2S.

Acknowledgement

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Speleogenesis in Newsome Sinks, Alabama, USA

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RESUM

Newsome Sinks és una vall tancada de 6 Km., desenvolupada en un altiplà de calcàries massives del Mississipià, recobertes d'una capa d'arenisca del Pensilvanià. S'han topografiat més de 40 cavitats d'aquesta zona. L'existència d'una falla, la direcció de la qual coincideix amb l'eix de la vall, ens indica que l'espeleogènesi es va iniciar quan es va fracturar el nivell d'arenisca. La cova de Black Walmut presenta una cavitat de dissolució plena de sediments per sota de l'arenisca i en tot el recorregut de la falla. En un nivell inferior del conjunt de la cavitat, un complexe enterrat de galeries ens indica un període d'escàs cabal d'aigua. Els «cañons» que es troben ben bé a sota d'aquest entramat són senyal inequívoca d'un període subsegüent de major cabal. Les galeries principals, pròximes a la base dels «cañons» ens indiquen un drenatge posterior més estable. El nivell de base actual es troba tant sols uns metres per sota. La cova de Newsome ens ofereix un exemple de la interelació entre els procesos tectònics i els de dissolució en l'espeleogènesi.

RESUMEN

Newsome Sinks es un valle cerrado de 6 km. desarrollado en una meseta de calizas masivas del Mississipiense, sobre las que hay una capa de areniscas del Pensilvaniense. Se han topografiado más de 40 cavidades en esta zona. La existencia de una falla cuya dirección coincide con el eje del valle implica que la espeleogénesis se inició cuando se fracturó el nivel de areniscas. La cueva de Black Walmut posee una cavidad de disolución rellena de sedimentos debajo de las areniscas y a lo largo de la falla. En un nivel inferior del conjunto de la cavidad, un complejo enterrado de galerías indica un período de escaso caudal de agua. Los cañones que se encuentran inmediatamente debajo de este entramado implican un período subsecuente de mayor caudal. Las galerías principales, cercanas a la base de los cañones indican un drenaje posterior más estable. El nivel de base actual se encuentra sólo unos metros por debajo. La cueva de Newsome ofrece un ejemplo de la interrelación de los procesos tectónicos y de disolución en la espelogénesis.

SUMMARY

Newsome Sinks is a six kilometer landlocked valley developed in a plateau of massive limestones of Mississippian age capped by a Pennsylvanian age sandstone. More than forty caves have been mapped in it. The existence of a fault whose strike coincides with the valley axis implies that speleogenesis began because the sandstone cap was breached. Black Walnut Cave has a sediment filled solutional void just below the sandstone and along the fault. At a lower elevation in the cave system, a network pattern of passages, suggests a period of low-gradient flow. Canyons found immediately below this network imply a subsequent period of higher gradient flow. Trunk passages near the base of the canyons indicate a later, more stable drainage. Present base level is only a few meters lower. The Newsome Sinks cave system provides an example of the interplay of solutional and tectonic processes in speleogehesis.

1. Location

Newsome Sinks is the name of a landlocked valley developed in a relatively level, sandstone-capped, limestone plateau named Brindley Mountain. Rain runoff that drains into Newsome Sinks from the surrounding plateau immediately goes underground into numerous dolines, locally called sinks. Some 30 such dolines are shown on the 7.5 minute series topographic map published by the U.S. Geological Survey and many more exist, but are too small to show on this scale map. The floor of Newsome Sinks averages about 230 m above sealevel. The level of the nearby Tennessee River and tributary creeks is at about 183 m.

An extensive system of caves is associated with these surface features. More than 40 caves are recorded in the Alabama Cave Survey, (1) and described individually (2).

2. Geology

The Cumberland Plateau is a inland, flat-bedded highland paralleling the Apalachian Mountains in the eastern part of North America. Brindley Mountain, containing Newsome Sinks, is a dissected piece of the southern end of this plateau. It consists primarily of Paleozoic, Carbonniferous, limestone rocks of Mississipian age. The limestones are capped by a Pennsylvania age sandstone layer. In the Brindley Mountain area, the average dip is a very gentle 1:85 to the south-south-east, (3). Therefore, local geological features can and do cause variations in the dip that are large enough to reverse the dip over a short distance. The Tennessee River is just north of Brindley Mountain, but streams on the mountain tend to flow south, down dip, away from the river. In the Newsome Sinks area, both surface and underground flow goes south until it joins a larger creek that cuts back north to the river.

Most of the caves are developed in the thickly bedded limestone layers called the Bangor Formation. A few are in the overlying Pennington Formation which consists of thinly bedded limestones with many thin chert, shale, and sandy limestones layers. The sandstone cap is known as the Pottsville Formation, and generally forms bluffs up to 15 m high at the edges of Brindley Mountain, including all but the southern boundaries of Newsome Sinks. Except where breached, the Pottsville Formation is impervious to water.

3. Field Observations

The strike of a principal fault (or zone of faulting) coincides with the geometrical axis of the main Newsome Sinks Valley, Fig. 1, (4). The most southerly clear exposures of the fault are in the walls of two dolines, named Fault Sink and Shine Sink. Measurements at these exposures show that this is a normal fault with strike 345° ± 5°, dip 67° ± 5° from horizontal, and with a 4.5 m displacement, east side lower than the west. Slickenside striations parallel to the dip seem to be present. Shine Cave lies between these two dolines and is just west of the fault. Breakdown

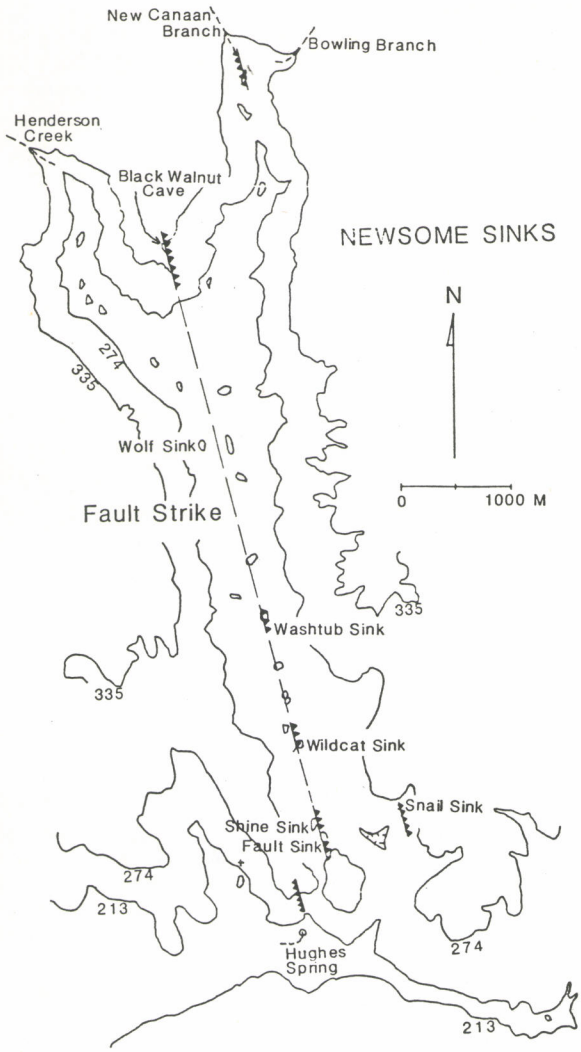


Figure 1. Newsome Sinks showing the locations of faults and their strikes. Contour elevations are in meters.

terminates the cave on the southeast where it approaches the fault plane.

Just north of Shine Sink, passages in Chapel Cave cross the northward projection of the fault strike, and the fault is present where projected. The main fault is accompanied by a companion having the same parameters but offset 10 m to the west, and with only a 0.3 m displacement. A passage carrying water from the east is a high canyon until it reaches the main fault, after which it continues westward as a solution passage 1 m wide and 3 m high. This passage turns southward along the companion fault for 13 m and the continues westward. At Wildcat Sink, one of the three Chapel Cave entrances, the fault is present. It was measured in a room just inside the cave and has the same characteristics previpusly noted.

When the fault strike is projected farther north, it intersects Washtub Sink and Cave. The fault is clearly present within this small cave. The measured displacement is 1.2 m. Appearances in the doline and leveling across it suggest that other parallel fault displacements are present. One is a few meters west of that measured in the cave and the other is 15 m east of it. The sum of these displacements would imply a total comparable to that measured farther south.

Even farther north, some 3 km of passages in Turtle Cave lie west of the fault, but passages or rooms terminate in breakdown when they approach the fault plane. Bullfrog Cave lies east of the fault with similar characteristics. Likewise, Mikes Wolf Cave, yet farther north, is just west of the fault.

Finally, where the projected fault plane leaves Newsome Sinks Valley, it is at least partly exposed in Black Walnut Cave, (5). The observed displacement is 1.0 m and the dip is 69° ± 5° to the east. This is a small cave immediately under the sandstone cap. A former cave passage or room, now completely filled with sediment, is exposed where the present cave crosses the relic cave. The fault plane passes through the relic passage on both its south and north sediment faces. The sediment shows some displacement where the fault passes through it. The distance between Black Walnut Cave and Fault Sink is 4.3 Km. Over this base, the fault strike is 345° ± 2.°.

A few other normal faults are known in Newsome Sinks. One is in a rock face above the wet-weather streambed going south to Hughes Spring, Figure 1. Its parameters are roughly: strike 340° dip 70° to the west, and displacement 2 m. Hughes Spring is the resurgence for the great majority of Newsome Sinks valley (6).

Still another fault was measured in the New Canaan Branch of the northeastern arm of Newsome Sinks. The 4.6 m displacement is between the two steep walls of the branch just above where it reaches the valley floor. The west side is lower than the east. The strike and dip are not unabiguously determined, but the strike seems to coincide with the geometrical axis of the northeastern arm, i.e. 349°. A further small fault is exposed in Snail Sink, near the south end of the valley (Fig. 3). Its parameters are approximately: strike 358°, dip 71° to the east, and displacement 0.6 m.

A feature common to many of the larger caves is a zone of horizontal passage development above a zone of canyon passages and a further zone of horizontal development at the base of the canyons, (7). In Wolf Cave and Mikes Wolf Cave, for example, the upper zone corresponds to an extended set of maze passages. Only a few domes and canyons seem to connect to the maze from above. The canyon zone below the maze has a typical vertical extent of perhaps 20 m.

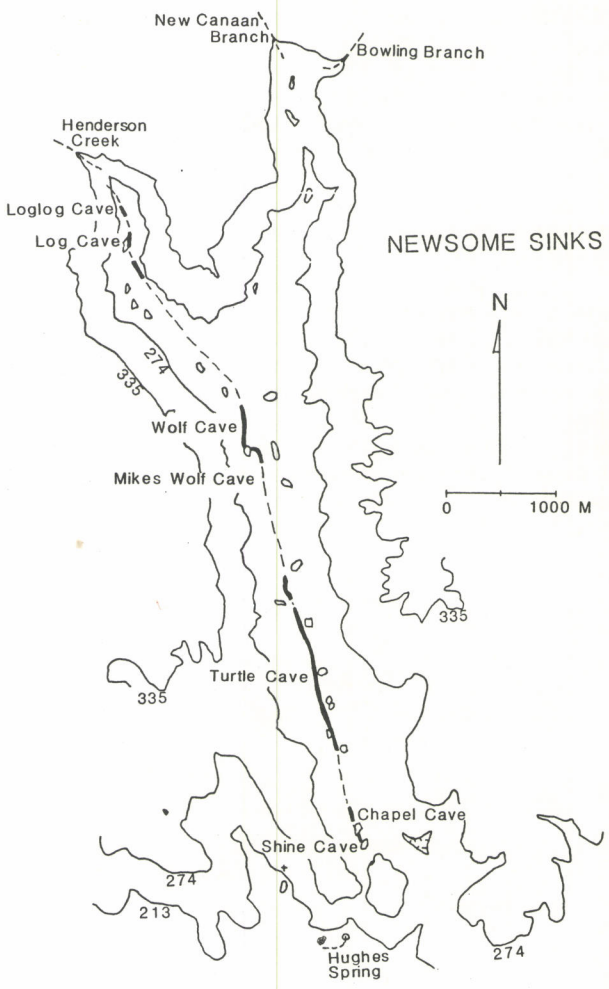


Figure 2. Newsome Sinks with solid lines depicting segments of trunk passage. Broken lines show the hypothetical original passage.

The horizontal development at the base of the canyons includes a sequence of abandoned trunk passages (Fig. 2). Characteristic cross sections are 10 m × 10m. These segments often are aligned, but are interrupted by collapse dolines. For example, the main room in Shine Cave and the large Sky Room in Chapel Cave are separated by Shine Sink. Similarly, segments of trunk in Wolf and Mikes Wolf Caves are separated by Wolf Sink. Thus a sequence of dolines follows the course of the abandoned trunk as indicated in Fig. 2. In Wolf Cave and Mikes Wolf Cave, the trunk itself has the character of a large canyon reaching up to the maze level. However, this is not typical of the situation to the south.

The trunk seems to have no geometrical relationship to the faults. The course of the trunk and the principal fault may cross at Fault Sink, but that is conjectural because the trunk has not been found south of Fault Sink. In general, little tendency exists for major passage development along the fault.

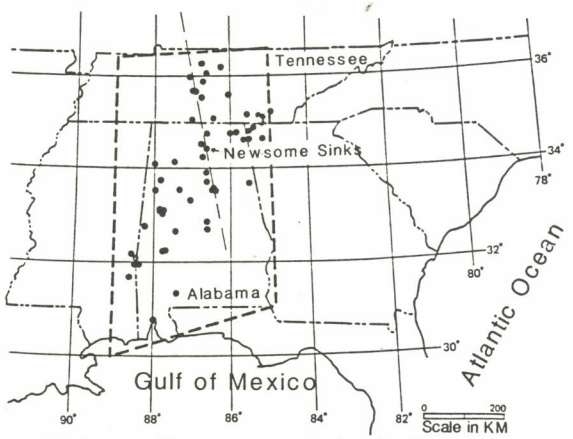
The present base level drainage must be only some 20 below the abandoned trunk, because Hughes Spring is at 177 m elevation and the trunk floor in Shine Cave is at about 197 m. To date, exploration in the Newsome Sinks Caves has failed to find access to the present main drainage channels.

4. Speleogenesis

The observations of the previous section can be interpreted to yield an outline of speleogenesis in Newsome Sinks. This is an example of a relatively rudimentary interplay of solutional and tectonic influences. The first conclusion asserts that the caves and the valley itself began development where faults breached the sandstone cap. Water could then reach the underlying limestone and begin solutional processes. This is the best explanation for the coincidence of the principal fault and the geometrical axis of the valley. It also explains the apparent coincidence of the fault in New Canaan Branch and the axis of the northeast arm of Newsome Sinks.

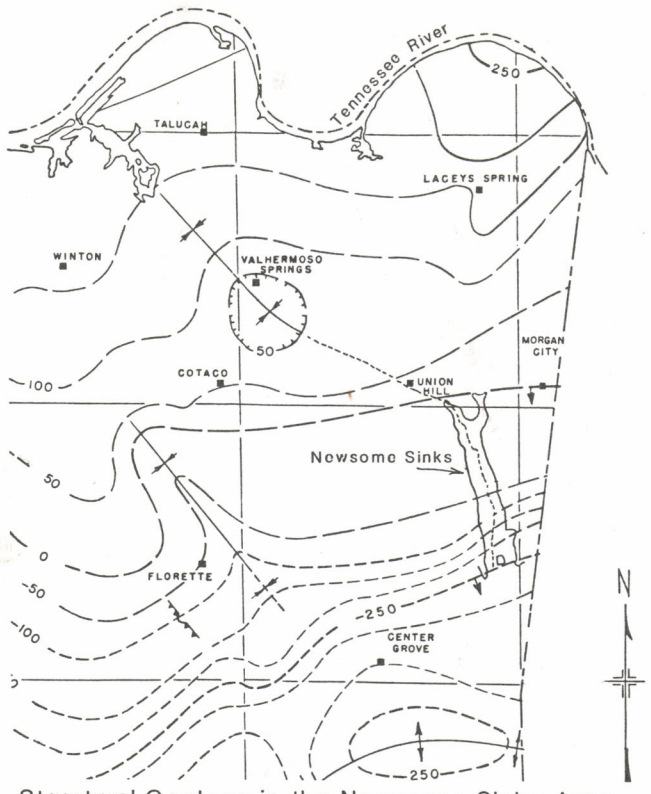
Some early caves formed immediately under the breached sandstone, as shown by the sediment filled relic in Black Walnut Cave. While this conclusion is based on a single observation, the principal fault now intersects the sandstone cap only at this site in Newsome Sinks. All other evidence has long since been removed by erosion.

The active faulting process continued at least for some time into the cave formation period. Thus the passage in Black Walnut Cave had to be formed, abandoned and refilled sediment prior to the tectonic episode that generated an observed displacement in the sediment. Clearly each displacement event could offer new drainage options or local dip changes that could influence subsequent cave development. There is no obvious evidence for very recent faulting, although the approximate coincidence of the fault with the active Alabama-Tennessee seismic zone (8) is suggestive (Fig. 3). Recent small earth-quakes have had



Alabama-Tennessee Seismic Zone

Figure 3. Alabama-Tennessee seismic event locations adapted from Ref. 8. A line extended from the axis of Newsome Sinks is added.



Structural Geology in the Newsome Sinks Area

Figure 4. Structure map of the Newsome Sinks area adapted from Ref. 2 showing contours of the top of the Chattanooga shale (in feet). An outline of Newsome Sinks and the hypothesized subsurface drainage have been added.

epicenters whose circles of uncertainty include Newsome Sinks. The most recent was in 1981.

Evidence of speleogenesis in the interval between void formation under the sandstone and development of the maze levels has largely been eroded away. But in Mikes Wolf Cave, the situation above the maze can be studied and it is evident that was not an earlier maze that evolved slowly downward. The same is true in the other caves where the issue can be examined.

The maze level of horizontal development can be interpreted as the result of an extended period of constant water level. That period seems to have been followed by rapid lowering of the water base level, producing a period of steeper gradients and canyon cutting. This abrupt water level drop is consistent with a hypothetical diversion of a gentle southward drainage. This drainage capture by Cotaco Creek, a northward flowing tributary of the nearby Tennesse River would have produced a steeper gradient. It is improper, of course, to assert that any given canyon was necessarily cut during any particular period, since the process continues today, but it does seem clear that the canyon development had to follow the maze period.

The most prominent feature at the base of the canyons is the now abandoned and segmented trunk. Establishment of an efficient drain for the system, probably a surface spring, is a likely requirement for the trunk to form. An ample source of water is also necessary. The most northern known segment of the trunk is found in Logrog Cave. Already the trunk has virtually the same size as it has farther south, suggesting that the principal water source was still farther up stream. The course of the trunk seems to be that expected from down dip drainage out of the Valhermoso Springs syncline (Fig. 4).

Perhaps the initial establishment of the trunk at a new low level was the immediate cause of the canyons.

The many dolines that give Newsome Sinks its name are also an important aspect of late stages of speleogenesis. Two significant subsets exist. One subset embraces the dolines caused by collapse into the abandoned trunk. Their occurrence is a very normal process that often divides a long trunk into segments that become individual caves entered trough new entrances in the dolines.

The collapse dolines along the faults are another subset. They occur where tributary stream passages cross a fault. The preexistence of a fault presumably weakens the roof and promotes collapse. An actual tectonic displacement in the roof of a passage subsequent to its formation would be very conducive to collapse, if such events happened.

Even when dolines are not involved, the presence of a fault often is responsible for local breakdown that blocks cave passages. Thus a number of instances were mentioned, in which breakdown constrains a cave to one side or the other of a fault. Perhaps some of these caves formed on only one side because the fault diverted the drainage downward so that solution did not continue beyond the fault plane.

A more tenuous consequence of faulting is the effect on the local dip of the geological formations. If down dip water flow has an important role in speleogenesis, then a change in dip could have an effect. It has not been possible to evaluate this phenomena in the Newsome Sinks, but is should not be discounted either.

Finally, some conjectures can be made about present speleogenesis. Certainly cave generation continues. The current situation does not seem to be one in which the main Hughes Spring stream is cutting a canyon, although many tributaries continue to do so. The situation would seem to be either development of a new lower trunk or formation of another maze level.

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Thresholds in Speleogenetic Processes

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RESUM

Els paisatges de coves originats per plans d'estratificació, fractures o disjuntures d'estrats plans, superen tres umbrals durant la seva evolució, des de les fractures permeables fins als conductes totalment desenvolupats:

1.– Umbral hidràulic: el fluxe de fractures és laminar, en una primera aproximació. La transició a un fluxe turbulent es produeix per als números de Reynolds 5-100, que corresponen a una obertura de 0,5 a 5 cm., a gradients hidràulics normals.

2.– Umbral de transport: És condició necessària per al desenvolupament del drenatge intern, la capacitat del sistema de transportar sediments clàstics, a fi i efecte que els sòls i els residus insolubles puguin ésser desplaçats. Les velocitats requerides per al transport dels sediments clàstics s'aconsegueixen, aproximadament, per a una obertura en què el fluxe esdevé turbulent, depenent de la càrrega de sediments i del tamany de les partícules.

3.– Umbral cinètic: El conducte sofreix sovint un procés de dissolució al llarg d'una via preferent a través de l'aqüífer. La major part de les aigües d'aquest conducte són sub-saturades. La cinètica de dissolució dels minerals carbonatats no és lineal i la resposta no lineal permet de seleccionar un camí hidràulic crític, a més dels possibles camins inicialment disponibles.

Els tres umbrals es donen per a la mateixa obertura, que marca també una ruptura entre la permeabilitat de la fractura i la del conducte, i entre la fase d'iniciació del desenvolupament de la cavitat i la fase d'eixamplament en el desenvolupament de la mateixa.

RESUMEN

Paisajes de cuevas originados por planos de estratificación, fracturas, o disyunturas en estratos planos. Estos superan tres umbrales durante su evolución, desde las fracturas permeables hasta conductos totalmente desarrollados (1) Umbral hidráulico: el flujo de fracturas es laminar en una primera aproximación. La transición a un flujo turbulento se da para los números de Reynolds 5-100 que corresponden a una apertura de 0,5 a 5 cm. bajo gradientes hidráulicos normales (2) Umbral de transporte: Es condición necesaria para el desarrollo de drenaje interno, la capacidad del sistema de transportar sedimentos clásticos para que los suelos y residuos insolubles puedan ser movidos. Las velocidades requeridas para el transporte de sedimentos clásticos se alcanzan a aproximadamente la misma apertura para la que el flujo se convierte en turbulento, dependiendo de la carga de sedimentos y el tamaño de las partículas (3) Umbral cinético: El conducto sufre disolución frecuentemente a lo largo de una vía preferente a través del acuífero. La mayor parte de las aguas de este conducto son subsaturadas. La cinética de disolución de los minerales carbonatados no es linear y la respuesta no linear permite seleccionar un camino hidráulico crítico a parte de los posibles caminos inicialmente disponibles. Los tres umbrales se dan para la misma apertura que marca también una ruptura entre la permeabilidad de fractura y la de conducto y entre la fase de iniciación del desarrollo de la cavidad y la fase de ensanchamiento en el desarrollo de la misma.

SUMMARY

Cave passages originate from joints, fractures, or bedding plane partings. These pass three thresholds during their evolution from fracture permeability to fully developed conduits. (1) Hidraulic Threshold: fracture flow to a first approximation is laminar. The transition to turbulent flow occurs at Reynolds numbers of 5-100 corresponding to an aperature of 0.5 to 5 cm under usual hydraulic gradients. (2) Transport Threshold: A necessary condition for the development of internal drainage is the ability of the system to transport clastic sediment so that soils and insoluble residue can be removed. Velocities required for clastic sediment transport are reached at about the same aperature where flow becomes turbulent depending on sediment load and particle size. (3) Kinetic Threshold: The conduit is preferentially dissolved along a prefered route through the aquifer. Most conduit waters are undersaturated. The dissolution kinetics of carbonate minerals is non-linear and the non-linear response allows the selection of a critical hydraulic path out of the total set of possible paths initially available. All three thresholds occur at about the same aperature which then marks a boundary between fracture permeability and conduit permeability and between the initiation phase of cave development and the enlargement phase of cave development.

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On the forming mechanism of the gigantic caves and steep peaks

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RESUM

L'autor efectua un estudi detallat de les relacions entre els tipus genètics estructurals, propietats físiques i mecàniques, acció diagenètica i deuterogenètica de les roques carbonatades en el mecanisme microcorrosiu del desenvolupament del carst, així com de les formes dels «peaks» aïllats en el «peak forest plain» prop de Guilin.

L'autor creu que la formació de cavitats gegants i de «peaks» escarpats depèn, no solament del grau de corrosió i de la intensitat de la carstificció, sinó també de la tolerància del procés de casrtificació per part de les roques.

RESUMEN

El autor efectúa un estudio detallado sobre las relaciones entre los tipos genéticos estructurales, propiedades físicas y mecánicas, acción diagenética denteragenética de rocas carbonatadas y desarrollo del karst, en el mecanismo microcorrosivo y las formas de picos aislados en las principales rocas carbonatadas y el grado de cavitación de picos aislados en los «peaks» de la llanura forestal cerca de Guilin.

Al autor le parece que la formación de cavidades gigantes y picos escarpados dependen no solamente del grado de corrosión e intensidad de karstificación, sino también de la tolerancia de karstificación de las rocas.

SUMMARY

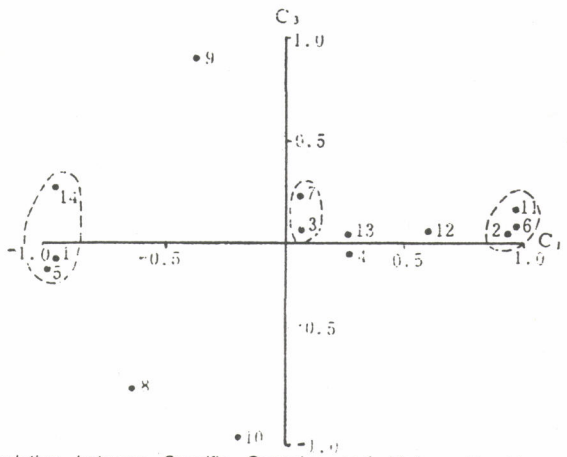
The author makes a detailed study on the relationship between textural genetic types, physical mechanic property, diagenetic deuterogenic action of carbonate rock and develpment of karst, on the micro-corrosional mechanism and the forms of isolated peaks of main carbonate rock and the cavitation degree of isolated peaks in peak forest plain near Guilin.

It seems to the author that the formation of gigantic caves and steep peaks depends not only on the corrosion rate and karstification intensity, but also on the supportability (or property) of the karstification rock bodies have. From this viewpoint, the author believes that the sparry allochemical limestone is the most favourable to form the gigantic caves and steep peaks. Such kind of corrosional mechanism is known as expanded-corrosion.

The mechanism of the formation of gigantic caves and the steep peaks is proposed after making a comprehensive investigation on the corrosional rate and the micro-corrosional features of main carbonate rocks, karstic topographic features and the caving degree of isolated peaks in Fenglin (peak forest) plain near Guilin.

1. Main factors affecting the corrosion rate of carbonate rock

Based on the corrosion test data of carbonate rock samples near Guilin, the author has studied the correlation between corrosion rate and thirteen variables such as composition, textural component and physical-mechanical properties etc. of rock, by using R-type factor analysis. All the data obtained are treated by electric computer. The result is shown in Fig. 1.



Correlation between Specific Corrosion and Various Variables (with Main Components C_1 and C_3 as Coordinate Axis)

It shows a close positive correlation of corrosion rate(14) with calcite (5) and CaO (1), a negative correlation with dolomite (6), MgO (2) and crystal grain (11), and little or no correlation for micrite (9), allochem (8) etc.

Thus it is clear that under identical water liquid and temperature, the main factors that affect the corrosional rate are, petrographically, first the composition, and next the textural components, in which micrite and allochem are dominant.

2. Micro-corrosion features of the main carbonate rocks

In order to further study the corrosion mechanism, binocular microscopy and scanning electron microscopy have been made of the corrosion surface of each smaple (with the photos omitted).

(1) Corrosion of dolomite takes place primarily along intercrystal pores or contacts between crystals. As a result of corrosion, crystal bodies often fall off.

(2) Corrosion of bioherm limestone takes place chiefly between individual organisms to form fissures or along the margin of organism bodies to form honeycombed cavities.

(3) The corrosion surface of samples where calcite and dolomite co-exist sags where calcite occurs and rises where dolomite is present. In the same sample, merely relatively shallow solution holes are formed on the crystal surface of dolomite, while calcite is coroded along clavage or jointing plane of crystal bodies to form residual corrosion cones. That is to say, the corrosion rate of calcite is larger than that of dolomite under the same conditions (4).

(4) All the micrite matrixes in micrite allochemical limestone are depressed, and all its allochem are slightly protruding.

(5) There is no marked difference in corrosion rate between sparite and allochem in sparry allochemical limestone, with only a faster corrosion mainly along their contact. Sparite slightly projects up and micrite slightly sinks down when both are present. In micrites the coarse components rise slightly above the finer ones. And corrosion is more marked along intercrystal boundaries or cleavage in sparry calcite.

(6) The corrosion surface of micrite limestone is generrally more even and smooth, sometimes accompanied by smooth solution holes. Even corrosion often takes place between crystals of micrite calcites as can be seen with a magnification.

3. Characteristics of karstic topography of the main carbonate rock types.

Carbonate rocks of different textural genetic types not only heve respective microscopic corrosional features, but also show different karst topographic characteristics in the field.

(1) En masse karstification of dolomite: Dolomite is subject to corrosional dissociation (1) and mechanical disintegration giving rise to en masse karstification to form gentle low hill with a tchick dolomite powder cover. In this kind of dolomite cave is rare, depression and funnel are less deloped, but samll springs often appear along its border.

(2) Corrosional collapse of bioherm limestone: The more porous and permeable bioherm limestone, as having a larger corrosion rate, often forms relatively homogeneous pore aquifer (2). On the other hand, its inhomogeneous composition and texture, often lead to collapse after intense karstification. And the resulting disruption of strata in the reef proper, makes it difficult to form gigantic caves and isolated peaks (3).

(3) Topographic features of micrite limestone and micrite allochemical limestone: In such kind of rocks, the thickness of a single layer and of continuous layers is small, joints and cracks, relatively closely spaced, mostly terminate at short distances, due to the constraint of bedding. As a result, atmospheric water flow and corrode mainly along the bedding plane or mountain slope, usually forming grooves on the bedding plane. Horizontal or horizontal-undulated corrosional fissures, developed along bedding or srylolite seam, are more common. Fissures normal or ablique to the bedding are seldom seem to cut them. Caves are always inclined, open, low and short, because their development is controlled by stratification. The mountain form depends on the dip angle of the layers: Gentle pyramidal– or screw-like peaks form at a dip angle 10°-20°, and cuesta results, when the dip reaches to 20°-30° (5).

(4) Topographic characteristics of sparry allochemical limestone: In such of limestone, the thickness of a single layer and that of continuous layers become larger. There develop two sets of vertical conjugate joints or fissures, which extend lengtwise to relatively longer distances. Atmospheric water permeates mainly along vertical joints or fissures, resulting in dominantly vertical corrosion. Corrosion lines or traces at right angles to the bedding are developed. Corrosion lines, often formed along two sets of joints or cracks, are further widened to form two sets of mutually perpendicular or ablique discontinuous corrosion fissures. Widening of corrosion lines on the bedding plane leads to the formation of corrosion grooves or a swarm of holes. Stone teeth occur where corrosion grooves or a swarm of holes. Stone teeth occur where corrosion grooves concentrate. The outer slope of the mountain would break down under gravity at a certain extent of corrosion, to form a cliff. The corroded mountain is generally bucket– or screen-like, steeper in slopes. The resulting caves, as often controlled by joint or fault, generally resemble a gallery or hall.

(5) Corrosion of a mountain composed of an overlying sparry allochemical limestone and an underlying dolomite or micrite allochemical limestone comonly result in a «caprock», populary known as a capped mountain, with a towering precipice over the gentle slopes. Small caves often develop at the border of these two kinds of rock.

4. Caving degree of isolated peaks in Fenglin (peak forest) plain

In an area of 550 km^2 near Guilin there are 263 isolated peaks in the peak forest plain. According to the statistics, the rock types forming them are as follows (Table 1).

Table 1
Rock Types of Isolated Peaks in the Peak Forest Plain

Rock Type	Number of Isolated Peak	Percentage
Dolomite	9	3.41
Micrite allochemical limestone	32	12.12
Sparry allochemical limestone	172	65.15
Microsparite limestone	50	18.94

It can be seen from the table 1, that the isolated peaks in the peak forest plain near Guilin consist dominantly of sparry allochemical limestone. The caving degree (surface karst rate) for 74 of these peaks is shown in Table 2.

Table 2
Caving Degree of Mountains Composed of Different Carbonate Rock Types

Rock Type	Number of Mountain	Mountain Area M(km^2)	Number of Cave	Number of Cave Entrance	Cave Length L(m)	Cave Area S(m^2)	Caving Degree K=S/M×100%
Micrite allochemical limestone	21	3.091	71	101	3745.4	27901.3	0.90
Sparry allochemical limestone	43	2.337	182	263	13460.4	92803.0	3.97
Microsparite limestone	10	1.352	25	34	2617.2	40363.5	2.99

It shows that under the same allogenic water conditions, mountains composed of sparry allochemical limestone are four times more caved than mountains composed of micrite allochemical limestone. But the latter type of mountains covers, on the average, an area 2.72 times that of the former. Mainwhile, the caving was found to govern the slope of the mountains: the more caved the mountain, the smaller the area and the steeper the slope.

5. On the mechanism of formation of gigantic caves and steep peaks

It can be concluded from the above that: (1) Composition of rock is the main factor that affects the corrosion rate. For example, limestone has a higher corrosion rate than that of dolomite under the same conditions. But this does no necesarily mean that dolomite is more sesistant to corrosion than limestone, because the en masse karstification caused by solution dissociation and physical collapse of dolomite may be operative. (2) In intensely corroded bioherm limestone often occurs corrosion induced collapse which prevents the formation of gigantic caves and steep peaks. (3) Mountains composed of micrite limestone and micrite allochamical limestone are less caved than mountains composed of sparry allochemical limestone (problaby due to its thickness and occurrence of bedding), despite the greater rate of corrosion of the former. Isolated peaks rarely occur in terrain of micrite limestone. (4) The development of gigantic caves and straight steep isolated peaks in the sparry allochemical limestone,which has a low corrosion rate, is consideed to be due to the greater thickness of the individual layers and the whole succession, the gentle dip and the far-extending vertical joints.

An important idea thus arises: The gigantic caves and steep peaks do not always occur in rocks which have a higher corrosion rate or in rocks which are intensely corroded. Conditions that are favourable for karstification may be instead unfavourable for the formation of gigantic caves and steep peaks. It seems to the author that the formation of gigantic caves and steep peaks depends not only on the corrosion rate and kasrtification intensity, but also on the supporting strength of the corroded rock bodies to withstand the load-a framework provided for gigantic caves and steep peaks. From this viewpoint, the author believes that the sparry allochemical limestone, with a greater thickness both of the individual layers and the whole succession, lower primary porosity and permeability and a higher strength is the most favourable rock type for their formation, especially when lying in synclinal axis, where the bedding is gentle and the vertical joints well developed. In such kind of rock bodies, ground water penetrates along the joints and cracks, and progressively corrods the rock on the both sides, slowly forming «initial conduit» (2). The presence of far-extending joints favours the discharge of the water in the initial conduits and replenishment of new corroding water to continue and develop the corrosion, thus progressivelly enlarging and extending the initial conduits. Ascorrosion proceeds to a certain extent, scouring of the water flow in the conduit is of great importance. Accompanied with the mechanical collapse, gallery– or hall-like caves are finally formed. Corrosion by atmospheric water seeping along joints and cracks may also aid in enlarging them. Outer slope of the mountain would collapse under gravity causing a continuous retreat of the mountain proper. Other parts of rock body, as having a greater thickness, compact texture, and high strength, would constitute a framework serving as a strong support for gigantic caves and steep peaks. Such kind of corrosional mechanism may called expanded-corrosion or heterogeneous corrosion (6).

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10207

Speleogenesis of vertical shafts in a Mediterranean environment (Ofra, Israel)

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Israel Cave Research Center

RESUM

Es va a dur a terme una investigació de pous verticals (avencs) de la conca càrstica d'Ofra (Israel), oberts en roques calcàries del Cenomanià.

Es va demostrar que els pous són originats per la corrosió del corrent d'aigua vadosa en el seu camí des de la superfície fins a les aigües profundes. L'aigua s'estén com una fina pel·lícula fluida sobre les parets del pou, produint-se un íntim contacte entre l'aigua i la roca.

Degut a la gran velocitat de l'aigua, prossegueix la seva agressivitat envers les parts més profundes de la zona vadosa (60 m., com a mínim, en la zona objecte d'estudi). El corrent d'aigua en els pous és, normalment, un corrent laminar subcrític.

El pou més ample d'Ofra (el «Chinese Pothole») podria haver-se format en 100.000 anys, aproximadament, en les presents condicions.

El sistema d'aigua vadosa, que consisteix principalment en fissures i pous, s'assembla, sota diferents punts de vista, a un sistema d'aigua superficial.

RESUMEN

Se llevó a cabo una investigación de pozos verticales (simas) en la cuenca kárstica de Ofra (Israel) que se originaron en rocas calcáreas del Cenomaniense.

Se probó que los pozos son creados por corrosión de la corriente de agua vadosa en su camino desde la superficie hacia el agua profunda. El agua se extiende como una fina película fluida sobre las paredes del pozo produciendo buen contacto entre el aguay la roca. Debido a la gran velocidad del agua, continúa siendo agresiva hacia las partes más profundas de la zona vadosa (60 m. como mínimo en la zona de estudio). La corriente de agua en pozos es usualmente una corriente laminar subcrítica.

El pozo más ancho en Ofra (el «Chinese Pothole») podría haberse creado durante 100.000 años aproximadamente bajo las presentes condiciones.

El sistema de agua vadosa, que consiste principalmente en fisuras y pozos se parece bajo varios puntos de vista, a un sistema de agua superficial.

SUMMARY

An investigation was carried out of the vertical shafts (potholes) in the Ofra karst basin (Israel), which were formed in Cenomanian calcareous rocks.

It was proved that shafts are created by corrosion of vadose flow water, on its way from the surface to the ground-water. The water, spreads as a thin film flowing on the shaft's walls, producing good contact between the water and the rock. Because of the high velocity of the water, it remains aggressive down to the deeper parts of the vadose zone (60 m. at least in the research area).

The water flow in shafts is usually a laminar sub-critical flow.

The largest shaft in Ofra (the «Chinesee pothole») could have been created in about 100.000 years under present conditions.

The vadose water system, which consists mainly of fissures and shafts, resembles a surface water system in some repects.

Karst shafts are common in Israel in limestone, dolomite and salt-rock

The present study deals with shafts in Ofra Karst plateau, situated 25 km. north of Jerusalem, 800 m. above sea level. The bedrock is Cenomanian massive micritic limestone and dolomite. The climate is Mediterranean with 600 mm precipitation per year.

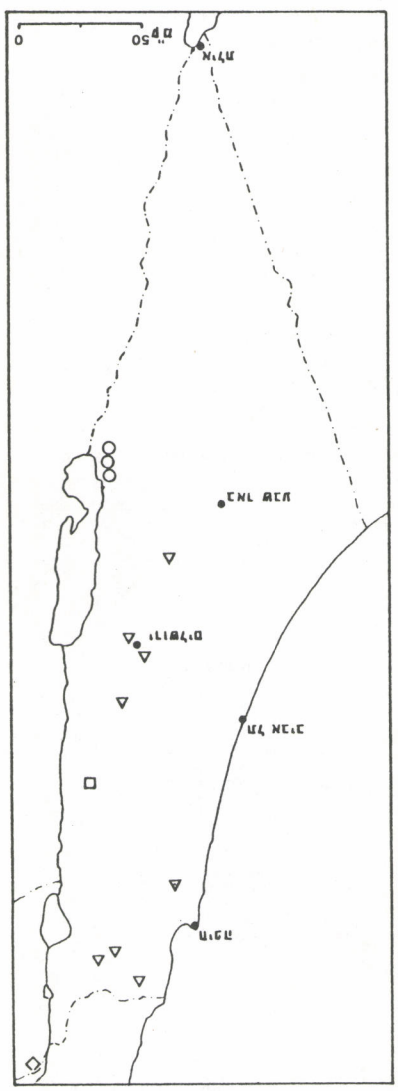

Fig. 1: Distribution of shafts in Israel according to lithology
○ Salt-rock, Pliocene-Pleistocene
Calcreaous conglomerate, Neogene
△ Limestone and dolomite, Cenomanian and Turonian Limestone, Jurassic
Limestone, Jurassic

The plateau is dotted by numerous dolines, 7-50 m. wide (fig.2). The sinkholes in the dolines are active only few days a year, during Ions storms. Some digging in the sinkholes led us into potholes, up to 60 m. deep.

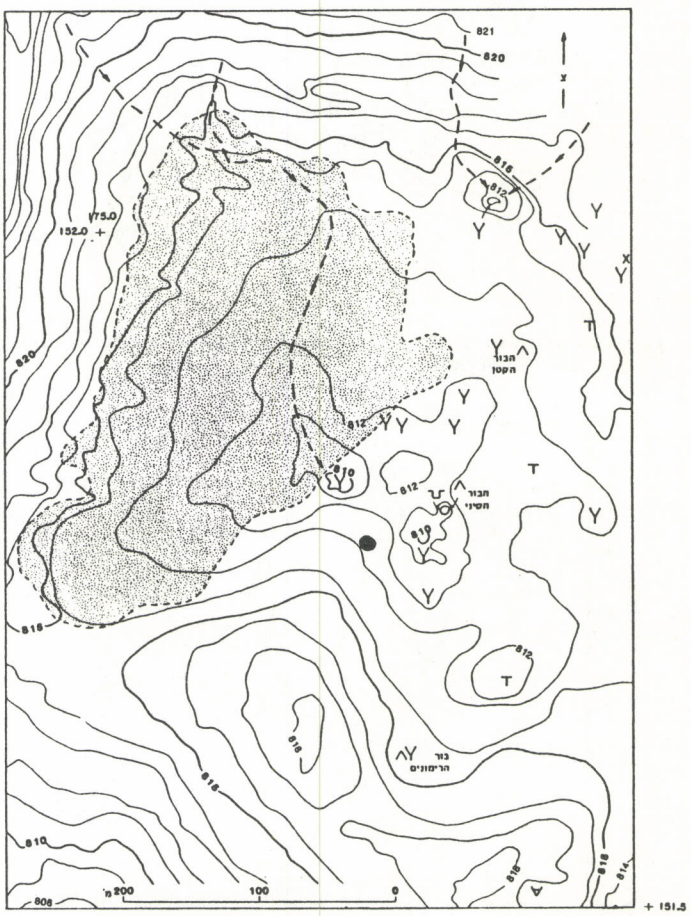

Fig.2: Karst phenomena in northern Ofra plateau
1. *collapse doline*
2. *pothole*
3. *fissures without soil*
4. *sinkhole*
5. *old cavern filled with travertine*
6. *altitude lines (1 m. apart)*
7. *short periodical stream entering a sinkhole*
8. *alluvium filled karst valley*
9. *doline fillet with soil*
10. *solution doline with a sinkole*

A pothole consists tipically of several interconnected vertical shafts with rare sub-horizontal galleries (fig.3).

32 water samples were analysed (fig.4). Gradual increase in Ca^{++} and Mg^{++} concentration was encountered on the water's path from rain through shafts to springs. In the shafts, seepage water (sampled from stalactites) were richer in solutes then flow water, and also had higher Mg^{++}/Ca^{++} ratio.

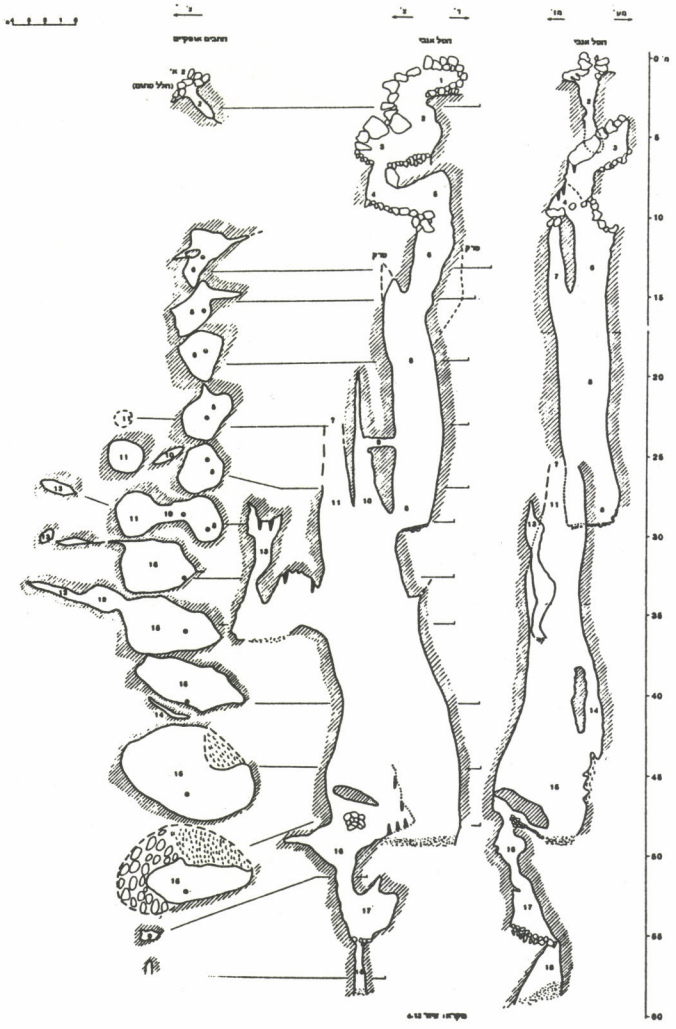

Fig. 3: The «Chinese Pothole» in Ofra, vertical and horizontal sections, survey: A. Frumkin, ICRC. BCRA grade 5D

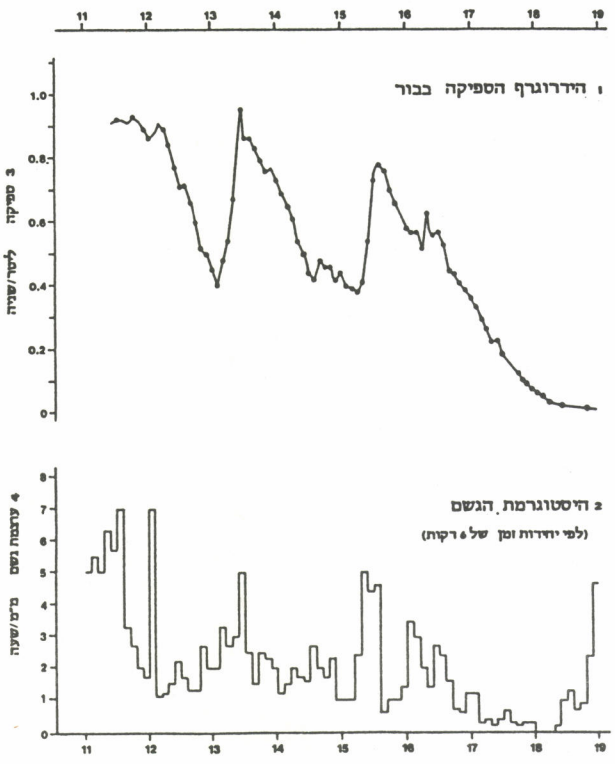

Fig.5: Discharge in the Chinese Pothole against rain intensity

1. *discharge hydrograph at 51 m. depth.*
2. *rain hystogram (6 minutes interval)*
3. *discharge (liters/second)*
4. *rain intensity (mm/hour)*
5. *time (hours)*

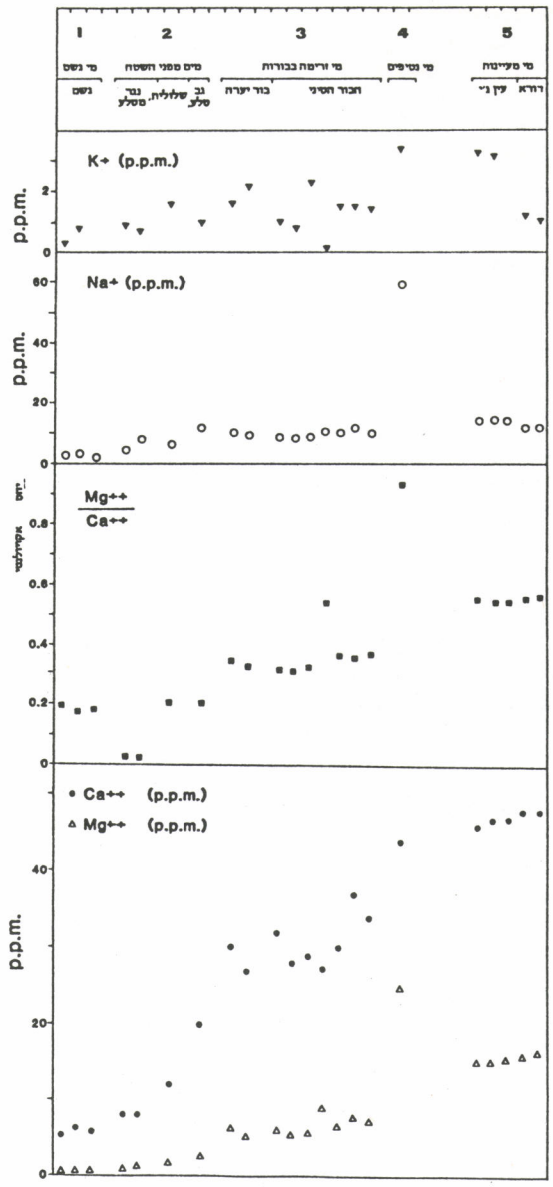

fig. 4: Chemical evolution of vadose water, Ofra region

1. *rain water*
2. *surface water*
3. *shafts flow water*
4. *shafts seepage water*
5. *spring water*

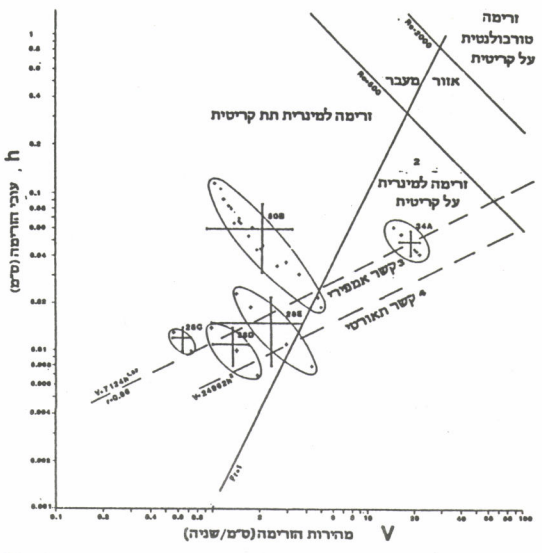

Fig. 6: Film flow dynamics in shafts, Ofra
Reynolds Number (Re) calculated for water temperature-10°C.
h. film flow thickness (cm)
v. flow velocity (cm/sec)

1. *sub-critical laminar flow*
2. *super-critical laminar flow*
3. *empiric function*
4. *theoretic function*

During a rain storm, discharge in a depth of 51 m. was continuously measured and compared with the rain intensity (fig.5). The water path consisted of 50 m. wide watershed, infiltration through soil and flow through fissures and shafts. Water velocities (calculated from reaction time) were 2-9 meters/minute, increasing with discharge.

In the shafts we recorded usually a laminar sub-critical film flow (on the walls), which became laminar super critical during intense sorms (fig.6).

The data suggest that the agressive film of water is responsible fot the shafts genesis.

On the basis of the present increase of solutes in the water along the shaft, it would take at least 100.000 years for the larger pothole to evolve under present conditions.

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1093

Carlsbad cavern and other caves in the Guadalupe mountains, New Mexico: A sulfuric acid speleogenesis related to the oil and gas fields of the Delaware basin

Carol A. Hill

RESUM

Les dades obtingudes a partir d'isòtops del sofre i la dependència del pH del mineral argilós endelita donen suport a la hipòtesi de que les grans galeries de les coves de les Muntanyes de Guadalupe (Nuevo Méjico) son degudes a una dissolució primària per àcid sulfúric, més que no pas per àcid carbònic. El guix del sòl i els dipòsits de sofre natiu de les coves tenen valors de S^{34} S^{34} tan baixos, que poden arribar a ser de l'ordre de −25,6 de −20, respectivament. Aquests corresponen a valors de S^{34} S^{34} del gas H_2S i del sofre natiu de la Conca Pèrmica, generats a partir d'una sèrie de reaccions relacionades amb el petroli i el gas.

En aquest treball se suggereix la possibilitat de que el progressiu desplaçament cap l'Est del marge hialític de la Conca Pèrmica pot haver estat un factor determinant per al desenvolupament de cavitats en les Muntanyes de Guadalupe a través del temps. On els estrats de halita romanen intactes, aquests actuen com a barreres impermeables, evitant que el sulfur d'hidrogen arribi a la superfície de la conca; en canvi, el gas arriba a l'interior del «Capitán reef» i allí s'originen coves de dissolució a través d'un mecanisme en el qual intervé l'àcid sulfúric. Però on els estrats de halita no han romàs intactes, l'aigua subterrània oxida el sulfur d'hidrogen a sofre natiu dins la mateixa conca (per exemple, el dipòsit de sofre de les surgències de Rusler) i el gas es veu incapaç d'assolir l'interior de l'escull i poder així formar coves.

RESUMEN

Los datos de isótopos de azufre y la dependencia del pH del mineral arcilloso endelita dan soporte a la hipótesis de que las grandes galerías de las cuevas de los Montes de Guadalupe, Nuevo Méjico, se deben a una disolución primaria por ácido sulfúrico, más que al ácido carbónico. El yeso del suelo y los depósitos de azufre nativo en las cuevas tienen valores de δS^{34} tan bajos como −25.6 y de −20, respectivamente. Estos corresponden a valores de δS^{34} de gas H_2S y azufre nativo en la Cuenca Pérmica generados con reacciones relacionadas con el petróleo y el gas.

En este trabajo se propone que el progresivo desplazamiento hacia el Este del margen halítico en la Cuenca Pérmica podría haber sido un factor determinante para el desarrollo de cavidades en los Montes de Guadalupe a través del tiempo. Donde los estratos de halita permanecen intactos actúan como barreras impermeables, evitando que el sulfuro de hidrógeno llegue a la superficie de la Cuenca; en cambio el gas llega al interior del Capitán reef y allí se producen cuevas de disolución a través de un mecanismo por ácido sulfúrico. Pero donde los estratos de halita no han permanecido intactos, el agua subterránea oxida el sulfuro de hidrógeno a azufre nativo en la misma Cuenca, (p. ej. el depósito de azufre de las surgencias de Rusler) y el gas ya no es capaz de alcanzar el interior del arrecife para formar cuevas.

SUMMARY

Sulfur isotope data and pH dependence of the clay mineral endellite support the hypothesis that the large cave passages in the Guadalupe Mountains, New Mexico, were dissolved primarily by sulfuric acid rather than by carbonic acid. Massive gypsum deposits and native sulfur in the caves have δS^{34} values as low as −25.6 and −20, respectively. These values correspond to δS^{34} values of H_2S gas and sulfur in the Gypsum Plain which are known to have been generated by oil and gas-related reactions.

In this paper it is proposed that the progressive eastward migration of the halite margin in the Gypsum Plain could have been a major factor controlling cave development in the Guadalupe Mountains. Where halite beds are still intact, they have acted as impermeable barriers, preventing, hydrogen sulfide from rising to the surface in the basin. Instead, the gas rose into the Capitan reef and dissolved out caves by a sulfuric acid reaction.

Recent dating results suggest that the Big Room leven of Carlsbad Cavern is about 850,000 years old, and that the Bat Cave level is about 1.3 my old. Other caves higher in the Guadalupe Mountains may be as old as 3 my.

At the International Congress in Bowling Green, Kentucky, Hill (1981) presented some preliminary results related to the speleogenesis of caves in the Guadalupe Mountains, New Mexico. This paper is an update on this research and it is also a short synopsis of a massive memoir on the geology of Carlsbad Cavern and other Guadalupe caves soon to be published (Hill, 1986). Specifically, this report will (1) concetrate on the aspects of a sulfuric acid speleogenesis which relate to the oil and gas fields of the Delaware Basin, and (2) it will present dating results which relate to the age of Guadalupe caves.

A Sulfuric Acid Speleogenesis

Three types of cave deposits attest to a sulfuric acid speleogenesis: endellite, massive gypsum, and native sulfur.

Endellite. Endellite is a waxy, colorful mineral which, in all of its non-cave occurrences, is known to form in a sulfuric acid, pH regime of 5 or below. In Guadalupe caves the endellite is associated with both montmorillonite and chert, and is believed to have formed by the following reaction:

$$(Mg,Al)8(Si_4O_{1o})3(OH_{10} \cdot 12H_2O + 10H^+ = 4(Al_2Si_2O_5$$
$$(OH)_4 \cdot 2H_2O + 4SiO_2 + 8\ Mg^{++}$$

Montmorillonite, when exposed to acidic water, reacts to form endellite and silica (chert).

Massive Gypsum. Massive floor deposits of gypsum up to 7.5 m high occur in Guadalupe caves, and these have δS^{34} values as low as −25.6. The gypsum formed as the by-product of the reaction of sulfuric acid with limestone:

$$H_2SO_4 + CaCO_3 + 2H_2O = CaSO_4 \cdot 2H_2O + CO_2 + H_2O$$

The extreme enrichment of the gypsum in S^{32} (leading to highly negative sulfur isotope values) can only be related to the biological oxidation and reduction of sulfur; such reactions have been proposed by Kirkland and Evans (1976) as having been related to oil and gas deposits in the basin.

Sulfur. Canary-yellow, rhombic sulfur crystals and pale-yellow, massive sulfur have been found in Cottonwood Cave and Carlsbad Cavern. In Carlsbad Cavern sulfur occurs in three localities: in the Big Room, New Mexico Room, and Christmas Tree Room (near the Lake of the Clouds). The New Mexico Room sulfur coats the undersides of bedrock projections and it also covers secondary gypsum flowers and crusts. The Christmas Tree Room sulfur occurs over bedrock, cave rafts, popcorn, and crinkle blisters. The Big Room and Cottonwood Cave sulfur is admixed with massive gypsum.

The Big Room sulfur has a $\delta\ S^{34}$ value of −20 and the Cottonwood Cave sulfur a value of −14.6. This compares with $\delta\ S^{34}$ values for H_2S gas in the basin which averaged −14.4 and −20.5 at the WIPP and ERDA sites, respectively. It also compares with the isotope values of the economic sulfur deposits in the basin ($\delta\ S^{34}$ as low as −15).

Relationship to Oil and Gas

Hill (1986) described the New Mexico Room bedrock which is coated with sulfur crystals as a clean, white, well-sorted sandstone which dips at angles of 30-35° toward the basin, and suggested that this sandstone is part of the Bell Canyon Formation, the major oil and gas producing unit in the basin. According to Hill's model, hydrogen sulfide gas ascended from the basin into the reef along the Bell Canyon Formation, and when it reached the New Mexico Room, it oxidized to form sulfur crystals on the undersides of bedrock projections according to the following equation:

$$2H_2S(g) + O_2(g) = 2S(s) + 2H_2O$$

The other occurrences of sulfur in Carlsbad Cavern, and also in Cottonwood Cave, have been ascribed to hydrogen sulfide moving up from the basin along regional fractures and joints.

It is proposed in this paper that the progressive eastward migration of the halite margin in the Gypsum Plain of the Delaware Basin has been a major factor controlling cave development in the Guadalupe Mountains. The Castile Formation of the Gypsum Plain is a thick, deep-water, evaporite sequence composed primarily of anhydrite and gypsum separated by impermeable halite beds. Over time, as the Guadalupe Mountains and Gypsum Plain have uplifted and tilted to the northeast, these halite beds have progressively eroded from west to east. This erosion has created in the basin a salt dissolution zone or margin which, according to Bachman and Johnson (1973), has had a horizontal rate of movement of about 10-13 km/million years.

The Gypsum Plain is characterized by oil and gas fields, sulfur fields, limestone «castile» buttes (formed by the reaction of oil and gas with the Castile anhydrites to produce limestone and hydrogen sulfide gas), and caves in the buttes where H_2S gas is still degassing (Fig. 1). Where sulfur exploration companies have drilled below the halite units, they have found plentiful H_2S gas, but no native sulfur (i.e., in the area to the right of the solid and dashed line in Fig. 1). The sulfur in the basin is found only at the edge of the halite front (just to the left of the line), where the H_2S is being oxidized to sulfur by meteoric ground water. Where halite beds are still intact, they have acted as impermeable barriers preventing hydrogen sulfide from rising to the surface in the basin. Instead, the gas moved from the basin into the reef along the Bell Canyon Formation or along regional fractures and joints, and where this gas mixed with oxygenated fresh water of the Capitan reef, it formed sulfuric acid, which in turn, dissolved out the caves.

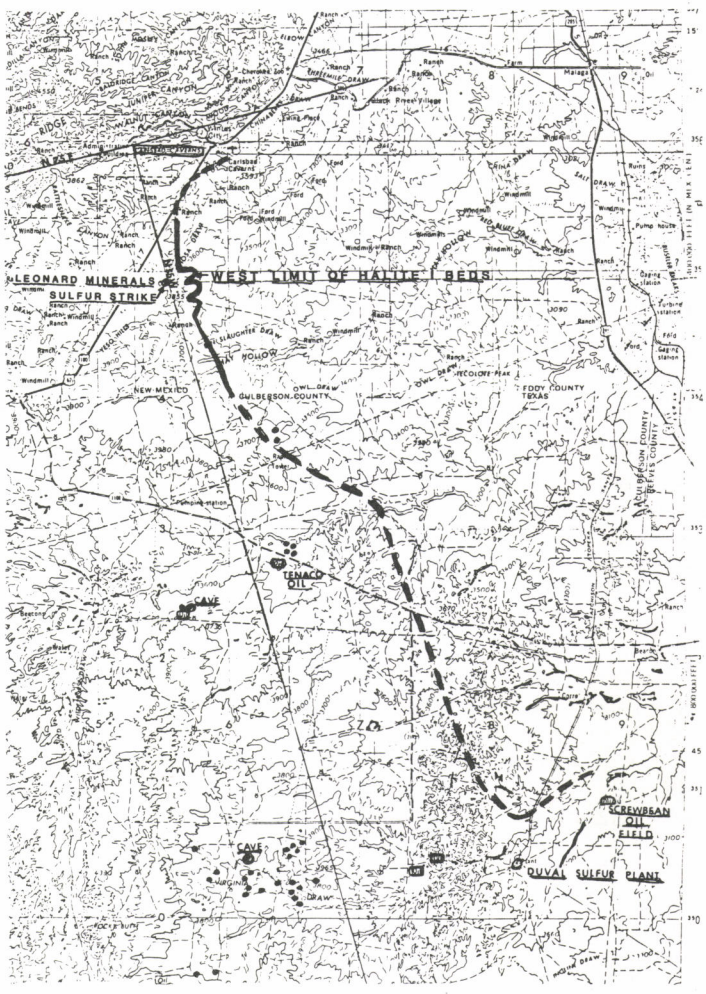

Figure 1. Location of Carlsbad Cavern with relationship to oil, sulfur, and the «castile» buttes (circular dots) of the Gypsum Plain. Line is the extension of the trend of the Big Room, Carlsbad Cavern (N15°W). Caves in the Gypsum Plain are tubular caves with degassing H_2S. Location of the west limit of the Halite 1 beds and Leonard Minerals sulfur strike courtesy of Leonar Minerals, Albuquerque, New Mexico. Scale, 1 cm = 1 km. From Hill (1986).

It is interesting to compare the age of deposits in the lowest passage in Carlsbad Cavern (Lake of the Clouds) with the supposed age of this passage as determined by the rate of salt dissolution in the basin. The halite margin in the Gypsum Plain has moved 0.5-0.65 km to the east of Carlsbad Cavern (see Fig. 1). At a rate of 10-13 km/1,000,000 years as suggested by Bachman and Johnson (1973), a distance of 0.5-0.65 km corresponds to about 50,000 years as being the time when H_2S gas stopped rising into Carlsbad Cavern (because the halite margin had moved past the location of the cave). The date of cave rafts in the 3 m high cones on the Balcony of the Lake of the Clouds, which record the last speleogenesis event in the cave, are 50.000 ± 4,000 yrs (Table 1).

TABLE 1
AGE-DATES OF SPELEOTHEMS AND CLASTIC DEPOSITS WHICH RELATE TO THE SPELEOGENESIS OF CARLSBAD CAVERN

Deposit	Place & Elevation	Date	Dating Method
Spar	Entrance 1310 m	>350,000 yrs >1.25 my (?)	U-series
Spar	Guadalupe Room 1160 m	>350,000 yrs >1.25 my (?)	U-series
Spar	Secondary Stream Passage 1128 m	879,000 ± 124,00 yrs	ESR
Spar	Left Hand Tunnel 1113 m	>350,000 yrs <1.25 my (?)	U-series
Spar	Lower Cave 1090 m	>350,000 yrs <1.25 my (?)	U-series
Rafts	Balcony, Lake of the Clouds	50,000 ± 4,000 yrs	U-series
Texas Toothpick Stlagmite (center of core)	Lower Cave, directly overlying silt	>350,000 yrs ~600,000 yrs (?)	U-series
Silt	Lower Cave	>730,000 yrs	Paleomag netism

U-series dates by Derek Ford, McMaster University
Electron Spin Resonance (ESR) date by Rainer Grün, McMaster University
Paleomagnetism done by Victor Schmidt, University of Pittsburg Rock
Magnetism Laboratory.
Core in the Texas Toothpick stalagmite done by Brooks Ellwood.

Age of Guadalupe Caves

The dates obtained by Hill (1986) for speleothem and silt deposits in Carlsbad Cavern are pertinent to the age of Guadalupe caves. Spar crystals (interpreted by Hill to be phreatic spar which formed below the water table, but not far below it) have U-series ages which exceed 350,000 yrs (Table 1). $^{234}U/^{238}$ ratios suggest that the spar of the upper levels (Bat Cave and Upper Guadalupe Room) is >1,25 my and that the spar below the Guadalupe Room is <1,25 my. Spart at the Big Room level has been dated at 879.000 ± 124,000 yrs by the Electron Spin Resonance (ESR) dating method. At the Lower Cave level, silts are >730,000 yrs according to paleomagnetic results (i.e., the silts are all reversed). The silts in Lower Cave Hill interpreted to be insoluble residue derived from limestone, and thus represent the time that the cave passage at that level dissolved.

These dates, and the date on the cave raft cones, indicate that the lowest passage in Carlsbad Cavern (the Lake of the Clouds) had finished forming about 50.000 years ago. Lower Cave dissolved >730,000 yrs ago, but probably not much earlier (because of the probable 600,000 date on the Texas Toothpick stalagmite directly overlying the silt), and the Big Room level formed about 850,000 years ago (the spar preceded the dissolution of the cave void, but not by much). Considering the probable >1,25 age of the spar above the Guadalupe Room level, and a rate of approximately 0.03 cm/yr as the average lowering of the water table, the upper levels of Carlsbad (Bat Cave) calculate to be about 1.3 my. Caves in the southwest, higher parts of the Guadalupe Montains are older than Carlsbad, and if one assumes a constant rate of water table lowering and mountain uplifting, then a cave like Cottonwood, with an entrance altitude of 960 m, must be about 3 my old. The caves of the Guadalupe Mountains are thus Pliocene-Pliestocene in age, a judgment that agrees with King's (1948) contention that the major rise of the Guadalupe Mountains was in the Late Pliocene to Early Pleistocene.

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The Hyperkarst phenomena with particular regard to the Iglesiente (SW Sardinia)

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RESUM

Al districte miner d'Iglesiente (S.O. de l'illa de Sardenya, Itàlia) existeixen fenòmens càrstics complexes i ben desenvolupats, localitzats a les formacions carbonatades càmbriques, on també hi podem trobar els jaciments de plom, zenc i barita més importants d'Itàlia.

En aquesta zona el carst és molt antic i es troba profundament afectat i condicionat per la complicada estructura geològica d'aquesta àrea, que ha fet possible l'existència de varis cicles càrstics d'erosió i/o sedimentació parcialment sobreposats els uns als altres.

Una anàlisis hidrogeològica detallada d'Iglesiente, efectuada recentment, ha posat de manifest el complex comportament químic de les aigües durant la llarga evolució càrstica de la regió. L'aigua procedent de les precipitacions es barrejava, en el passat i encara avui, amb aigües profundes salades o molt àcides, o bé amb aïgues termals molt calentes.

Això ha originat diferents formes hipercàrstiques d'espeleogènesi, tal i com ens recorden la morfologia i els dipòsits físico-químics, pocs habituals, però molt espectaculars que es troben a l'interior de les cavitats. La importància dels estudis interdisciplinaris realitzats en aquesta zona càrstica de característiques úniques, radica en el fet de que s'ha aprofundit en el coneixement del paper que els factors hipercàrstics juguen, no solament en situacions concretes, sinó també en tots els mecanismes espeleogenètics, malgrat que fins avui no havien estat considerats ni s'havien entès suficientment.

RESUMEN

En el Distrito Minero de Iglesiente (SW de Cerdeña, Italia) existen fenómenos kárstico complejos y bien desarrollados en las formaciones carbonatadas cámbricas, en las que también se hallan los depósitos de plomo, zinc y barita más importantes de Italia.

En esta zona, el karst es muy antiguo y se halla profundamente afectado y controlado por la complicada estructura geológica del área, que ha provocado la existencia de varios ciclos kársticos de erosión y/o sedimentación parcialmente superpuestos unos con otros.

Un análisis hidrogeológico detallado de Iglesiente, efectuado recientemente ha puesto de manifiesto el complicado comportamiento químico de las aguas durante la larga evolución kárstica de la región. El agua procedente de las precipitaciones se mezclaba en el pasado y aún hoy, con aguas profundas saladas o muy ácidas, o bien con aguas termales muy calientes.

Esto ha originado diferentes formas hiperkársticas de espeleogénesis, tal como muestran la morfología y los depósitos físico-químicos, poco habituales y muy espectaculares que se hallan en el interior de las cavidades. La importancia de los estudios interdisciplinarios efectuados en esta zona kárstica de características únicas radica en el hecho de haber profundizado en el conocimiento del papel que los factores hiperkársticos juegan, no sólo en situaciones particulares, sino también en todos los mecanismos espeleogenéticos, a pesar de que hasta ahora no han sido considerados ni entendidos de manera suficiente.

SUMMARY

In the Iglesiente Mining District (SW Sardinia, Italy) well developed and complex karst phenomena are located in the Cambrian carbonate formation, in which also the most important Pb, Zn, barite deposits of Italy are present.

Here karst is very old and therefore deeply affected and controlled by the complicated geological and structural settlement of the area, which lead to the activation of several cycles of karstic erosion and/or deposition, partially overimposed by each other.

A detailed analisis of the hydrogeology of the Iglesiente, carried out recently, made evident the complex chemical behaviour of the waters during the long karst evolution of the region. Metheoric fresh water migled in the past and still mingle together with deep salt, or with very acid, or with hot termal ones.

These situations lead to different complex hyperkarstic speleogenesis as testified by uncommon and spectacular morphologies and/or physico-chemical deposits inside the caves. The importance of the interdisciplinar stdy carried out over this unique karst area is that to have greatly improved the general knowledge of the hyperkarst play a noticeable role, not only in particular situations, but in quite all the speleogenetic mechanisms, even if even now have not been sufficiently considered and understood.

Introduction

In the Iglesiente the Cambric limestones and dolostones with a width ranging from 400 to 800 m are located between sandstones and scists. Carbonate sequences are strongly karstified and also host Pb-Zn and Baryte ore bodies.

The peculiar characteristic of the Iglesiente is that its limestones and dolostones underwent several karst cycles following the complex geological and structural evolution of that area (CIVITA & al., 1977; FORTI & al., 1981).

In the Iglesiente aquifers water circulation is different zone by zone (CIVITA & al., 1983). In the occidental part fresh infiltration waters mingle in the depth with slightly thermalized marine ones, whose dynamic is surely related to some physical discontinuities, which are in turn geothermically active.

In the other zones despite the high structural complexity the groundwater dynamic is sufficiently normal with well defined watersheds and risings in springs (Gutturu Pala, Pubuxinu) and blowouts (S. Giovanni and Cuccuru Tiria caves).

In the Iglesiente, following the lowering of groundwaters induced by the eduction minining, activities went far below the sea level reaching complex karst features, developed in «phreatic» conditions.

In these zones, during the karst evolution in, very particular physico-chemical conditions were time by time attained with the presence or of high chlorine waters, of strong acids caming from the oxidation of sulphides, or lastly of thermal waters. The complex chemical behaviour of these waters, close to «normal» speleogenetic processes, created the conditions for the development of several hyperkast reactions (CIGNA, 1978) controlled time by time by diffusion, strong acids, electrochemical potentials, and thermalism (FORTI & PERNA, 1985).

«Normal» Karst

In the upper zone the normal karst morphologies are developed, which over the groundwater level are represented by sinkholes, pits, vertical or orizontal caves often with active internal rivers; on the surface kamenitze and karrenmay be observed, even though not often. Cave deposits are the normal ones, both chemical (speleothems and crystals) and physical (sand, gravel and silt) (FORTI & PERNA, 1982).

Slightly below the original watertable cave clouds are normally developed where the influence of the carbonic waters is still active.

In the depth normal karst features are still present with pits and orizontal cave passages, while the chemical deposits consist of phreatic crusts originated by CO_2 diffusion.

Deeper very large calcite crystals are normally found. A period in which the depositon of «phreatic» barite crystals took place was also observed inside the Santa Barbara cave (ROSSETTI & ZUCCHINI, 1956). More frequently the karst cavities crossed by mines have no chemical deposits at all but are often filled by a very large quantitie of red silts. These sediments are layered and intercalated with sand and/or gravel levels, are allochton and related to a continental erosion or to a sea water ingression.

Diffusion hyperkarst

In the diffusion zone between the deep chlorine and the fresh meteoric waters it is possible to observe a noticeable increase in the corrosion processes, which lead to the development of caves and a widening of the macro and micro – fractures.

The strong corrosion generally don't allow the deposition of speleothems, which may be represented by calcite crystals, or mor rarely by barite and other minerals.

The increase in calcium carbonate solubility is related to the salinity increase through the well known «salt effect», which lowers the ionic activity of each ion present in the solution as well as the ionic strenth is enhanced.

But there is another factor which causes and additional magnification of the karst development in the mingling zone between deep chlorine and metheoric fresh waters: in fact, in these conditions the equilibrium line is parabolic and therefore the effect of the mingling of two waters with a different salt content is similar to that obtainied in the normal «Boegli effect» (BOEGLI, 1965).

The lifting of high salt waters inside the Iglesiente «metalliferous ring», allowed karst to develop deeply below the groundwater level thus creating very large cavities just under the natural boundary between meteoric and salt waters.

Strong Acids Hyperkarst

In the Iglesiente, the carbonate formations host sulphides which sometimes give rise to oreboides, where, with galena and sphalerite pyrite is also present. Sulphide oxidations is caused by the oxygen present in the upper part of the orebodies (ROUTHIER, 1963). This reaction may develops in two different ways:

– The deposition of limonite in neutral or weak acid environment (eluted or netralized by CaCO3)

– In more acid conditions the iron remains in the olution or precipitates as simple ferrous or ferric hydrated sulphates and/or complex sulphates together with other metallic ions.

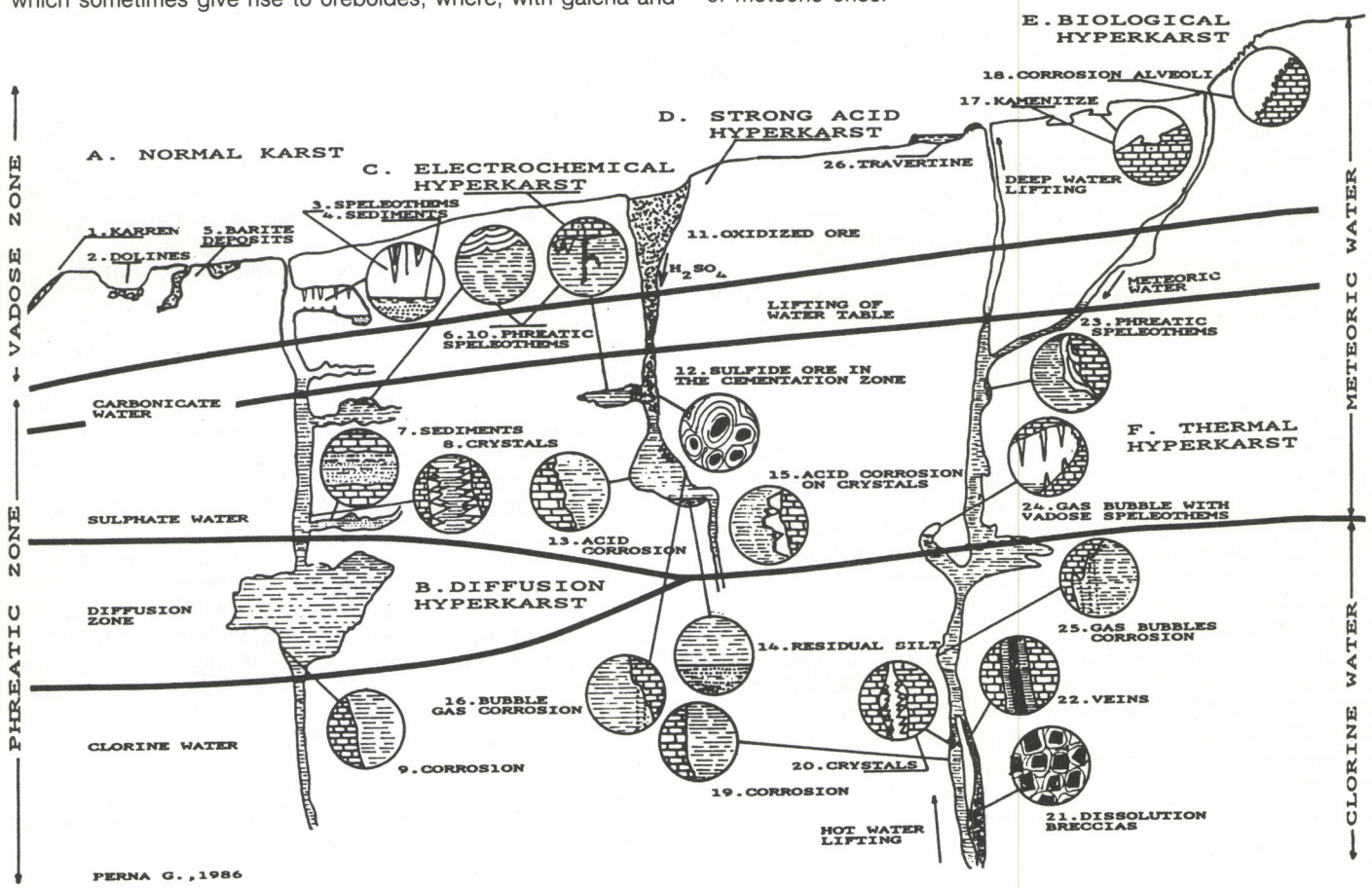
All these reactions are largely inproved by the presence of specific bacteria.

In conclusion the oxidation of a sulphide produces sulphoric acid, which reacts with the limestone forming gypsum and CO2. But in phreatic conditions like those normally present in the microfractures and embrional drainage tubes, the reaction between the H2SO3 and the limestone is rapidly inhibited due to the impossibility of the produced CO2 to escape. The CO2 may be released by diffusion close to the vadose zone and therefore the aggresive reaction shall be completed.

The importance of this hyperkarst reaction may be well understood if we analize its quantitative result: 1 mole of FeS2 (= 100 g of pyrite) causes the issolution of 4 moles of CaCO3 (= 400 g of pure limestone) if the reaction is stoichimetric.

Thermal Hyperkarst

Deep waters are often thermal and they always have temperatures fairly different from those coming from the seepage of meteoric ones.



A. NORMAL KARST, EXTERNAL MORPHOLOGIES: *karren (1), dolines (2), sinkholes etc.; barite deposits;* NORMAL KARST, INTERNAL MORPHOLOGIES: *vadose speleothems (3), physical deposits (4), phreatic cave clouds (6), physical deposits (7), crystals (8).*

B. DIFFUSION HYPERKARST: *in the mingling zone between meteoric and deep chlorine waters a noticeable increasing of corrosion takes place (9);*

C. ELECTROCHEMICAL HYPERKARST: *chemichal deposits due to this phenomenon lead to flowstones and crystals growth in the phreatic zone (10);*

D. STRONG ACID HYPERKARST: *in the upper part the oxidation of sulfides causes the genesis of metallic oxides (11) and in the cementation zone a concentration of sulfides (12); sulforic acid causes a strong karstification of the host rocks (13) and of crystals (15), and gas bubble corrosion (16). Residual muds and sands were also deposited (14);*

E. BIOLOGICAL HYPERKARST: *on the surface it causes the genesis of kamenitze (17), corrosion alveoli (18) and travertine deposition (26);*

F. THERMAL HYPERKARST: *it leads to solution and/or corrosion of the limestone (19), crystals growth (20), disolution breccias (21) and, in the mean time, to partial remobilization and redeposition of ore veins (22). Phreatic spleothems grow in the zone reached by meteoric waters (23). Gas bubble, in particular structural conditions, may develop deep vadose karst cavities (24), in which stalactites and stalagmites may grow. Gas bubble corrosion (25).*

In the mingling zone this fact causes two different effects: enhanced corrosion but also supersaturation.

In fact the temperature of water affects the solubility of CO2 and of CaCO3 in an opposite manner: increasing the temperature the solubility of CO2 lowers, while that of the CACO3 increases. The balance of the two opposite effects, therefore, may lead, from time to time, to the corrosion of the limestone or to the deposition of speleothems or crystals, which normally are of calcite but may be also of several other minerals like quartz, opal or sulphides.

The lifting of all the deep waters (not only the thermal ones) may cause, due to the lowering of the pressure, the diffusion of gases, which determine the evolution of particular corrosion morphologies like the bell shaped ceilings or the reverse gutters on the cave walls. In extremely particular structural conditions gas traps may be created by the gases escaping from the solutions deep below the watertable: in this manner «vadose» conditions are achieved and stalactites and stalamgites may develop. The presence of these speleothems have been wrongly explained time by time as evidencies of older lower steady levels or as supergenic depositions.

We have observed direct examples of these particular depositional environments inside the Trepca mine (Serbia) (PERNA, personal observation) and the Trzeblionka mine (Polan) (FORTI & al., 1986).

Electrochemical Hyperkarst

The oxidation of the sulphides ore bodies induces stay currents, which theoretically may cause the corrosion of some other metallic mineral: anyway till now this effect was not observed.

On the contrary electric currents may induce the electrochemical deposition of minerals from solution rich in metallic ions.

In the Masua mine (Iglesias) we observed iron oxides helictites growing over metallic draining tubes close to calcite-opale-sphalerite formations filling boreholes. In this occurrence a potential difference up to 0.8 V was measured between the tubes and the filled boreholes.

Biological Hyperkarst

Recently the importance of the role played by biological reactions, mainly due to endolitic algae, in the corrosion of the limestone (FOLK & al., 1973; PERNA & SAURO, 1978).

In these reactions the corrosive power of the meteoric water is enanced by biological processes. This hyperkarst mechanism is active only on the surface owing to the fact that biological processes need light; the resulting morphologies are pinnacles or alveolar structure and kamenitzes.

The degradation products of organisms and humic acids still develop a biological hyperkarst corrosion. In fact the oxidation of all the organic matters always produces CO2 and H2O and therefore waters rich in organic matter reaching a karst environment become slowly but progressively aggressive.

In this case it is difficult to quantitatively define the hyperkarstic process, but it was shown that in some conditions it represents more than the 20 % in the karst development of a system (BRAY; 1972).

On the contrary the deposition of calcite flowstones and crusts outside is often controlled by micro-organisms (PERNA & SAURO, 1978; FORTI, 1984).

In the Iglesiente we observed (FORTI & PERNA, 1985) that the opal spelothems actually growing inside the quartzite caves on the top of Mt Acqua (Domusnovas) have a very high organic content (up to 20 %), thus suggesting that the solubilization and the following deposition of opal processes may be deeply controlled by biological reactions.

Conclusions

The detailed analysis of the complex karst phenomena of the Iglesiente were mostly made possible by mining activities which allowed us to visit karst systems far below the natural watertable. These analyses clarified the noticeable importance of the hyperkarst mechanisms in the speleogenesis.

In the fig.1 there is a sketch in which all the actually known principal hyperkarst speleogenetic mechanisms are reported. From time to time they may cause enhanced corrosion of the cave walls or the deposition of speleothems and/or crystals of calcite or other cave minerals.

In this field, however, a lot of work is still to be done to achieve a quantitative definition for each of these phenomena in all the possible speleogenetic environments. Anyway, such a definition is really very difficult to obtain due to the large number of variables to be taken into account. Therefore, depending on the time required to prepare theoretic models and to that necessary to test them, the quantitative knowledgment of the hyperkarst processes will not be acheived in the near future.

But we are sure that in the next few years the hyperkarst phenomena, which were quite completely ignored just twenty years ago, will become more and more important in all the speleogenetic studies.

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Process of karst caverns'development and three phrases'Flow

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RESUM

El desenvolupament de les cavitats càrstiques guarda una estreta relació amb el fluxe de tres fases, format pel corrent sòlid/líquid i bombolles de gas o una mescla de diversos materials. Bassant-nos en els components i les característiques dels dipòsits de les cavitats i les característiques dels dipòsits de les cavitats i en les característiques hidràuliques, s'examinen els principals mecanismes de transport-de posició de partícules sòlides del corrent. Després d'analitzar les característiques d'origen i moviment de les masses gasoses, aquest treball es centra en la discusió sobre la cavitació juntament amb els fenòmens de corrosió, erosió i deposició, a partir del fluxe de tres fases de les cavitats subterrànies.

RESUMEN

El desarrollo de las cavidades kársticas tiene estrecha relación con el flujo en tres fases, que está formado por la corriente solido-líquida y burbujas de gas o masas en estado de mezcla. Basando se en los componentes y características de los depósitos de cavidades y las características hidraúlicas se discuten los mecanismo principales de transporte-deposición de partículas sólidas en la corriente. Después de analizar las características de origen y movimiento de las masas gaseosas, este trabajo se centra en la discusión sobre cavitación junto a corrosión, rosión y de posición desde el flujo en tres fases en cavidades subterráneas.

SUMMARY

The developments of karst caverns have the closed relationships to the three phrases'flow, that is formed by liquid solid runoff and gas bubbles or masses in mixture state. Basing the components and features of cave deposits and the hydraulic features, the main mechanisms of transportation-depositions of solid particles in the flow are discussed. After analysing the origins and moving features of gas mass, this paper centres on the discussion about cavitation together with corrosion, erosion and deposition from three phrases'flow in caves system.

The dissolution is the basic process for karst cave's development, but the mechanical erosion, gas erosion-cavitation and many kinds of depositions always come in existences. There are corroded pores and fissures together with larger conduits as the three kinds of medium in karstified rock mass to lead the existing of pore, fissure and conduit waters, which movements with different characters posses of their internal relationships[1]. Particularly in karst cave system, the three phrases'flow of liquid, solid and gaseous masses in mixture state is actually playing very important roles.

(1) The Formations of Solid Runoff and Environments in Caves

Except the chemical deposits, the karst flow carrying certain solid clastic matters in usually occurring depositions.

First, the solid clastic particles to be transported or deposited in caves may be classified into endogenous and ektogenic both kinds in geneses and separated into clays ($d < 0.005$ mm), sands ($d = 0.005$-2 mm), gravels ($D = 2$-50 mm), larger gravels ($D = 50$-100 mm), blocky rockmass ($d > 100$ mm) and colluvial rock mass in particle size.

Second, the mineral components of sands and clays in caves with relationship to their geneses may reflect the characters, that are useful for studying hydrodynamic condition and environment in the sedimentary stages. The heavy minerals in several caves of typical regions been measured are summarized in table 1; from which the nonstable minerals of cave deposists in south China are only a few quantity, and that ratios to stable minerals are mostly in the range of 0.003-0.05 or near zero; but that of quartzs to feldspars are mainly 0.97-2.77. In middle level of a cave developed in west Hubei, a brown-red clay layer with the ratio of quartz to feldspar about 0.97 is overlying by a grey clay bed, that may express the climatic change from warm to pleasantly cool in late Pleistocene. The contents of ferrohydrites in several caves are rather larger, because which were formed by the oxidation of pyrites under damp-hot climatic condition: but a fault in south Guizhou still contain uncorroded pyrite about 99 percent to the sum of ferropyrites and pyrites. As to north China, the ratios of non-stable minerals in some caves may over 5; and the values of ratio in quartz to feldspar are lowe than 1, these results will indicate the changes of paleo-climatic conditions in Quaternary from warm-moist to dry-cold or warm– dry conditions[2].

Basing the results of differential thermal analyses and X-rays diffraction patterns of cave clays, the related data may indicate that the constituents of cave clays either in south or in north of China are mainly htdromica-kaolin kind, so that when the caves developed, the paleo-climatic conditions mainly were damp-hot or warm-moist. The deposits in a paleo-cave developed in Zhoukoudian of Beijing with askonites, pelhamites, chlorites and illites etc. minerals, where the first skull of te Chinese ape-man was unearthed, will reflect the changes about warm-moist, nice and cool cold-arid and temperate-semi-moist etc. climatic conditions.

Otherwise, the results of sporo-pollen analyses from cave fillings will indicate the paleo-climates. Either in north China or in south China,– the five times of climatic changes from damp-hot or temperate to rather cool or glacial conditions had happened to influence karst developments and related trasnportations and depositions in caves[2].

(2) Features of Hydraulics and Related Depositions in Caves

Generally, the water flows in karst caves have brought certain content of solid clastic matters to form three phrases'flows.

1. Lifting force of liquid flow and starting movement of solid particles: The forms of karst caves and their passage-ways are irregular, and their flow movements as well as hydrodynamic conditions also are changeable. When the water flow running into

Table 1 SUMMARY ANALYSIS OF HEAVY MINERALS IN FILLINGS OF CAVES AND CORRODED FISSURES IN SOME TYPICAL REGIONS

Region	Karst type	Property of cave	Sampling horizon	Content of heavy sand %	Non-stable minerals / relative stable, stable, and very stable minerals (content ratio)	Non-stable and relative stable, minerals / stable and very stable minerals (content ratio)	Significant minerals of karst development			Other minerals and rock debris				
							Content of pyrite %	Content of ferro-hydrite %	ferro-hydrite pyrite (content ratio)	content of rock debric %	content of calcite %	content of quartz %	content of feld-spar %	quartz feld-spar (content ratio)
West Hubei	Hill-valley	ground river	upper earth	0.61	→ 0	0.20	2.16	39.33	18.20	13.53	1.69	62.32	22.46	2.77
			lower earth	0.42	0.0003	0.171	0.16	5.16	8.08	25.75	/	53.85	20.4	2.63
		subsurface stream	upper earth ①	0.01	0.006	0.229	meet by chance	11.25		76.36	/	14.43	9.18	1.57
			upper earth ②	0.01	0.028	0.315	1.81	0.90	0.49	67.96	/	16.83	15.21	1.10
			middle earth ①	0.025	0.006	0.671	5.07	17.96	2.56	90.03	/	6.11	3.86	1.58
			middle earth ②	0.02	0.04	0.449	1.03	1.03	1	42.76	/	28.29	28.95	0.97
North Guizhow	Low mountain -valley	fault	filling earth	0.51	0.02	0.24	99.28	0.18	0.0018	/	/	/	/	/
South Guizhow	Medium-high mountain-valley	corroded fissure	filling earth	0.30	0.05	0.125	0.20	90.8	454	/	/	/	/	/
South Sichuan	Ridge-slope land	ground river	river bed of outlet	8.90	0	→ 0	4.90	43.40	8.85	/	/	/	/	/

Annotation: 1. This table is not counting the less content of several unknown minerals;

2. the calculation of content ratio about non-stable minerals to stable minerals is not included the values of pyrite and ferrohydrite.

a clastic particle may occur the roundabout phenomenon; if its instantaneous velocity reaches the critical value, then its pushing force Px will lead the particle to slip in first, while the lifting force as its one component Pz may promote the particle into suspensive movement. Such starting velocity near cave floor Ud and that average velocity Vo of whole section with the relationships to other factors are expressing in some functions:

$$P_x = f(W_x, V_d, p_s, p, c_1) \quad \ldots\ldots (1)$$
$$P_z = c_2 P_x \quad \ldots\ldots (2)$$
$$V_0 = f(d, h, K_{c1}) \quad \ldots\ldots (3)$$
$$\text{or} \quad V_0 = f(g, p, p_s, d, K_{c2}) \quad \ldots\ldots (4)$$

W_x projective area of particle in vertical; p_S particle density; p water density; c_1 coefficient related to Re and cave feature; C_2 component coefficient; d particle diameter; h water head; g acceleration of gravity; K_{c1}, K_{c2} coefficient.

2. Flowing speed and depositing of solid particles: When all the suspentive particles are transporting under high speed, the larger the Wx, the more stronger the Pz, then the big particles may be suspending in the upper part of mixed flow, and the smaller clays ' particles by the diffusion may be carrying in all parts; under lower kinetic energy, the case is contrary (Fig. 1).

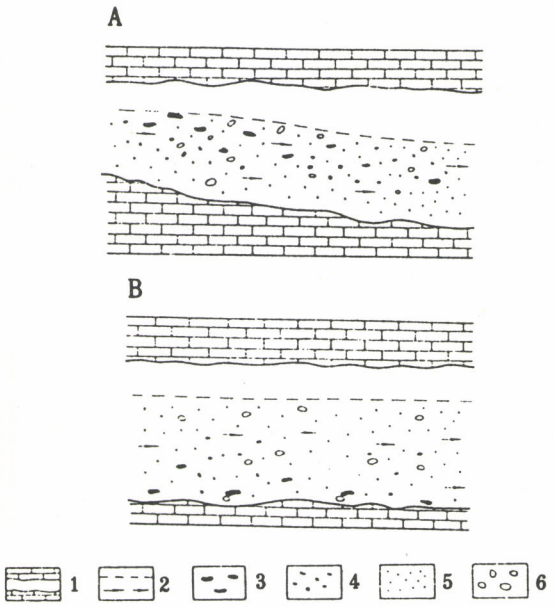

Fig. 1. Sketch of three phrases'flow in karst cave
A three phrases'flow with kinetic energy; B three phrases'flow with low kinetic energy; 1 karst cave; 2 flowing surface and direction; 3 sands and gravels; 4 sands; 5 clay particles; 6 gas

If the flowing way in cave may separate into N parts, each part has the primary velocity ViO and the actual speed Vi, their relationship in some caves may be expresing in following funcion:

$$V_i = V_{o1}\, e^{\alpha\, k\, l_i} \quad \ldots\ldots (5)$$
$$\text{or} \quad V_i = V_{01} \exp\left[\ \alpha_{k\,i} \cdot \frac{\delta H_i}{\alpha S_i}\ \right] \quad \ldots\ldots (6)$$

$\delta_{k\,i}$ coefficient; $\frac{\delta H_i}{\delta S_i}$ hydraulic gradient

then for n part:

$$V_n = V_{ol} \cdot e^{\alpha k1 \cdot l_1} \cdot e^{\alpha k2 \cdot l_2}$$
$$e^{\alpha k_{n-1} \cdot l_{n-1}} \cdot e^{\alpha k_n \cdot l_n} \quad \ldots\ldots (7)$$
$$V_n = v_{c1} \left| \prod_{i=1}^{n} \right| e^{\alpha k_1 l_1} \quad \ldots\ldots (8)$$

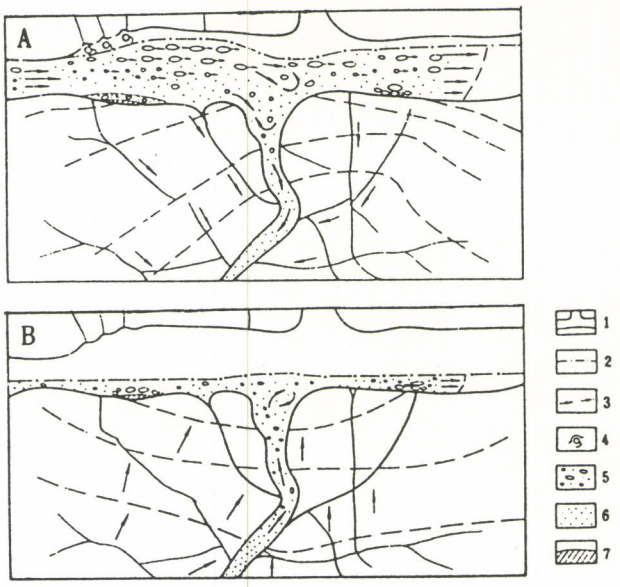

Fig. 2
A model of transportation-deposition of solid runoff
A. high water level; B. lower water level; 1. cave; 2. water head; 3. flowing direction; 4. air hole; 5. gravels; 6. sands; 7. clays

3. The mechanisms of transportation-deposition of solid matters: The karst cave flow near valley belt is easy to converge the percolating or puring stream from surface (Fig 2). During high water level, the large cave near valley will quickly increase its kinetic energy to move the sands and clays into small passage ways until toward the zone, where the kinetic energies of both flows with reversal moving directions are equal, then the differential temperature effect may lead mixture corrosion in deep zone together with sands and clays'depositions. But in the case of lower level, the large cave will decrease its kinetic energy quickly; owing to the delaying action of percolating, that of small caves still hold up at high level case, therefore its flow may emerge out sands into upper large cave., Therefore the zoned rule of solid clastic depositions is: the upper large cave with gravvels, sands and clays'deposition, the lower passage-ways in deep zone with clays'deposition and the middle zone with sands mainly owing to their less cohasion to reciprocate.

Several models of solid clastic depostion in caves are summarized in Fig. 3.

(3) Several Problems of Three Phrases ' Flow

Except the large caves existing their throughafares to ventila, the origins of gas in karstified rocks even have many ways such as karstification, vaporization, dispersion, reduction, oxidation, decay of radio elements and bacterial actions. Otherwise, some problems related to three phrases'flow may be briefly discussed.

1. Vibration of elastic wave from gas mass: For the uncompresive liquid-solid runoff, their hydrodynamic features may express as continuously differential equation:

$$\frac{\delta V_x}{\delta x} + \frac{\delta V_y}{\delta y} + \frac{\delta V_z}{\delta z} = 0 \quad \ldots\ldots (9)$$

$$p(\text{denstity}) = \text{const} \quad \text{then} \quad \frac{dp}{dt} = 0$$

But for the compressive gas mass, that is:

$$\frac{dp}{dt} = \frac{\delta p}{\delta t} + \frac{\delta p}{\delta x} V_x + \frac{\delta p}{\delta y} V_y + \frac{\delta p}{\delta z} v_z \quad \ldots\ldots (10)$$

$$\text{div}\ V = -\frac{1}{p}\frac{dp}{dt} \quad \ldots\ldots (11)$$

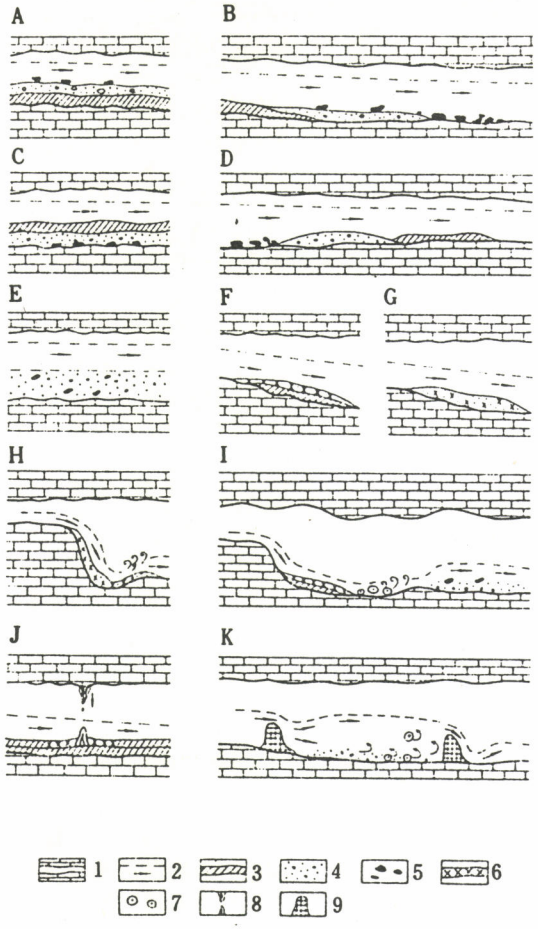

Fig. 3

Several models of depositional series of solid clastic matters in the caves
1. cave; 2. flowing surface and direction of three phrases'flow; 3. clays; 4. sands and gravels; 5. great gravels and blocky rocks; 6. speleothems with more pores or liquid-gaseous enclusions; 7. cave pearls or cave pancake; 8. stalactite and stalagmite; 9; rimestone, dragon shaped or bank shaped speleothems.

In three phrases'flow, if the starting speed Vo of a gas mass is zero, then compressed gas mass has the speed potencial φ:

$$\Delta\varphi = \frac{\delta^2\varphi}{\delta x^2} + \frac{\delta^2\varphi}{\delta y^2} + \frac{\delta^2\varphi}{\delta z^2} = \text{div } V \quad \ldots\ldots\ldots (12)$$

Its instantaneous speed of elastic wave is existing, that is:

$$v = \frac{\delta\varphi}{\delta s} \quad \ldots\ldots\ldots (13)$$

$$v_z = \frac{\delta\varphi}{\delta z} \quad \ldots\ldots\ldots (14)$$

2. Floating of gas mass: The gas mass floating in three phrases'flow has been bearing the buoyancy, that force P is related to the density, volume, flow velocity and water head.

3. Compressing or mixing of upper atmosphere: Increasing the water level in cave may lead the atmosphere in caves as free state to be compressing as hermetic mass or mixing in flow. The critical value of flow kinetic energy head for compressing air mass with 1 atm. is:

$$H_{pa} = \frac{p}{\gamma} + \frac{u^2}{2g} \geqslant 10 \text{ m} \quad \ldots\ldots\ldots (15)$$

p water pressure; γ ater unit weight; u flow speed; g acceleration of gravity; p/γpressure head, speed head

4. Cavitation of three phrases ' flow: Under ceitain condition a) such as high speed, high temperature, lowering internal pressure and changing of flowing section etc., the mixed flow may happen variation and cavitation. If speed u has not changed, cavitation coefficient Kca[3] is:

$$K\,c_a = \frac{(p_o - p_b)/\gamma}{uo^2 / 2g} \quad \ldots\ldots\ldots (16)$$

P_o– absolute static pressure to a datum level; V_o datum flow speed; P_b absolute pressure in gas hole; γ liquid speecific gravity

If changing the size of gas mass, then the radial speed from a liquid position to the gas mass center is:

$$v_L = -\frac{\delta\varphi}{\delta r} = \frac{R^2}{r^2}\frac{dR}{dt} \quad \ldots\ldots\ldots (17)$$

R–radius of gas mass; radial distance from gas mass center; t-time.

(5) Major Types of Mixed Erosions and Cavitations

The mixed erosions and cavitations in three phrases'flow may be separated into several types and sub-types (Fig.4):

A. adsorption type, forming mill hole, nest hole etc.; B. push type, forming trough hole, rock ridge etc.; C. vortex type, forming ceiling dome, subsurfarce shaft etc.; D. falling type, forming pit, hole and cave pearl etc. and E. vibration type, forming many phenomena.

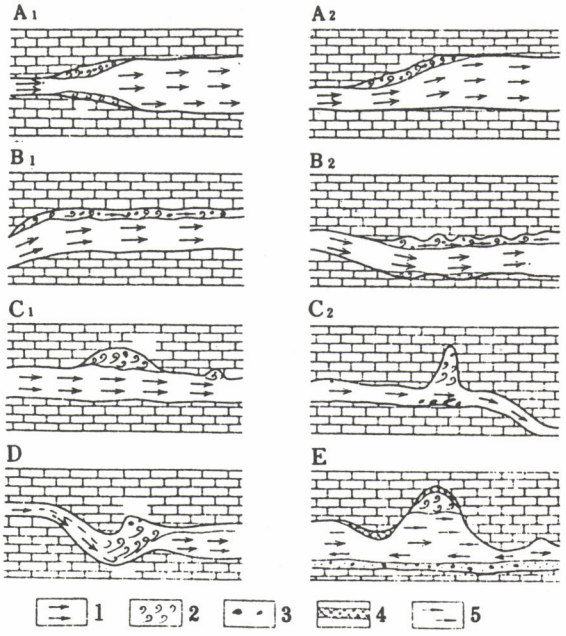

Fig. 4

Major types of mixed erosions and cavitations
1. flow direction: 2. cavitation and erosion; 3. solid particle; 4. speleothem; 5.pouring flow direction

Mixed erosions and cavitations with different feature to that of hydraulic builfding may strongly influence the corrosion and deposition in cave from three phrases'flow, that is very important to karst development and related hydrogeologic and engineering geologic condition as well as mineralizations.

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The way of cave formation by mixing corrosion

Ferenc Cser and István Szenthe,
Budapest, Hungray

RESUM

Sha efectuat un programa de computadora d'equilibri de les aigües kàrstiques utilitzant l'equilibri químic i llurs contrasentits. La corrosió per barreja es calcula amb una fórmula iterativa que sorgeix de la composició de dues aigües saturades per la seva barreja.

La corrosió es produeix en cada cas quan difereix algun dels paràmetres de les aigües.

Les formes de corrosió es troben generalment a les cavitats. Les observacions morfològiques demostren que la corrosió sota el nivell piezomètric pot ser el factor més important en la formació de les cavitats. Les anomenades formes d'erosió es poden explicar també per corrosió, en molts casos.

Es discuteix l'efecte de diferents factors en la formació de les cavitats.

RESUMEN

Se ha efectuado un programa de computadora para calcular la concentración de equilibrio de las aguas kársticas utilizando el equilibrio químico y sus constantes. La corrosión por mezcla se calcula con una fórmula iterativa que parte de la composición de dos aguas saturadas para su mezcla.

La corrosión se produce en cada caso cuando difiere alguno de los parámetros de las aguas.

Las formas de corrosión se encuentran generalmente en las cavidades. Las observaciones morfológicas demuestran que la corrosión bajo el nivel piezométrico puede ser el factor más importante en la formación de las cavidades. Las llamadas formas de erosión se pueden explicar también por corrosión, en muchos casos.

Se discute el efecto de distintos factores en la formación de las cavidades.

ABSTRACT

Computer program has been written for calculating the equilibrium concentration of karstic waters using chemical equilibria and their constants. Mixing corrosion is calculated with an iterative formulae starting from the composition of two saturated waters to be mixed.

Corrosion takes place at each case when any of the parameters of the waters differs.

The corrosion formes are generally found in the caves. The morphologycal observations show that corrosion below the piesometric level may be the most important factor in the formation of caves. The socalled erosion formes can also be explained by corrosion in many cases.

The effect of different factors in formation of caves is discussed.

Introduction

Bögli /1964/ proposed a mechanism for forming karstic cavernes the socalled mixing corrosion /Mischungskorrosion/. The chemistry of this process has been discussed by many authors /e. g. Ernst, 1965 and Markó, 1962 in the Hungaryan literature/. All the authors discussed the case of waters with pure Ca^{++} content. There is only one estimation for the corrosive effect of mixing waters with different temperature /Ernst, 1965/.

Recently Szenthe, 1986 found many morphological evidences indicating the corrosions power of water on cave walls. They were found not only in karstic caves, many trivial formes were found also in many of the Budapest caves of thermal origin /Ferenchegyi cave, Szemlöhegyi cave, Mátyáshegyi cave tec./. We had to extend the studies on the mixing corrosion over the normal karstic conditions taking into account the waters with hidrothermal origin, too.

Theoretical bases

The saturation of karstic waters is determined by the chemical equilibria each characterised by a constant as folloves:

$CaC0_3 \rightleftarrows Ca^{++} + CO_3^{--}$ $\quad L = [Ca^{++}]\,[CO_3^{--}]$

$HCO_3^- \rightleftarrows CO_3^- = H^+$ $\quad K_2 = [H^+]\,[CO_3^{--}]\,/[HCO_3^-]$

$H_2CO_3 \rightleftarrows HCO_3^- + H^+$ $\quad K_1 = [H^+]\,[HCO_3^-]\,/[H_2CO_3]$

$H_2CO_3 \rightleftarrows H_2O + CO_2$ $\quad K_P = [CO_2]\,/[H_2CO_3]$

$H_2O \rightleftarrows H^+ + OH^-$ $\quad S = [H^+]\,[OH^-]$

$CaMg(CO_3)_2 \rightleftarrows Ca^{++} + Mg^{++} + 2CO_3^{--}$

$L_D = [Ca^{++}]\,[Mg^{++}]\,[CO_3^{--}]^2$

Here the [] means the concentration of a component /ion, molecule etc/. in mol/l units.

The value of the constants can be evaluated using chemical basic data as give e. g. by Fagunda and Valdes, 1975. The bases of our calculations are the ionic ballences:

$2[Mg^{++}] + 2[Ca^{++}] + [H^+] = 2[CO_3^{--}] + [HCO_3^-] + [OH]^- + [A^-] + [OH^-] + [A^-]$

Where $[A^-]$ means the concentration of any non carbonatous anions i. e. the permanent hardness of the waters.

We had no data for the dissociation constant of the water at different temperatures. Therefore, started from the data given by Erdey, 1955, the following function was created by a least square fit:

$S = \exp / -34.182 - 0.096t - 4t^{1.9618}$

where T is given in °C, and exp means natural exponentials.

Calculations and results

As the first approximation we were limited to the case of waters without Mg, as the L_D values in the literature /e. g. Hodgemann, 19 / are very unsure. Its probable value is:

$L_D = L * L / 10^{-14}$ mole^{-4} 1^4 /.

After substituting the concentrations of carbonates by the values calculated from the constants and the concentration of the Ca, we get a second order equation for the concentration of H^+:

$[H^+]\,([Ca^{++}] - L/K_1) + [H^+]\,(2[Ca^{++}]2 - 2L - [A^-]\,[Ca^{++}]) - [A^-]\,[Ca^{++}] = O$

The pH of the water is a single function of the concentration of $[Ca^{++}]$ at fixed amount of permanent hardness and the temperature of the water. This is given in Figure 1.

Figures 2-4 represent the variation of the different parameters of saturated karstic waters as a function of their Ca-content.

All the Figures show hyperbolic functions, i. e. there is a mixing corrosion at each cases when one of the parameters differ by mixing of two saturated waters.

A computer program has been written a COMMODORE 64 home to calculate the exact value of solved amunts of $CaCO_3$

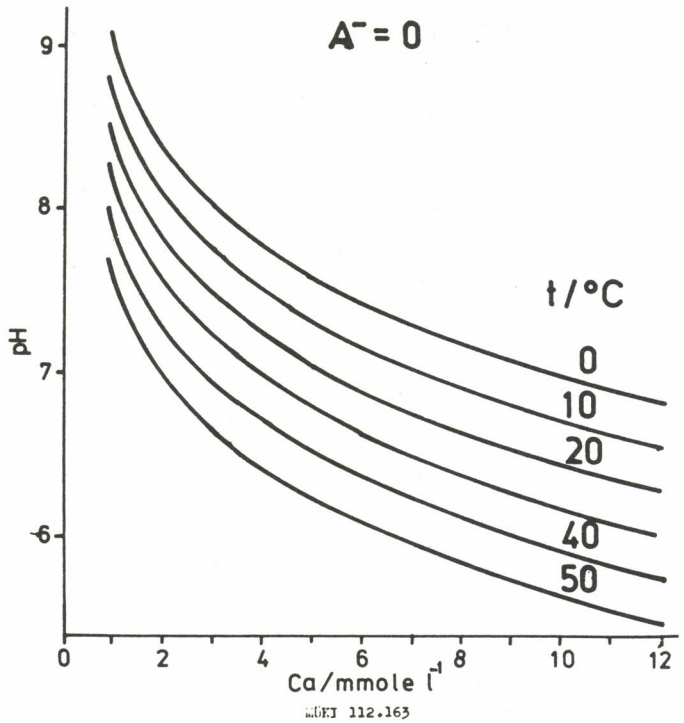


Figure 1. The change of the pH as a function of the Ca content of saturated karstic waters at different temperatures.

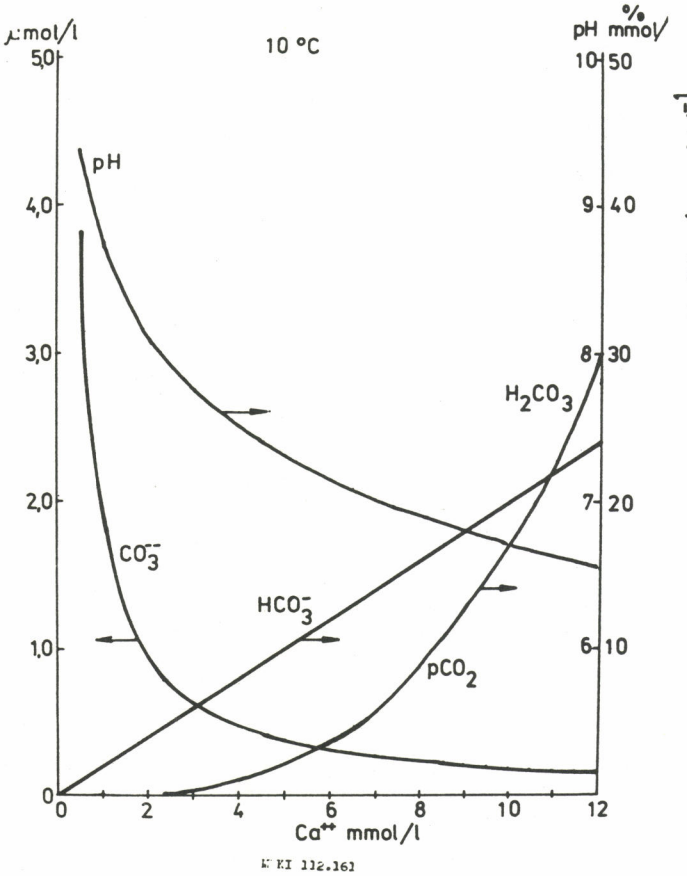


Figure 2. The change of the chemical composition of saturated karstic waters as a function of its Ca content.

by mixing of two satirated waters with different compositions or temperatures. First an analytical formulae was going to be developed. The result was an equation with sixth order what could not be solved by this simple computer. Than an iterative procedure was introduced with a suitable result at greated differencies in the parameters. At small differencies the convergence of the procedure is unsure as the functon at zero is very flat. The process is the following:

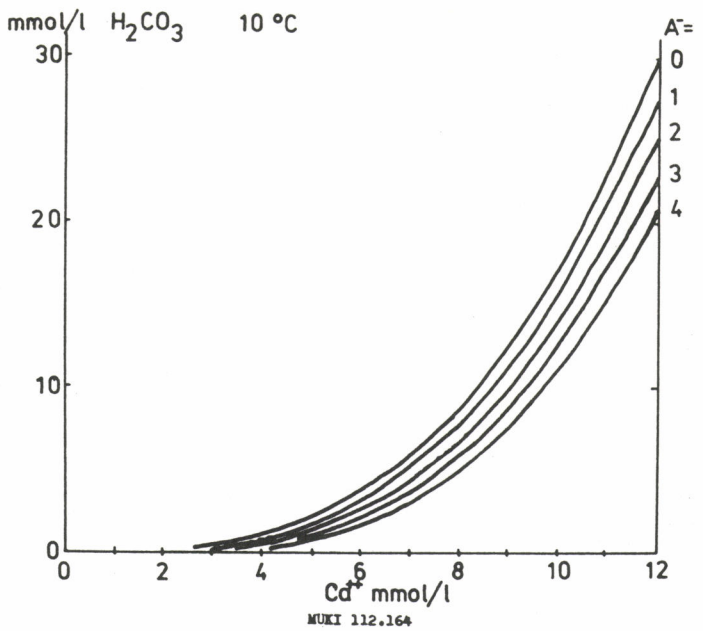


Figure 3. The change of the H_2CO_3 content of saturated water as a function of its Ca content at different amounts of permanent hardnes expressed as the concentration of an univalent anion $[A^-]$.

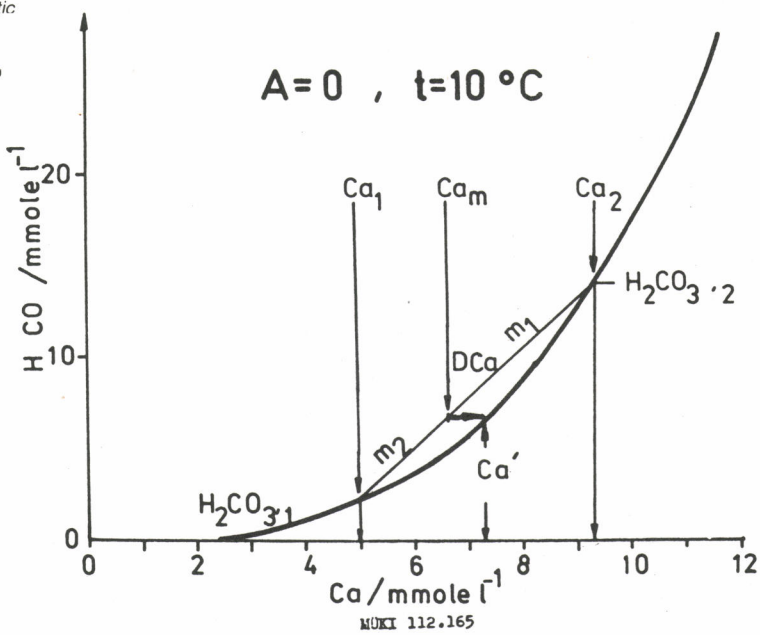


Figure 4. The origin of corrosion power /Dca/ from the mixing of two saturated karstic water /Ca_1, Ca_2/ in a ratio of m_1/m_2.

1. Ionic concentration of the waters each in equilibrium are calculated from equilibrium data.

2. The starting composition of the mixed water is calculated by the mixing role: $X_m = m_1X_1 + m_2X_2$ where $m_1 + m_2 = 1$.

3. Starting from the concentration of H_2CO_3 as a result of the mixing role new concentration of Ca and the difference was calculated / $DCa = Ca' - Ca_m$/.

4. Using the Ca value new concentration of the carboates and their differences /DH_2CO_3, $DHCO_3^-$ and DCO_3^{--} /were calculated with their sume of DCS.

5. New DCa is calculated by the equation of $DCa_n = DCa_{n-1} - /DCS - DCa_{n-1}/^* 0,2$

The processes 4. and 5. have been repeated until abs/ DCa - DCS/■ $\leqq 10^{-6}$.

The iteration converged usually within 40-60 cycles. The process was unsure when there was a difference in any of the ionic concentration less then 0,2 mmol/l or 0,1 °C in the temperature of the waters. Some important results are summarized in Table I.

Table I. Excess $CaCO_3$ in mmole/l solved in the 1:1 mixture of two waters

parameters	$[Ca^{++}]$	$[A^-]$	t	$[Ca^{++}]$	$[A^-]$	t	$[Ca^{++}]$	$[A^-]$	t
	Example I			Example II			Example III		
water 1	3.0	0.3	10	3.0	0.3	10	3.0	0.3	10
water 2	4.0	0.3	10	3.62	0.64	41	4.87	1.1	74
water mixed	3.52	0.3	10	3.54	0.46	25	5.77	0.68	42
excess $CaCO_3$: 0.026/0.74 %				0.231/6.99 %			1.816/46.16 %		

The concentrations are given in mmole/1, t in °C.

Example Iis the mixing of two karstic waters. One is the average concentration of dropping waters from stalagmites in the Vass I. cave, Jósvafö referred by Czajlik, 1981.

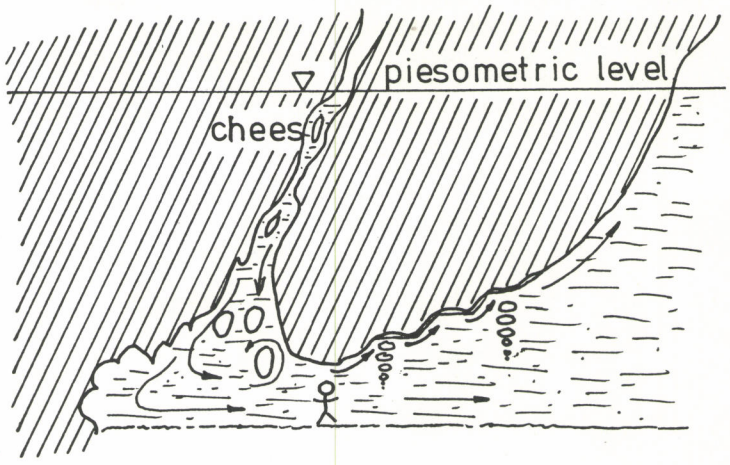
The second component is a hypothetical water with the composition different with the standard deviation in the concentrations from the averaged one.

Example II is the mixing of normal karstic water with the water of a mixed thermal spring.

Example III is the mixing of a normal karstic water with a hot spring. The composition of the thermal /Árpád–/ and that of the hot /Városliget–/ springs were taken from the data of VITUKI, /Budapest, Hungary/.

Table I shows that at least 1-50 % of the corrosion power of a normal karstic water can be found in the mixing zone.

A very great corrosion power of the mixed water of hot springs and normal karstic water is indicated by the Table.



The role of the time scale

Whyte, 1977, discussed the rate of the solution of the lime stone in karstic aquifers. He referred the Berner-Mose experiment, 1974. According to the data there is a highly decreasing rate of solution when the water gets to the vicinity of its saturation. The mixing corrosion of karstic waters infiltrated has a corrosion power correspondig to their region 3-B, i.e. the pH is inbetween 0.1 and 0.3. The rate of solution varied in this range between 10 to 1000 mg cm^{-2} $year^{-1}$.

An estimation can be made from the data of Example I in Table I. If a cave with triangular cross section is filled with water has the to day mean measures, /e.g. Vass I. cave/ each m^3 of stored water has cca. 1 m^2 of contact surface at the walls. Using the rate of solution with the lower allowded pH value /A pH = 0.1/ 7-10 days is necessairy to realize the corrosion power. There is sufficient time to realize the corrosion power, as the output time constants out of fload periods exceeds 10 day^{-1}.

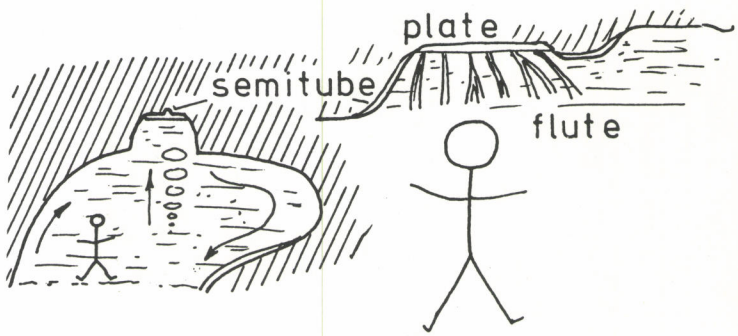


Figure 5. Typical cross section of a cave indicating the characteristic forms of the moving air bubbles.

Morphological observations.

The corrosion power is a hipothetical power, as the water should be contacted with the limestone. The mixing of the different waters takes place usually in greater cavernes with a very low flow-rate. It means, that the greated volume of corrosive water does not contact te walls at normal conditions. Consequently, we should find some typical morphological forms indicating the way of the corrosive water to contact the wall. According to Szenthe, 1986, channels, flutes, plates semi-tubes and semi-channels at the ceiling, chees-like formations at the midle or at the top of cavernes, wave shells, key-holes etc. on the walls are the typical indicators of the corrosiw pover due to the mixing corrosion below the piesometric level. Figure 5 represents these forms and their position in a typical cross section of the Vass I. cave. The low stream is moving from the chees to the plates at the ceiling. Air bubbles moves the water at the ceiling forming the flutes, and semi channels. Semi channels leads the bubbles from one plate to the other upwards. The motion of the bubbles results in local turbulescent of the water puting the corrosive power to the lime surface.

Many such kind of morphological indicators can be found in caves at those walls, where there is no sinter. In some cases /e. g. Ferenchegyi cave, a thermal cave/ the morphological indicators can be observed also on sinters indicating, that the cave was under the piesometric level after the sinter had been formed.

Conclusion

The mixing corrosion is a sufficient corrosion power to solve the rock below the piesometric level forming the big cavernes explored recently. Greater corridors, and caverns can be formed at places, where the mixing of water with very different composition occured. There is no need to suppose the effect of erosion, although, there are caves where the effect of the erosion can not be excluded. The erosion may be very effective in iced periods at those cavernes what had well developed open ponores. The triangle like cross section of caves indicates that the cevern was formed with corrosion, i.e. with mixing corrosion. The greater the difference in the vegetation above the cavern the greater the probability to have great corrosion power by mixing. The longer the way of the water from the surface to the piesometric level, the greater the probability of the corrosion power.

A very great corrosion power of saturated karstic waters with mixing of thermal –or hot springs can be occured. The slow laminar stream of the waters below the piesometric level in this case keeps the mixing power effective for longer time. This may be the reason of big labyrinth of corridors in limestones with thermal spring activity.

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ESPELEOCRONOLOGIA I PALEOCARST
ESPELEOCRONOLOGIA Y PALEOKARST
SPELEOCHRONOLOGY AND PALEOKARST

10131

Speleothems of the Winterberg and Quaternary Climate of the Harz Mountains

Kay-Christian Emeis and Stephan Kempe

RESUM

Datacions radiomètriques (^{14}C, U/Th), conjuntament amb anàlisis d'isòtops estables d'espeleotemes recoberts de cristalls del Winterberg, a les muntanyes de Harz (Rep. Fed. d'Alemanya) revelen la història del clima complex del Plistocè recent d'aquesta àrea. Quatre interglaciars càlids, corresponents a les fases 7, 5, 3 i 1 de Shackleton & Opdyke, podrien ésser establerts i correlacionats amb mètodes geològics convencionals. Les discontinuïtats més grans observades en el creixement dels espeleotemes i inclús la pròpia destrucció de les estalagmites podrien estar relacionats amb els períodes freds i possiblement van ser causats pel gel. L'anàlisi del factor R-mode, va revelar una correlació significativa de concentracions de Sr en el carbonat, amb valors $\delta^{13}C$ i $\delta^{18}0$, mentre que la separació d'altres elements no pot ser controlada mitjançant la temperatura. No es va detectar cap indici de metasomatisme diagenètic en cap element divalent per al Ca^{2+} en la cristal·lització. Aquest fet s'agafa com una prova de que els espeleotemes, en la major part dels casos, són autèntics «sistemes tancats» i mereixen ésser sotmesos a estudis paleoclimàtics posteriors.

RESUMEN

Dataciones radiométricas (^{14}C, U/Th) en conjunción con análisis de isótopos estables de espelotemas recubiertos de cristales del Winterberg, de las montañas Harz (Rep. Fed. Alemania) revelan la historia del complejo clima del Pleistoceno reciente de este área. Cuatro interglaciares cálidos correspondientes a las fases 7, 5, 3, y 1 de Schakleton & Opdyke podrían ser percibidos y correlacionados con métodos geológicos convencionales. Las mayores disrupciones durante el crecimiento del espeleotema e incluso la destrucción de estalagmitas, podrían ser relacionadas con los períodos fríos y posiblemente fueron causadas por el hielo. El análisis del factor R-mode reveló una correlación significativa de concentraciones de Sr en el carbonato, con valores $\delta^{13}C$ y $\delta^{18}0$, mientras la separación de otros elementos no puede ser controlada mediante temperatura. No se detectó indicación alguna para metasomatismo diagenético, en ningún elemento divalente para Ca^{2+} en la cristalización. Esto se toma como una indicación de que los espeleotemas en la mayoría de los casos son verdaderamente «sistemas cerrados» y merecen trabajos paleoclimáticos posteriores.

SUMMARY

Radiometric dating (^{14}C, U/Th) in conjunction with stable isotope analyses of speleothems recovered from the Winterberg quarry of the Harz Mountains (F.R.G.) revealed a complex Late Pleistocene climatic history of this area. Four warm interglacials corresponding to stages 7, 5, 3, and 1 of Shackleton & Opdyke could be discerned and correlated with conventional geological methods. Major disruptions during speleothem growth and even destruction of stalagmites could be correlated with cold periods and possibly was caused by ice. R-mode factor analysis revealed a significant correlation of Sr concentrations in the carbonate with $\delta^{13}C$ and $\delta^{18}0$, values, while partitioning of other elements appears to be controlled by temperature. No indication for diagenetic metasomatism of any divalent element for Ca^{2+} in the crystal lattice was detected. This is taken an indication that speleothems in most cases are indeed «closed systems» and merit further paleoclimatic work.

1. Introduction

Combined radiometric and stable isotope methods have been used on calcite from speleothems to reconstruct Pleistocene climate (Atkinson et al., 1978; Gascoyne et al., 1980; Hendy, 1971). It can be shown that this inferred land temperature record agrees well with the record from marine sediments (Glazek & Harmon, 1981) and that temporal resolution due to the fast and continuous growth of stalagmites during Interglacials (0.5-1mm/yr) generally is better than that of classical geological methods (loess stratigraphy, fluvial terraces, lake sediments). In these studies, ^{14}C and U/Th dating of calcite provide a time frame for speleothem growth periods in which high resolution profiles of $\delta^{13}C$ and $\delta^{18}0$ are fitted.

Theoretically, the partitioning of certain elements between the water and the precipitating calcite is depending on temperature (Kinsman & Holland, 1968), much like the partitioning of stable and radioactive isotopes (Hendy, 1971). In consequence, concentration changes of certain trace elements may be indicators of climatic changes. Candidates for this kind of «geochemical thermometer» are the elements Sr, Ba, and Mg because of similar ionic radii and charge. Because kinetic effects in the aqueous solution precipitating calcite and diagenetic metasomatism have to be considered (Fischbek, 1974; Geyh, pers. comm., 1984), the relationships between concentration of these ions relative to Ca in the calcite lattice has not been investigated in the past. The use of speleothems for paleoclimatic investigations infers that the primary calcite crystal lattice does not undergo postdepositional diagenetic alteration. To test this concept, statistical evaluation of age and geochemical properties may give an indirect clue as

to changes ocurring after deposition and verify the assumption that all speleothems of a certain age are similar and morphological and chemical properties.

In this article, we report geochemical investigations conducted on seven speleothems froom caves destroyed by the Winterberg quarry which mines Devonian reef-limestone (Franke, 1973) (Fig. 1).

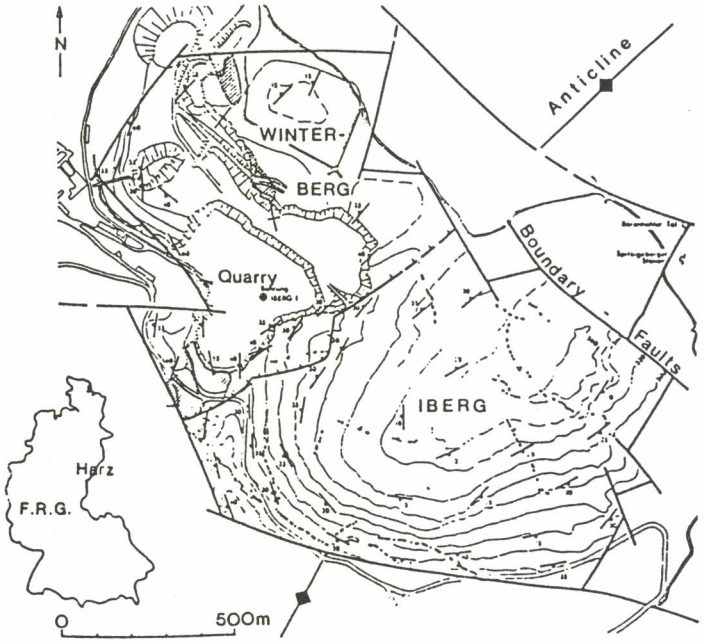

Figure 1: The Iberg/Winterberg karst in NW Germany (see inset) is a middle to upper Devonian atoll reef with massive limestone exposed in the Winterberg quarry. It is surrounded by lower Carboniferous graywackes.

2. Material and Methods

Six stalagmites and a flowstone were sampled for geochemical and morphological investigations (Fig. 2). They were analyzed by standard geochemical techniques of the various laboratories involved in this study (see Acknowledgements) (Emeis, 1982).

Subsamples for radiochemical dating were taken from the base (oldest) and the top (youngest) of each specimen, with additional sample couplets bordering obvious hiatuses. Subsamples of each growth phase were prepared for determinations of major and minor element composition by XRF Spectroscopy against rock standards. Porosity, as well as mineralogical (X-Ray Diffraction) and chemical (EDAX in conjunction with a SEM) composition of the HC1 insoluble residue was determined. Subsamples for determinations of stable isotope composition were taken along growth axes at close intervals (see Fig. 2). In addition thin sections were prepared. Cross correlation and factor analysis were used to fit individual isotope curves to give a continuous record for the time span covered by speleothem growth, and to determine geochemical relationships between individual speleothems, respectively (for details see Emeis, 1982).

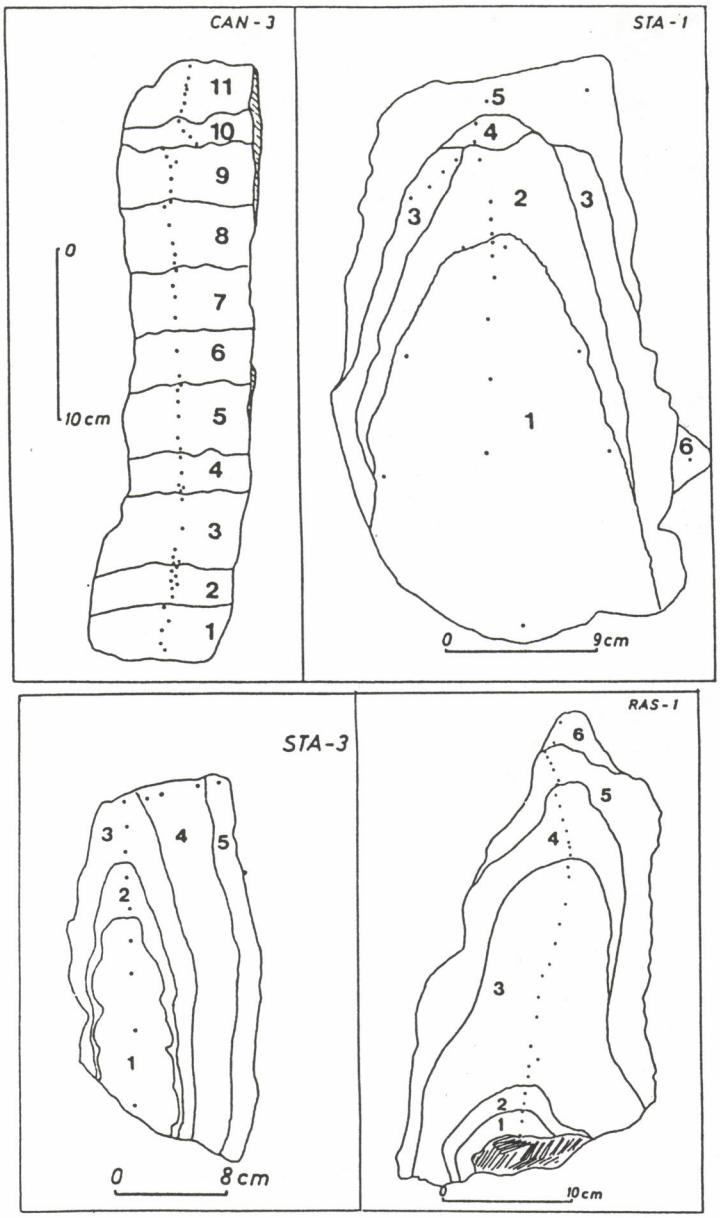

Figure 2: Cross sections along growth axes of speleothems used in this study. Outlined are discernable generations of calcite and erosional hiatuses. Dots show sample locations for stable isotope analyses.

Table 1: Radiometric Ages of Objects

Name	Age Base	Age Top	Remarks
CAN-3	248.0 ka ±24.0	107.0 ka ±7.0	Hiatus from 190 to 114 ka (U/Th dating; Peters, 1981)
STA-1	44.5 ka ±1.8 ka	30.6 ka ±0.7 ka	Several hiatuses (^{14}C dating)
STA-3	43.4 ka ±2.9ka	n.d.	Erosional top
RAS-1	10.0 ka	Recent	Age determined by ESR (Grün, pers. comm. 1985)

3. Results and Discussion

Four specimens will be discussed in the context of «dated» stable isotope records. Ages for CAN-3, STA-1, and RAS-2 are given in Table 1. They range from about 250 ka b.p. to Recent. Profiles of stable isotopes for CAN-2 and STA-1 are statistically connected by significant cross correlation with the isotope record RAS-1.

A combined stable isotope record of these specimens is given in Fig. 3. Fig. 4 plots stable isotope values for stalagmite STA-1, which exhibits three marked dissolutional/erosional events during its deposition in the intra-Weichselian interstadials. Hiatuses corresponding to phases of non-deposition or even destruction are found in many of the speleothems, but are best visible in STA-1. Four growth phases, two of them dated at 44.5 ka (start of growth) and 30.6 ka (youngest calcite) are separated by three major erosional events. In the first erosional event, which is documented by dissolution of calcite on the boundary and deposition of a residual clay on top of the surface of phase 1 (see Fig. 2), temperatures of formation inferred from $\delta^{13}C$ values decreased, followed by a marked increase in temperature some time after the erosional event. Both other erosional events

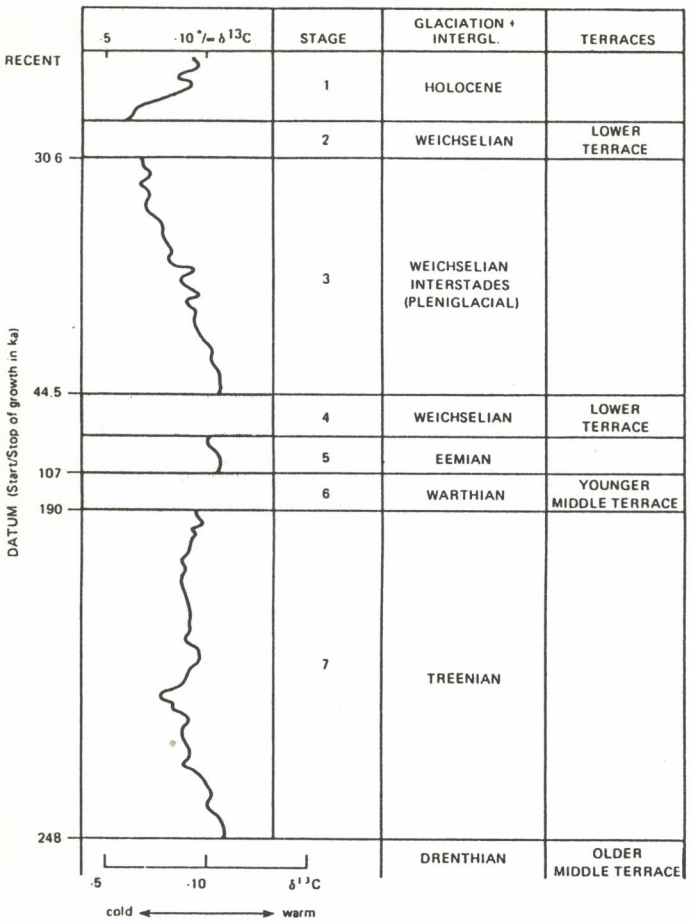

Figure 3: Combined stable isotope records of speleothems recovered from the Winterberg quarry, age assignement of the basis of radiometric dating, and correlaton with other paleoclimatic records (For errors on age control, see Table 1). The plot was smoothed by filtering to reduce scatter, hiatuses are indicated by shaded areas.

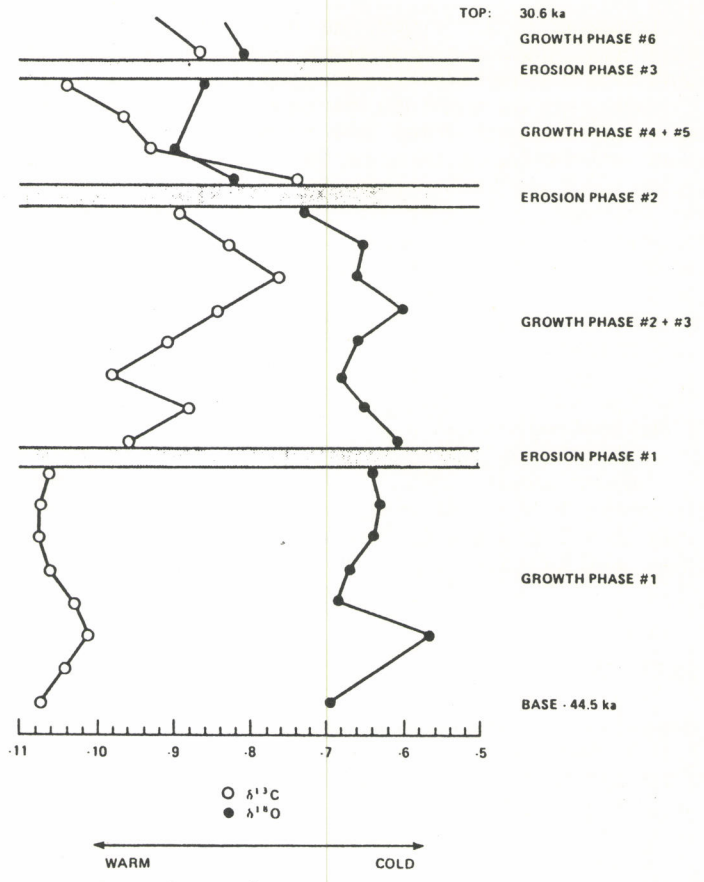

Figure 4: Plot of $\delta^{13}C$ and $\delta^{18}O$ of specimen Sta-1: Hiatuses are depicted as shaded areas. Light isotope values record warm temperatures.

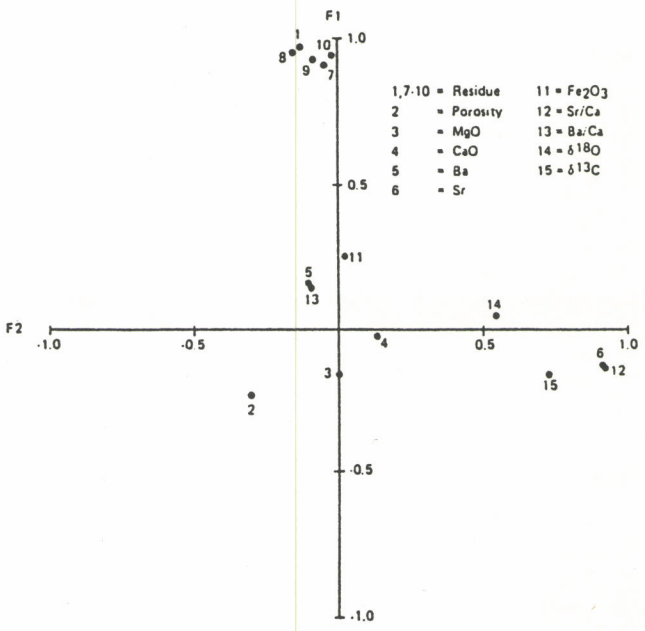

Figure 5: Plot of factor scores for parameters, based on all samples analyzed in the study. Note the close relationship between isotope characteristics, Sr concentrations, and Ca/Sr ratio.

–between phase 3 and phase 4 the top was abrased, and after deposition of layer 5 the stalagmite toppled– removed older calcite. Increasing temperature after the hiatus indirectly proves the transition from cold, non-depositional periods to warm periods favourable for calcite accretion. We believe that periglacial cave ice is responsible for the abrasion of speleothem tops.

Results from these investigations are the following:

1) At least four major phases of speleothem growth are documented by dating, with high resolution stable isotope curves allowing extimates of relative changes of temperatures in the caves: The Treene Interstadial of the Saalian glaciation (corresponding to Stage 7 of Shackleton & Opdyke, 1976), the Eemian Interglacial (Stage 5), intra-Weichselian interstadials (Stage 3), and finally the Holocene.
2) Hiatuses (disruption and destruction of spelothems) are accompanied by an increase in $\delta^{13}C$ values before and after erosion, indicating cooler temperatures of formation, dissolution of calcite, clay deposition on the erosional surface of even abrasion, and a subsequent rise in temperatures after the hiatus. We interpret this sequence as an indication for a drastic deterioration of climate, possibly leading to the formation of ice in the caves during the advance of permafrost which in turn may have mechanically damaged speleothems.
3) Stable isotope trends of speleothems at present cannot be correlated with those of marine sediments due to the much higher resolution of this continental record.

Of all geochemical parameters measured only Sr concentrations and Sr/Ca ratios bear any relationship to the primary indicators for the temperature of formation, i.e. to $\delta^{13}C$ and $\delta^{18}O$. The Q-mode factor analysis, depicted in a plot of factor loadings (Fig. 5) for all parameters in a coordinate system of two main statistical components extracted from the geochemical data pool, groups these three parameters in one section. Neither the composition of the acid insoluble residue (amorphous iron oxohydroxides and clay minerals), nor porosity, magnesium, or barium concentrations appear to be temperature related. Furthermore, checking sample clusters for an indication of similar ages did not yield any results: rather geochemical parameters appear to be related to specific environmental conditions prevailing in the micro environment of a specific cave. In short: All speleothems of a particular cave, and even subsamples of individual speleothems, are geochemically different. The reasons

are changing water supply, variations in the supply of allochthonous material, surface staining by clay minerals, or kinetic partitioning of elements during evaporation and calcite deposition. This lack of any relationship between geochemical properties with age suggests further that post-depositional metasomatism (replacement of Ca^{2+} in the calcite lattice by other divalent ions, i.e. Mg^{2+}, Sr^{2+}, Ba^{2+}) did not occur. This inference is corroborated by investigations of thin sections, which display original boundaries of calcite crystals without post-depositional recrystallisation. The original morphology and chemistry of the calcite is indeed preserved in the speleothems investigated in this study, underscoring their validity as tools for paleoclimatic reconstruction.

4. Acknowledgements

The samples were dated by Dr. M.A. Geyh and Dr. G. Hennig (Hannover). Dr. M.A. Geyh and Dr. W. Mook (Groningen) provided analyses of $\delta^{13}C$ and $\delta^{18}O$. This study was part of a master's thesis (K.-C.E.) and was funden by the state of Lower Saxony.

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1055

U-series ages and oxygen, carbon isotopic features of speleothems in Guilin

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RESUM

De les cavitats conegudes amb el nom de Big Cave i Feisi Cave (Maomaotou Hill, Guilin) es varen recollir tres estalagmites (mostres 82-29, altura 1,07 m.; mostra GL, 0,73 m., mostra 82-28, 0,56 m.), les quals es van dividir en 14 submostres per a ésser sotmesses a una datació mitjançant Th^{230}/U^{238}. Les seves antiguitats es varen fixar en l'interval 41->350 x 10^3 anys BP, d'una manera ajustada al seu creixement. Totes les estalagmites presentaven clares interfases de diposició cap els 130, 210 i 220-230 x 10^3 anys BP, aproximadament.

Simultàniament, es va constatar una gran concentració dels components isotòpics δO^{18} i δC^{13}. La concentració de δO^{18} i de δC^{13}, prop de les interfases mostrava una clara tendència a augmentar, cosa que es relaciona amb els canvis paleoclimàtics de Guilin.

L'autor agraeix al Dr. M.M. Sweeting i a Miss Angela Rae la seva ajuda i la seva aportació de resultats de datacions.

RESUMEN

De las cavidades conocidas como Big Cave y Feisi Cave, Maomaotou Hill, Guilin, se recogieron tres estalagmitas (muestras 82-29, altura 1,07 m., muestra GL, 0,73 m., muestra 82-28, 0,56 m.) que se dividieron en 14 submuestras para someterlas a una datación mediante Th^{230}-U^{238}. Sus antigüedades se fijaron en el intérvalo 41->350x10^3 años BP y de un modo acorde a su crecimiento. Todas las estalagmitas presentaban claras interfases de deposición hacia los 130, 210 y 220-230x10^3 años BP aproximadamente.

Simultáneamente se determinó una gran concentración de los componentes isotópicos δO^{18} y δC^{13}. La concentración de δO^{18} y δC^{13} cerca de las interfases mostraba una clara tendencia a aumentar, lo que está en relación con cambios paleoclimáticos en Guilin.

El autor agradece al Dr. M.M. Sweeting a Miss Angela Rae su ayuda y aportación de resultados de mediciones.

SUMMARY

Three stalagmites (sample 82-29, height 1.07 m; sample GL, 0.73 m; sample 82-28, 0.56 m) were collected from Big Cave and Feisi Cave, Maomaotou Hill, Guilin and were divided to 14 subsamples for Th^{230}-U^{238} dating. Age data were in the interval 41->350x10^3 yr. BP and accorded with normal growth order. In all stalagmites were occurred clear depositional intefaces approximately about 130, 210 and 220-230x10^3 yr. BP.

Simultaneously, it is determeted densely δO^{18}, and δC^{13} isotopic components. δO^{18}, δC^{13} features near depositional interfaces showed a tendency to rise, which connected with cold paleoclimatic changes in Guilin.

Author was in acknowledgment to Dr. M.M. Sweeting and Miss Angela Rae for their help and provided measurment results.

Maomaotou Hill is located at right shore of Taohua River, west-northern Guilin, and is a peak-bunch in the peak-forest plain. In the hill four caves were found, from the south to the north are Ludi Cave, Big Cave, Feisi Cave and Chuangyan Cave, and distribute with equal distance (Fig. 1). Three stalagmites were collected from Big Cave and Feisi Cave (Fig. 2) and were divided to 14 subsamples for ^{230}Th-^{234}U dating. Simultaneously, they were divided densely to 46 subsamples for ^{18}O and ^{13}C isotope component measurement. ^{230}Th-^{234}U dating had completed respectively in three isotopic laboratories of Institute of Geology, Academia Sinica (Peking), South China Sea Geological Survey Headquaters (Guangzhou) and Geography Department of Oxford University (England). Stable isotope measurement had completed respectively in Institute of Geology, Academia Sinica (Peking) and Institute of Karst Geology (Guilin). All laboratories worked independently, but their data were replenished one another, so it is may be completely believe in these results.

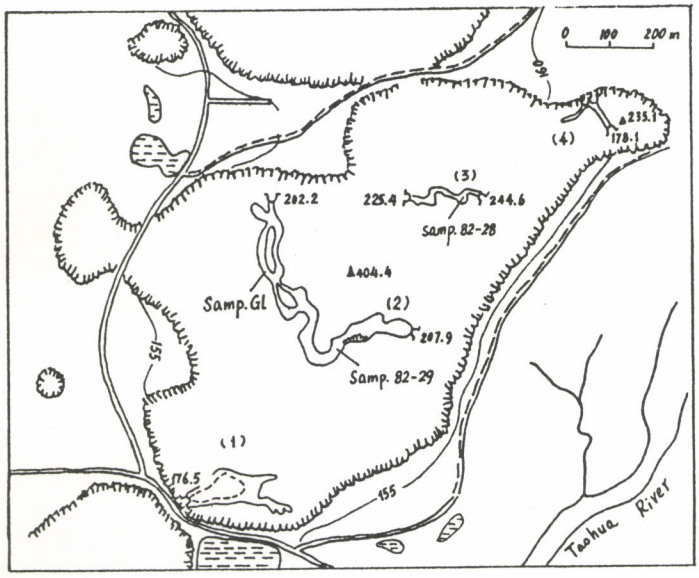

Fig. 1. Location map of sampling stalagmites.
82-28, GL, 82-29 show the location of sampling.
Other numbers show the absolute altitude of Hill and cave (m). (1) Ludi Cave; (2) Big Cave; (3) Feisi Cave; (4) Chuangyan Cave.

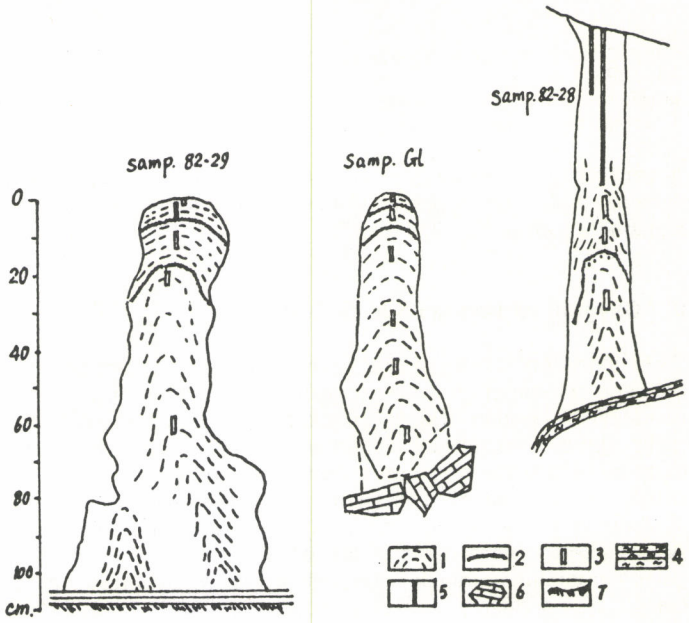

Fig. 2. Locations of subsampling for U-series dating of three stalagmites.
1. Growth veins in stalagmites; 2. depositional interrupcions; 3. locations of subsamples; 4. travertine; 5. straw stalactite; 6. brockdown rock pieces; 7. clay.

1. Results of U-series dating

Measured results of U-series dating were listed in Table 1. Sample 82-29 was collected in the travertines of the terrace of the key-form cross-section in Big Cave, height 1.07 m. In 4 cm and 16 cm from the top two depositional interruptions were occurred and were recognized by hydroxyapatite coating 0.5-3 mm thick and by partial powerring and hydrolysis of the calcite(1). Five ages measured by ^{230}Th-^{234}U method showed a normal growth order and that the stalagmite was deposited since >350x10^3 yr. BP to 41x10^3 yr. BP and had grown for about 300x10^3 yr. Lower part of the stalagmite 40-45 cm long exceeded the limit of U-series method (>350x10^3 yr.) and can't be measured.

Sample GL was collected in breakdown rock pieces in upper passage of Big Cave, height >0.73. In 4 cm and 9 cm from the top two clear depositional interruptions were occurred too. Six age data showed, that the stalagmite had grown for about 200x10^3 yr. from >385 to 191x10^3 yr. BP. Lower part of this stalagmite 10-15 cm long had older ages than the limit of U-series method.

Table 1. U-series data of three stalagmites in Maomaotou Hill, Guilin

No of samples	Name of caves	Locality of subsamples (from top to bottom, cm)	U concentration ppm	$\frac{U^{234}}{U^{238}}$	$\frac{Th^{230}}{U238}$	$\frac{Th^{230}}{U^{238}}$ ages x10^3y.	Meas. labor.
82-29-0	Big Cave	0-2	0.14±0.005	1.66±0.06	0.32±0.01	41 ± 1.5	P
82-29-7		0-4	0.07±0.003	1.52±0.05	0.68±0.03	112^{+10}_{-7}	P
82-29-6		7-15	0.06±0.002	1.45±C.05	0.80±0.03	152^{+13}_{-10}	P
82-29-5		17-22	0.04±0.002	1.24±0.05	0.91±0.04	220^{+30}_{-25}	P
82-29-3		57-62	0.63±0.02	1.11±0.03	1.03±0.04	>350	P
GL-1	Big Cave	1-4.5				191^{+31}_{-24}	E
GL-2	upper passage	7-10				224±75	E
G-1		14.5-17.8	0.06±C.003	1.07±C.05	0.93±0.05	267±55	G
G-2		31.5-34.5	0.04±C.003	1.02±0.06	0.93±0.05	288±67	G
G-3		44-47	0.05±0.002	1.06±0.06	0.97±0.07	344±105	G
G-4		62-66	0.08±0.004	0.92±0.06	0.94±0.05	385±152	G
82-28-7	Feisi Cave	0-10				173±30	E
82-28-6		10-17	0.09±0.002	1.12±0.03	0.87±C.03	205^{+25}_{-20}	P
82-28-3		27-36				260^{+50}_{-69}	E

Measurement isotope laboratory:
P--Institute of Geology, Academica Sinica (Peking),
G--South China Sea Geolcgical Survey Headquaters (Guangzhou),
E--Geography Department of Oxford University (England),(Personal communication by M.M.Sweeting)

Sample 82-28 was collected in Feisi Cave and was a lower part of the collumn, height 0.56 m. In 40 cm from the bottom a depositional interruption was occurred too. Three ages data showed that the stalagmite was grown for about 173-260x10^3 yr. BP. and growth process of complete collumn may be prolonged about 150-200x10^3 yr.

Thus it can be seen that growth ages of three stalagmites was simultaneous almostly and was compareable (Fig. 3).

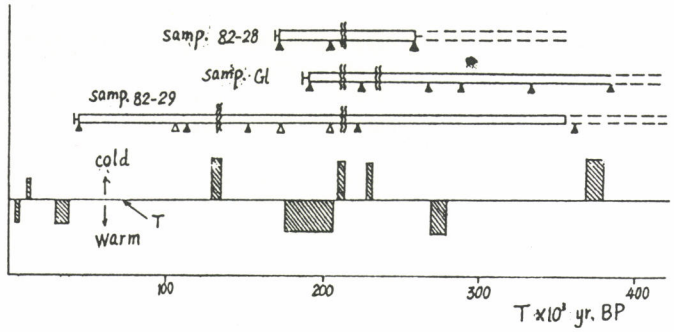

Fig. 3. Compare of U-series dating of stalagmites and paleoclimatic change since 400x100³ yr. BP.
▲ age data; Δ age data (consulting); depositional interruption; T-today's annual air temperaturature (about 19 °C).

According to the location of subsamples and their dating, it is evident that three epoches of depositional interruptions in stalagmites were 130, 210 and 220-230x10³ yr. BP respectively.

II. Oxygen, carbon isotope features

In the interior zone of the cave stable isotope components between air-dripping water-speleothem were in equilibrium condition[2]. Therefore, stable isotopic components of speleothems reflect the air temperature in interior zone of the cave, that is an average annual temperature in earth surface. Paleotemperature could be calculated with isotopoic components of both speleothem (calcite)-water (nonalterring water in maternal rock). When isotopic components of parcelled water hadn't measured, paleotemperatures couldn't be calculated with singe data of calcite. But a change curve of isotipic features in continuous sampling of the stalagmite formed under same dripping water location could be well reflect relative paleotemperatures and their change features.

We made a densely sampling from these stalagmites for $\delta^{18}O$ and $\delta^{13}C$ measurment and according to their results made time-$\delta^{18}O$ and time- $\delta^{13}C$ change curves (Fig. 4). Isotopic features of subsamples without age dating had thrown in the figure according to the distance between two neighbouring subsamples having age dating. Figure 4 showed that $\delta^{18}o$ and $\delta^{13}C$ features of the calcite in different stalagmites were different. On the basis of Fig. 4 following conclusions may be taken:

1. Change curves of T-$\delta^{18}O$ and T-$\delta^{13}C$ for each stalagmite were similar correspondly. Curve tendency of $\delta^{18}O$ and $\delta^{13}C$ of three stalagmites were similar approximately.
2. Near depositional interuptions of above-mentioned stalagmites $\delta^{18}O$ and $\delta^{13}C$ features take positive peak form, which showed that depositional interruptions in the speleothems resulted from paleoclimate change. Epoches about 130, 210 and 220-230x10³ yr. BP had relatively cold paleoclimate.
3. According to positive peak of $\delta^{18}O$ and $\delta^{13}C$ curves, it was happened a cold paleoclimate in 370-380x10³ yr. BP; on the contrary, in the time about 170-205 and 270x10³ yr. BP isotopic curves had two negative valleys which matched warm paleoclimate periods (Fig. 3).

III. Discussion

Results of above mention and ^{14}C dating of speleothems[3] indicated that since meddle Pleistocene (about 400x10³ yr.) paleoclimate in Guilin area was changes and undulated. Compared with today's climate, five colder climate periods had happened about 11, 130, 210, 220-230 and 370-380×10³ yr. BP and four warmer –– about 5-7, 30-40, 170-205 and 270x10³ yr. BP. Have had the glacier in Guilin appeared in cold paleoclimate period? This is a squabble problem. We also try to calculate paleotemperature with stable isotope components of speleothems. In Big Cave near sample 82-29 a modern dripstone (No. 85-01) was collected and its isotope components had been measured: $\delta^{18}0$=24.10 ‰ (SMOW), $\delta^{13}C$=10.23 ‰ (PDB). Average air temperature in intereous zone of Big Cave measured in 1.5 hydrological years was t=19.2 ± 1.2° C. According to O'Neil's experimental formula: 1000lnK=2.79x10^{6}T^{-2}+2.89 (for calcite-water), average $\delta^{18}O_w$ of mordern dripping water was calculated -5.58 ‰ (SMOW). Using this data for rough calculation the changing interval of $\delta^{18}O_c$ for sample 82-29, 23.5-26.23 ‰ (SMOW) could be equal to average annual temperature 21.9-10.2 °C.

Therefore, since middle Pleistocene annual temperature in Guilin area undulated over or lower todat's 18.9 – 19.2° C. During cold period annual temperature could be reach 10.2 °C that was lower 9 °C than today's, equalling Peking-Taiyuan latitude; a during warm period –––– rise 2°-3 °C, equalling today's climate in Xishuangbanla area of Yannang province. Obviously, above-mentioned calculation was very rough and hard works will be made again in paleoclimate research of Guilin area.

Author was in acknowledgment to Dr. M.M. Sweeting and Miss Angela Rae for their help and provided measurment results.

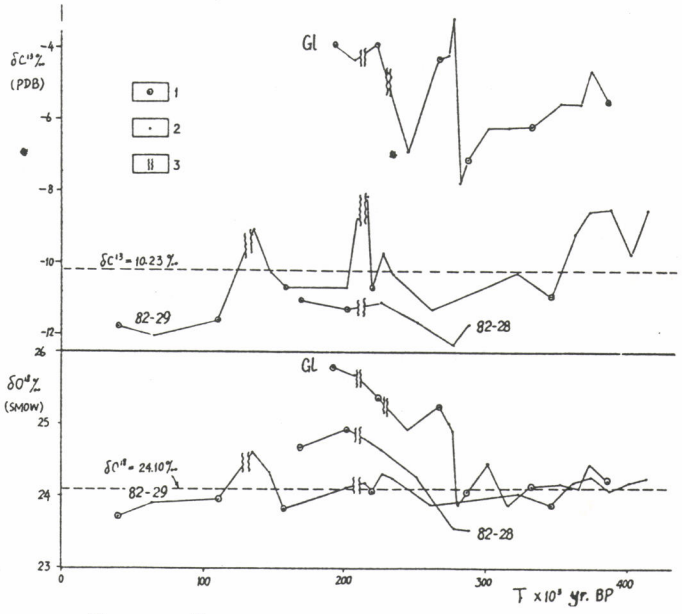

Fig. 4. T-$\delta^{18}O$ and T-$\delta^{13}C$ change curves of stalagmites.
O data T and isotope feature, measured simultaneously;
● isotope feature without dating and throwed between neigh-bouring subsamples.

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A review of recent studies of calcite sepelothems at McMaster University, Canada

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RESUM

En la universitat de McMaster s'estan realitzant estudis químics i físics sobre espeleotemes de calcites des de l'any 1966. La finalitat principal és la datació i la reconstrucció del medi ambient d' èpoques ancestrals. Aquesta revisió resumirà els resultats dels darrers cinc anys i inclourà:

1) *La millora de les tècniques de datació per les sèries de l'urani.*
2) *Les investigacions per a la datación ^{234}U fins ^{238}U.*
3) *L'abast de les limitacions del mètode regional d'urani.*
4) *La tècnica isocron ESR.*
5) *Les aplicacions dels isòtops estables.*
6) *Els estudis de la matèria orgànica.*

RESUMEN

En la Universidad de McMaster se realizan estudios químicos y físicos sobre espeleotemas de calcitas desde 1966. Las principales finalidades son la datación y la reconstrucción del paleomedioambiente. Esta revisión resumirá los resultados de los cinco últimos años, incluyendo:

1) *Mejora de las técnicas de datación por las series de U.*
2) *Investigaciones para la datación ^{234}U hasta ^{238}U.*
3) *El alcance de las limitaciones del método regional de uranio.*
4) *La técnica isocrono ESR.*
5) *Las aplicaciones de los isótopos estables.*
6) *Los estudios de la materia orgánica.*

RÉSUMÉ

Il y a des études chimiques et physiques faites sur les spéléothémes calcites à l'université de McMaster depuis 1966. Les principaux buts son la datation et la reconstruction du paléo-environement. Cette révision va résumer les résultats de ces cinq dernières années, incluant:

1) *des améliorations des techniques de datation par les séries U.*
2) *des recherches pour la datation de ^{234}U à ^{238}U.*
3) *la portée et les limitations de la méthode regionale d'uranium.*
4) *la technique isochrone ESR.*
5) *les applications des l'isotopes stables.*
6) *les études de la matière organique.*

There have been chemical and physical studies of calcite speleothems at McMaster University since 1966. The principal aims are dating and paleoenvironmental reconstruction. This review will summarise results of the past five years including 1) improvements in techniques for U-series dating; 2) prospects for ^{234}U – ^{238}U dating; 3) scope and limitations of the Regional Uranium method; 4) the ESR isochron technique; 5)stable isotope applications; 6) studies of organic matter.

Late quaternary environments in northern Somalia

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RESUM

Les fases de creixement d'espeleotemes i la seva redissolució, així com les fases de reompliment clàstic i sedimentari de les cavitats i la seva posterior erosió, han aportat valuoses dades sobre climes pretèrits de l'Est i del Sud de l'Àfrica. La datació $^{234}U/^{230}Th$ d'espeleotemes de les coves d'Hula, Galweda i Shawale, a Somàlia, revela unes condicions climàtiques molt més humides fa 260-250, 176-172, 116-113, 87-75, 12-19 i 6-8 mil anys BP Al Transvaal, a l'Àfrica del Sud, datacions ^{14}C i $^{234}U/^{230}$ Th d'espeleotemes procedents de les coves d'Echo, Sudwala i Sterkfontein, suggereixen unes condicions més humides que les actuals C.200, > 45-30 i C.12 mil anys BP La re-dissolució d'espeleotemes està datada entorn dels > 45-30 mil anys BP, quedant soterrats molts d'ells a l'emplenar-se les cavitats de sediments clàstics laminars. Això ens indica que la humitat disponible i els nivells freàtics van aconseguir un màxim durant la darrera etapa glaciar C.20 mil anys BP. Les proves trobades dins les cavitats ens demostren que a la zona tropical de l'Est de l'Àfrica, les condicions climàtiques més humides es van presentar durant els períodes interglacials i entre els diferents estadis, mentre a l'Àfrica del Sud, això succeí durant els períodes glacials i interestadis.

RESUMEN

Las fases de crecimiento de espeleotemas y su re-disolución, y las fases de relleno clástico y sedimentario y su erosión en cavidades, han aportado datos sobre climas pasados en el Este y Sur de Africa. La datación $^{234}U/^{230}$ Th de espeleotemas de las cuevas Hayla, Galweda, y Shawale, en Somalia, revela unas condiciones climáticas más húmedas hace 260-250, 176-172, 116-113, 87-75, 12-9 y 6-8 K años BP. En el Transvaal, Africa del Sur, dataciones ^{14}C y $^{234}U/^{230}$Th de espeleotemas procedentes de las cuevas Echo, Sudwala y Sterkfontein, sugieren condiciones más húmedas que las actuales C.200, > 45-30 y C.12 K años BP. La re-disolución de espeleotemas datada sobre los > 45-30 K años BP, y el enterramiento de muchos de ellos por un relleno de sedimentos clásticos laminados que se depositaron en las cavidades, indican que la humedad disponible y los niveles freáticos alcanzaron un máximo durante la última etapa glaciar C.20 K años BP. Las pruebas halladas en las cavidades muestran que en la zona tropical del Este de Africa las condiciones climáticas más húmedas se presentaron durante los períodos interglaciares e interestadios, mientras que en Africa del Sur lo hicieron durante los períodos glaciares e interestadios.

SUMMARY

Phases of speleothem growth and re-solution, and phases of clastic sediment fill and erosion in caves have provided evidence of past climates in East and South Africa. $^{234}U/^{230}$ Th ages of speleothems from Hayla, Galweda, and Shawale caves in Somalia indicate wetter climatic conditions 260-250, 176-172, 116-113, 87-75, 12-9, and 6-8 k yr. BP. In the Transvaal, South Africa ^{14}C and $^{234}U/^{230}$ Th ages of speleothems from Echo, Sudwala, and Sterkfontein caves suggest wetter conditions than present C.200, > 45-30, and C. 12 k yr. BP. Re-solution of speleothems dated in the range > 45-30 k yr. BP, and burial of many of these by a laminated clastic sediment fill introduced into the caves, indicates that available moisture and ground water table levels reached a maximum during the last glacial C.20 k yr. BP. The cave evidence shows that in tropical East Africa wetter climatic conditions occurred during interglacial and interstadial periods while in South Africa they occurred during glacial and interstadial events.

Introduction

Recent research has forced a revision of the idea that the intertropical belt of East Africa (23 1/2°S to 23 1/2°N) experienced pluvial conditions during the glacial stages of higher latitudes. It now appears that this region was drier than today at these times. Unfortunately, most terrestrial records are relatively short being limited by the range of the ^{14}C dating technique. Paleonthropological research in northern Somalia during 1982 (Brandt and Brook 1984) has not only provided the first dated evidence of Quaternary climatic changes in this region but has also extended the terrestrial record of East African climates to c. 260,000 yr BP.

The Study Region

Northern Somalia can be divided into two physiographic regions: (1) the flat coastal plains of the Guban, bordering the Gulf of Aden, and (2) the Somali Plateau lying to the south of the Guban and separated from it by a steep escarpment marking the edge of the Gulf of Aden rift (Fig. 1). The Somali Plateau is topographically diverse and ranges from the northern maritime Golis Mountains, which reach over 2,000 m in elevation, to the flat, monotonous Hawd and Sool Hawd plains of the south.

The Guban is a coastal desert with an annual precipitation of < 500 mm. Precipitation in the semiarid Somali Plateau is highest in the Golis Mountains where it averages 400 mm/yr, it decreases southwards into the Hawd and Sool Hawd plains. The region has a monsoonal climate. Most of the precipitation occurs during the summer «gu» rains which are brought by the southwest monsoon. There is a second, less significant winter rainy season associated with the northeast monson which brings the «der» rains. The southwest and northeast monsoons develop as the Intertropical Convergence Zone (ITCZ) migrates northwards in summer and southwards in winter. Rainfall occurs chiefly as sporadic storms during which surface runoff is rapid and gives rise to violent streamflows.

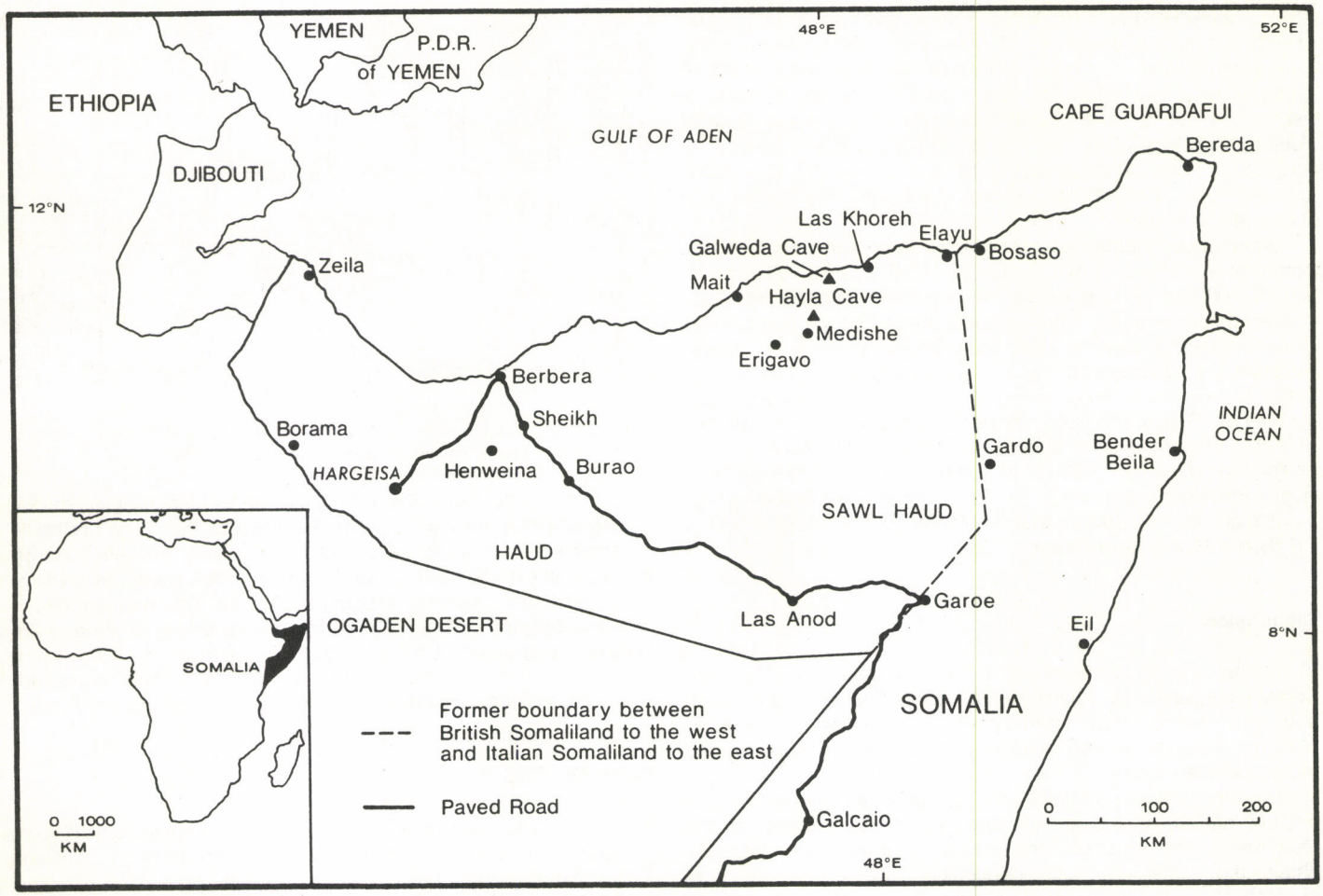

Fig. 1. Map of Northern Somalia Showing Sites Mentioned in the Text.

During February and March, 1982 reconnaissance research in the Guban and Somali Plateau regions between Hargeisa in the west and Bosaso in the east uncovered numerous caves in limestone and anhydrite, and three relict spring tufa deposits. This paper will present information on four of the sites discovered.

The Cave and Spring Tufa Sites

Galweda Cave, 50 m deep, with its lowest passages close to present sea level, is located in the Guban region 1-2 km south of the abandoned settlement of Galweda (fig. 1). The cave is in Miocene Dubar Series limestones. The upper levels of the cave are dry and dusty today, but relict stalactites, stalagmites, and wall flowstones, generally less than 30 cm long, are numerous and attest to somewhat wetter conditions in the past.

Hayla Cave is located in the Golis Mountains a few km north of Medishe. The cave is 800 m long in Lower Eocene Auradu Series limestones and has an impressive 20 m wide and 7 m high entrance which overlooks Hayla Valley 100 m below. The cave contains massive calcite deposits including a travertine floor more than 1 m thick and columns 3 m high and more than 1 m in diameter. Small speleothems are being deposited at several locations within the cave today. However, it is likely that many of the older inactive formations in the cave, which are substantially larger, were deposited when precipitation was more abundant.

Relict spring tufas were discovered at two locations in the Golis Mountains, in the Heneweine Tug northeast of Hargeisa and in Injeraley Tug near the village of Medishe (Fig. 1). At Heneweine 10 m of tufa rests on a boulder deposit 3 m thick with some boulders > 1 m in diameter. Dalow Spring issues from the base of the tufa but there is no evidence that the spring waters are depositing tufa today. The tufa in Injeraley Tug is 7.5 m thick, 40 m long, and 20 m wide. It too rests on a boulder bed 1-2 m thick which includes boulders > 0.5 m in diameter. The Heneweine and Injeralay tufas are considered to record periods of increased moisture in northern Somalia.

Paleoclimatic Implications of Speleothem and Tufa Ages

Twelve speleothems, six each from Galweda and Hayla Cave, were $^{234}U/^{230}$ Th dated along with two tufa samples from Injeraley and one sample from Heneweine (Table 1). The ages fall into five distinct groups which suggest that conditions in northern Somalia were significantly wetter at times during the interglacials (isotope stages 7, 5 and 1) of the last 260,000 years (Fig. 2). Stalagmite HL-5 and travertine HL-11 from Hayla Cave, dated to 250,900 ± 32,400 and 260,400 ± 26,600 yr BP respectively, are considered to have been deposited during the early part of isotope stage 7.

Table 1. Ages of Cave Speleothems and Spring Tufas from Northern Somalia*

Sample ID	Sample Age YR B.P.	Sample ID	Sample Age YR B.P.
GG-5	5,000 ± 600	GG-2	75,500 ± 14,500
HL-8 (top)	6,300 ± 1,500	HE-1	79,100 ± 3,850
IN-3	7,000 ± 500	HL-4 (top)	87,200 + 4,600
GG-4	7,600 ± 300		
		HL-6	113,400 ± 26,600
GG-6	9,500 ± 800	IN-2	115,900 ± 6,400
GG-7	9,700 ± 1,100		
		HL-4 (base)	172,200 ± 23,900
HL-8 (base)	11,800 ± 400	HL-9	176,500 ± 27,000
		HL-5	250,900 ± 32,400
		HL-11	260,400 ± 26,600

* GG = Galweda Cave speleothem, HL = Hayla Cave speleothem, IN = Injeraley tufa, HE = Heneweine tufa

Speleothems HL-4 and HL-9 from Hayla Cave, dated to 172,200 ± 23,900 and 176,500 ± 27,000 yr BP, respectively, were deposited during the major interstadials of isotope stage 6 centered at c. 175,000 yr BP. This implies that during interstadial (isotope stage 3, and the interstadials of stages 8 and 6) conditions at Hayla Cave may have been at least as wet as they are today. None of the deposits dates conclusively to a major glacial interval suggesting that conditions were much drier than today at these times.

When speleothems and spring tufas were being deposited in northern Somalia c. 116,000-113,000, c. 87,000-75,000, and c. 12,000-5,000 yr BP the pollen rain over the Arabian Sea was characterized by highly increased amounts of humid tropical and Sudano-Sahelian savanna taxa, indicating a stronger southwest monsoonal flow and more moisture in Somalia (Van Campo et al. 1982) Closer examination of the speleothem and tufa age data for the Late Glacial and Holocene period suggests discrete phases of wetter climate prior to 11,800 yr BP, between 9,700 and 9,500 yr BP, and between 7,600 and 5,000 yr BP. This finding is in good agreement with data on East African lake levels, which were high from 12,500-11,500, 10,000-8,000, and 7,300-5,000 yr BP (Street-Perrott and Roberts 1983).

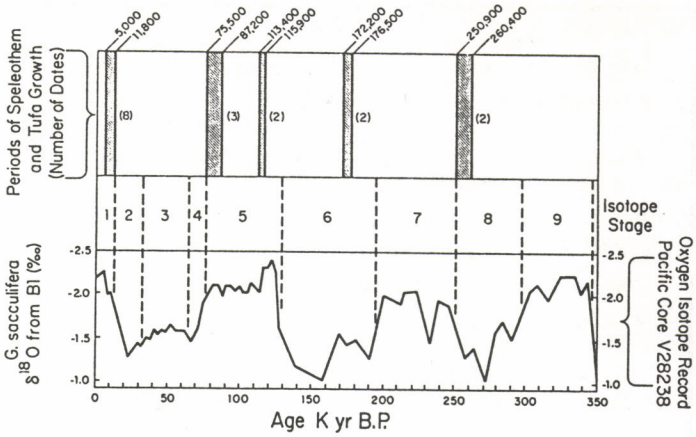

Fig. 2. Periods of Speleothem and Tufa Deposition in Northern Somalia Compared to the Oxygen Isotope Record of Pacific Ocean Core V28238.

Discussion

The ages of speleothem and spring tufa deposits in northern Somalia suggest that during the last 260,000 years interglacials, and to a lesser extent interstadials, were times of increased moisture. These ages also indicate that glacials were substantially more arid than today.

The stratigraphies of the spring tufa sites provide information on the nature of the wetter and more arid phases of the Quaternary. The basal boulder beds at Heneweine and Injeraley show that prior to tufa deposition stream activity was characterized by frequent flash floods capable of moving extremely large bouldes. During the periods of tufa accumulation ground water levels must have been higher (implying increased rainfall), flash floods less common (suggesting a reduction in the incidence of intense rains), and spring waters must have contained more dissolved carbon dioxide (indicating a denser vegetation cover). Under the present hydrologic conditions –with frequent intense rains and flash floods– the Heneweine and Injeraley tufas are inactive and with their underlying boulder beds are being eroded by the present stream activity.

It is probable that during interglacial times there was increased precipitation in northern Somalia because of the more northerly summer position of the ITCZ and the resulting intensification of the southwest monsoonal winds. Even today these winds are responsible for most of the region's moisture. The more southerly summer position of the ITCZ during glacial times, together with reduced evaporation from a colder Indian Ocean, must have led to a weakening of the southwest monsoon, the increased dominance of the northeast Trades, and a more arid Horn of Africa.

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Underlining an interesting paleokarstic phenomenon in the Lessini (Prealpi Venete-Northen Italy)[1]

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Gruppo Speleologico CAI-Verona, Società Speleologica Italiana – Centro Ricerche Naturalistiche Monti Lessini, Società Speleologica Italiana.

RESUM

El Lessini és un altiplà càrstic situat a la zona pre-alpina de Venete (Nord d'Itàlia).

Durant l'exploració d'una cova, s'ha trobat un fenomen paleocàrstic interessant, el qual consisteix en una sèrie de canals càrstics, plens de lava basàltica.

L'activitad del volcà comença ja a l'era Cenozoica. En aquest treball, després d'una descripció inicial del fenomen paleogeogràfic, analitzem el seu interès paleotectònic.

RESUMEN

El Lessini es una meseta kárstica situada en los prealpes de Venete (Norte de Italia).

Durante la exploración de una cueva se ha encontrado un fenómeno paleokárstico interesante: el cual consiste en una serie de canales de karst rellenados de lava basáltica.

La actividad del volcán se remonta al Cenozoico. En este trabajo, después de una descripción inicial del fenómeno paleogeográfico, se considera el significado paleotectónico.

SUMMARY

The Lessini is a karstic plateau situated in Prealpi Venete (Northern Italy).

During some caving explorations an interesting paleokarstic phenomenon has been found: it consists of a serie of karstic channels filled up with basaltic lava.

The volcano activity goes back to the Cenozoic. In this paper after an initial description of the fenomenon peleogeographic and paleotectonic meaning is preliminarily debated.

Geographic Features

The Monti Lessini, lying to the north of Verona (Veneto-Northern Italy) are part of a Prealpine plateau that covers a surface of about 800 sq km.

The phenomenon taken into account is located in the valley of the Covolo (central Lessini) which joins the valley of Illasi near Selava di Progno. The valley of the Covolo, which presents a large collecting basin, begins north of Monte Purga near Velo Veronese; the upper section of the hydrographic basin is constituted by the canyon of Tezze (Vajo of Tezze) and by the canyon of Molini (Vajo of). The upper-central part of the botton of the valley is characterized by jutting out rocky surfaces, erosion-resistant, which determine a series of small waterfalls.

The strong thermoclastic action together with the presence of strata more easily affected by erosion has caused, especially in the central part of the valley, the formation of steep slopes and vertical rock-walls.

On the right hydrographic versant of the valley of the Covolo, at 878 m above sea-level, lie the Covoli of Velo (register n.° 44 V VR; geographic co-ordinates: Longitude West l° 19'54'', Latitude North 45° 36'28''.)

The Covoli of Velo

The Covoli are formed by a system of springs for the most part inactive, placed in a line along a rocky wall. Only the cave on the extreme east, which is the lowest from the altimetrical point of view, shows a perennial water circulation (Zorzin, 1982) while the other cavities are partially filled up with clay, probably riss-würmian, with plenty of *Ursus spelaeus* remains and of other mammals.

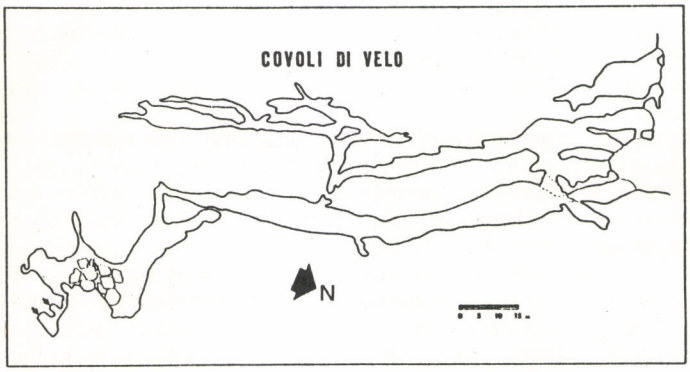

Fig. 1. Map of the Covoli of Velo with the indication of the conduits taken into account.

In the cavity called «Grotta Inferiore», near the terminal chamber, sub-circular conduits can be noticed, which might be considered, at first sight, as empty basaltic seams presenting nevertheless a karst morphology (fig. I). It is a group of three conduits one of which is accessible because of erosion of the lava filling. The complete filling of even this accessible section is

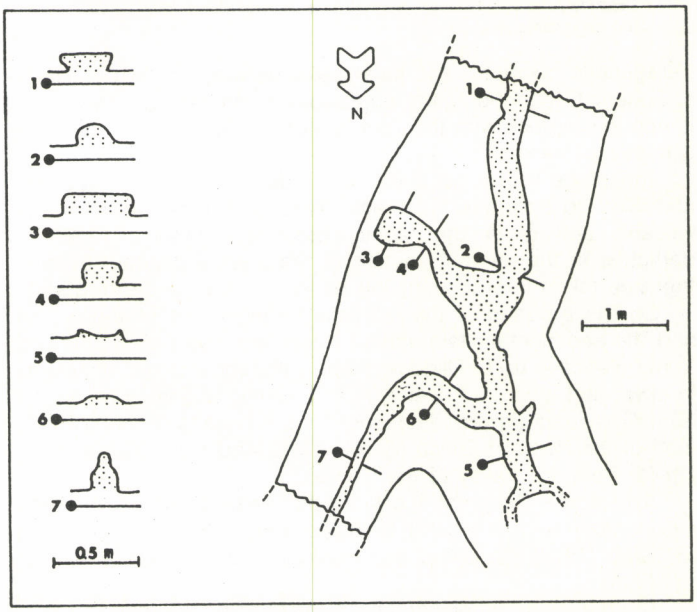

Fig. 2. Plan and detailed cross sections of the vault-channels pointed out by dotting.

proved by small residual basaltic fragments visible on the conduit surface while the floor is concealed by debris and modest stalagmitic formations. Mantel-shaped formations, of karst origin, jut out of the walls: at first sight they may be considered as the result of the selective chemical-physical action exerted on the interstrata by magma.

But the karst genesis of the phenomenon can be demonstrated, in our opinion, by the presence of a series of anastomosed roofchannels. The main one winds its way along the conduit axis and it is from 10 to 15 cm deep and from 10 to 40 cm wide (see cross-section, fig. 2, 3, 4). Its roof is for the most part flat.

At the end of the accessible conduit, it is still possible to see the roof channel still filled up with basalt.

Further evidence is given by great scallops carved on some of the conduit surfaces.

Interpretation of the phenomenon

The data at our disposal suggest that the phenomenon may have evolved through the following stages:

Ist stage.– A Karst network sets up inside the carbonate rocks of the tectonic unit of the Covoli di Velo, which would logically correspond to an emersed area. What follows is the paragenetic development of a number of conduits and of vault channels. Inside the paragenetic conduits, the «slow» water circulation taking place between the filling deposits and the vault-roof causes the vault channels to be formed. What comes next is an increase in the water circulation together with a removal, by erosion, of alluvial sedimentary layers and, consequently, the emptying of the

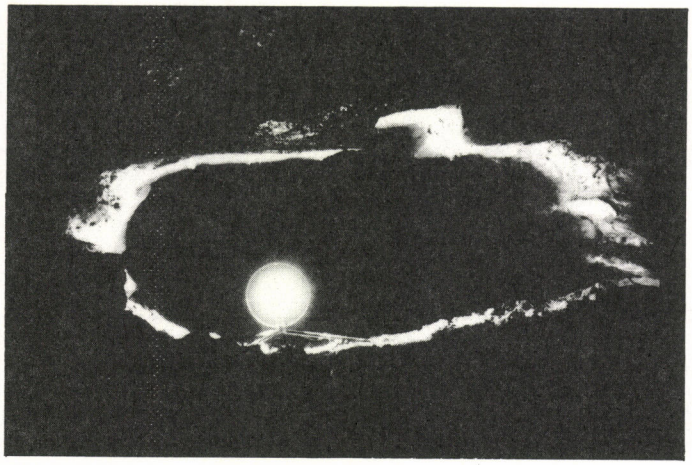

Fig. 3. Section of the main conduit: in the upper part the vault channel can be seen. The ring diameter is 25 cm.

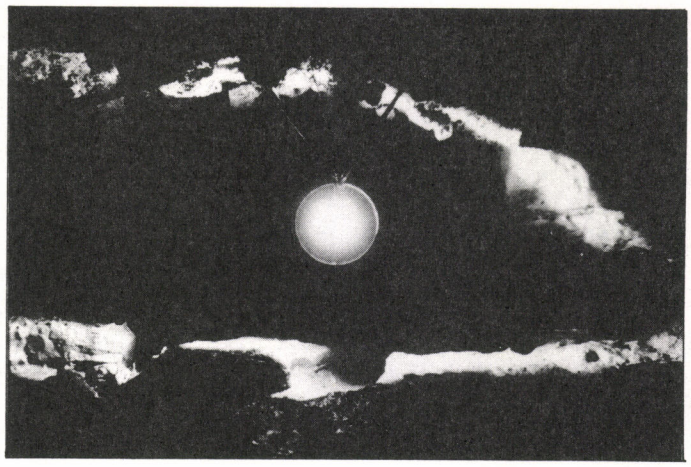

Fig. 4. Cross section of the main conduit in proximity to the point where the two vault channels actually start. The ring diameter is 25 cm.

paragenetic conduits. The karst paleo-network might date back to Eoceno-Oligocene age (a potassium/argon dating of the basalt is non in progress with the contribution of Museo Civico di Storia Naturale of Venora).

2nd stage.– The conduits so far described are intercepted and filled up by a basaltic seam. There is abundant evidence of volcanic activity in the Monti Lessini (Castellarin, 1962), in particular in the eastern section of the Lessini plateau: even in the area taken into account the basaltic outcrops are frequent.

On the grounds of the relations between the stratigraphies and the sedimentary formations, volcanism may have continued from Paleocene up to Oligocene age with higher peaks of activity in lower and medium Eocene. A K/Ar dating indicates an age of 36 million years (lower Oligocene) for the basalts of the volcanic cleft of the Purga di Bolca (Barbieri and Medizza, 1969) about 7 km far from the Valley of the Covolo.

3rd stage.– The present cavities develop in a partially or totally independent way as regards to the paleokarst network. According to Sauro (1973) the last phase would go back to Mindel-Riss or to Mindel.

The presence of considerable bony remains referring to *Ursus spelaeus* (Massalongo 1851, Benetti and Cristofori 1968) implies that during the Würm the caves were used as wintering shelters, which would indicate a reduction in the hydrological function of the caves themselves.

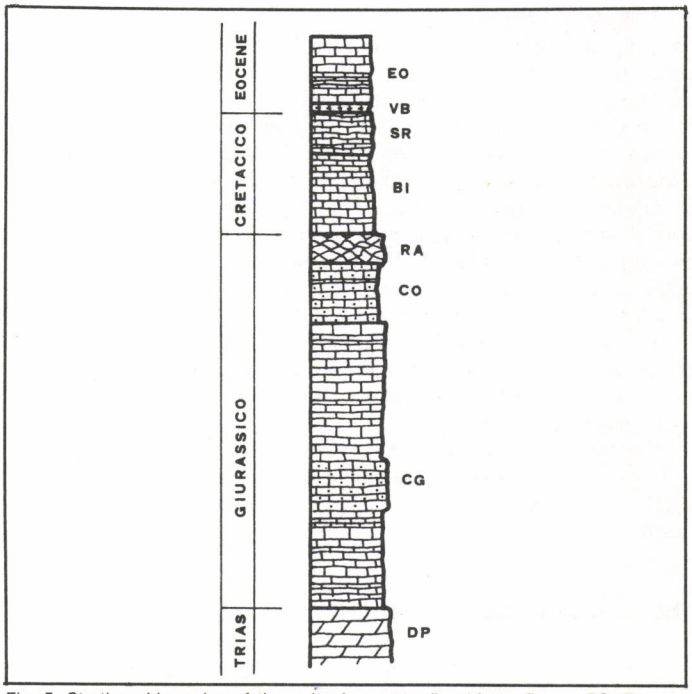

Fig. 5. Stratigraphic series of the uplands surrounding Monte Purga. EO: Eocene, VB: Basic volcanic rocks, SR: «Scaglia rossa», BI: «Biancone», RA: «Rosse ammonitico Veronese», CO: «Oclitic limestone of S. Vigilio», CG: «Calcari Grigi», DP: «Dolomia Principale.»

Paleogeographic Interpretation

The Covoli of Velo have developed within the formations, of a partial dolomitic consistence, of «Calcari Grigi», dating back to liassic age. The series of stratigraphies of Verona consists of formations for the most part sedimentary, ranging from upper Triastic to Miocene. The area taken into account is characterized prevalently by Mesozoic outcrops (fig. 5). The Cenozoic lithotypes come to surface in a small area on the Purga di Velo, a mountainous area next to the cavities examined. The rocky formations overhanging the Covoli di Velo are, presently, 130 m thick.

The tectonics is characterized by'horst and graben'structures. The western unit, lying near the one in which the Covoli open, is morphologically in relief but structurally depressed: here the eocene limestone outcrops (fig. 6).

The presence of paleokarst may provide useful information about the paleographic and paleotectonic environment of the area taken into account. As a matter of fact, even considering the karst conduits in proximity to the eocene-oligocene levels of base, it may be assumed that the emersed section would reach at least the sedimentary layers presently overhanging the cave.

The dating of the paleokarst conduits back to Eocene-Oligocene is likely to be the most probable as this is the most logical supposition as far as the geologic setting of the Lessini plateau is concerned. Two hypothesis have been stated:

1) The sedimentation of the eocene limestone may be proved only for the unit of the Purga di Velo: it is missing, presumably because of erosion, in the unit of the Covoli di Velo.

2) The sedimentation of the eocene limestone located on the unit of the Purga di Velo did not occur in the unit of the Covoli di Velo because the latter consisted of a structural emersed system.

In the first hypothesis the conduits would be more recent than the eocene limestone area thus probably going back to lower eocene or oligocene; therefore it could be proved that in the interval elapsed between the limestone depositing and the conduit fossilization the unit of the Covoli di Velo has been subjected to a up rising movement, the extent of which is at least equal to thickness of the stratigraphic series overhanging the cavity (about 400 m) as regards to the base level. If the cavities taken into account had been located at a higher altitude as regards to the base level, the entity of the raising would be more relevant.

The first hypothesis, which is likely to be more probable, is supported by further geologic data:

a) Lack of Oligocene features in the whole Lessini plateau with the exception of a small area at Cavalo, about 19 km far from the Covoli di Velo, where sandstone deposits may be found, which look transgressive and unconformable, for the most part on lower Eocene terrains (Castellarin and Farabegoli, 1974).

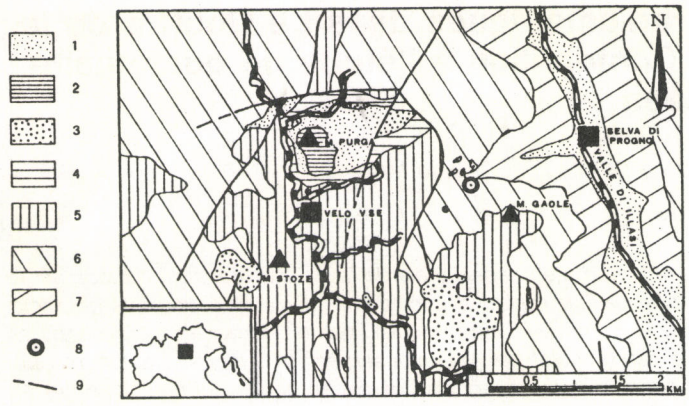

Fig. 6. Geologic map of the area surrounding Monte Purga and index map.
1) Layer debris and fluvial flooding (Quaternary)
2) Organogenic limestone (Central Cuisiano)
3) Volcanoclastic rocks (lower Eocene and Paleocene)
4) Scaglia rossa (upper Cretaceous p. p.)
5) «Biancone» (upper Cretaceous p. p. -lower Cretaceous p.p.)
6) Nodular, oolitic and argillaceous limestone (lower Cretaceous p. p. -Jurassic)
7) «Dolomia Principale» (Rhaetian - Noric)
8) Covoli of Velo
9) Faults

b) Presence of marked paleokarst phenomena in the hills surrounding Venora («Torricelle») which are about 20 km far and may be considered as the result of an oligocene-miocene regression (Fabiani, 1919; Castellarin and Farabegoli, 1974). In the mentioned locality, as a matter of fact, the paleokarst phenomena develop in marl limestone of upper Eocene on which the sandstone of Miocene result transgressive. The time or space entity of the transgression is a mere supposition. If the paleokarst conduits of the Covoli are to fit in this context, it is logical to admit that the northern part of the plateau was characterized by the presence of at least some emersed tectonic units.

The second hypothesis accounts for the existence of lands already emersed since Eocene. This is also proved by the palm-trees and by the turtles of Avesa as well as by the round eocene cobbles present in the upper Eocene of «Torricelle». Barbieri (1972) ascribes the remarkable heap of volcanic rocks east of the fault of Castelvero to the existence of a structural lowering inside the basin, which would give evidence of a marked tectonic activity during the Eocene age. As a matter of fact, «continent» type phenomena are supported, near the Purga of Bolca, by the finding of lake and saltish deposits with remains of terrestrial plants.

While waiting for an accurate dating, it is not possible to make a choice between the two hypothesis; yet, for this section of the Monti Lessini, the beginning of karstification may be back-dated to Eocene-Oligocene.

Special acknowledgements are due to Dr. P. Forti from the Geology Institute-University of Bologna, and to Dr. L. Sorbini, director of the Museo Civico di Storia Naturale of Verona, for their interest and helpful collaboration.

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1. Study executed with the contribution of the Gruppo Speleologico CAI-Verona and of the CRN Monti Lessini.

Etudes sedimentologiques et datations radiométriques dans Le Gouffre de la Pierre Saint Martin (Pyrénées, France): Contribution à l'étude du quaternaire Pyrénéen

Ives Quinif (1) et Richard Maire (2)

RESUM

Els estudis sedimentològics efectuats a la xarxa de la Pierre Saint-Martin, i en especial els de la galeria Aranzadi, situada sobre de la sala de la Verna, expliquen el funcionament hidrogeològic de la cavitat durant el pas d'una glaciació a una interglaciació. L'època glacial es caracteritza per la presència d'una fina sedimentació detrítica («farina» glaciar, rica en carbonats i dipositada en forma de varves a les galeries inundades). El període interglacial ve caracteritzat per un enfonsament dels dipòsits anteriors i per la formació de terrasses fluvials esglaonades. Les datacions de les concrecions estalagmítiques situen aquest interglacial entre els 210.000 i 176.000 anys BP.

RESUMEN

Los estudios sedimentológicos en la red de la Pierre Saint Martin, en especial los de la galería Aranzadi situada encima de la sala de la Verna, explican el funcionamiento hidrogeológico de la cavidad durante el paso de una glaciación a un interglaciar. La época glaciar se caracteriza por una fina sedimentación detrítica («harina» glaciar rica en carbonatos depositada en forma de varvas en las galerías inundadas). El período interglaciar está marcado por un hundimiento de los depósitos anteriores y la formación de terrazas fluviales escalonadas. Las dataciones sobre concreciones estalagmíticas sitúan este interglaciar entre 210.000 y 176.000 años BP.

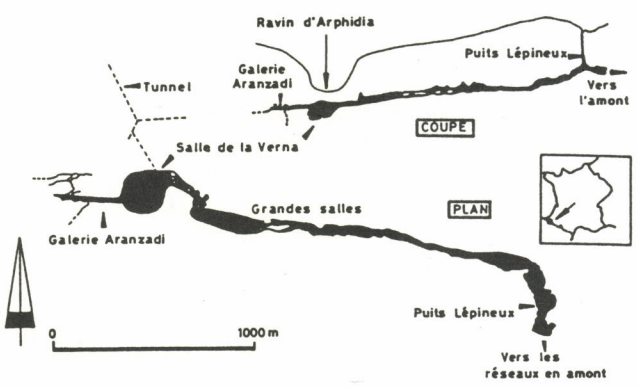
RESUME

Les études sédimentologiques dans le réseau de la Pierre Saint-Martin, notamment dans la galerie Aranzadi située au-dessus de la salle de la Verna, éclairent le fonctionnement hydrogéologique de la cavité lors du passage d'une glaciation à un interglaciaire. L'époque glaciaire se caractérise par une sédimentation détritique fine (farine glaciaire riche en carbonates disposée sous forme de varves) dans des galeries noyées. La période interglaciaire est marquée par un recreusement des dépôts antérieurs et la mise en place de terrasses fluviatiles étagées. Les datations sur concrétions stalagmitiques situent cet interglaciaire entre 210.000 et 176.000 ans BP.

I. Introduction

Le milieu karstique souterrain constitue un milieu très conservateur: formes et microformes, dépôts y sont à l'abri des dégradations dues aux intempéries extérieures. Les sédiments jouent un rôle fondamental comme enregistreur des phénomènes géologiques, géomorphologiques et paléoclimatiques régionaux ainsi que, biensûr, en temps que jalons interprétables et datables de l'évolution karstique.

Dans le cadre des karsts haut-alpins, le Gouffre de la Pierre Saint Martin renferme d'abondants sédiments diversifiés, spécialement dans la galerie Aranzadi, abandonnée par le torrent principal suite à la formation de la salle de la Verna en amont. Elle renferme ainsi d'importantes accumulations sédimentaires intactes (Maire, Quinif, 1984). C'est une première synthèse de l'étude de ces sédiments qui est présentée ici.



1. Situation du réseau et plan de la partie inférieure du Gouffre de la Pierre Saint Martin. C'est un réseau haut-alpin, l'entrée la plus haute s'ouvrant à 2.047 m d'altitude dans le lapiaz. Il se développe essentiellement sous 400 m de calcaires crétacés sur le socle paléozoïque.

II. Structure du gouffre de la Pierre Saint Martin

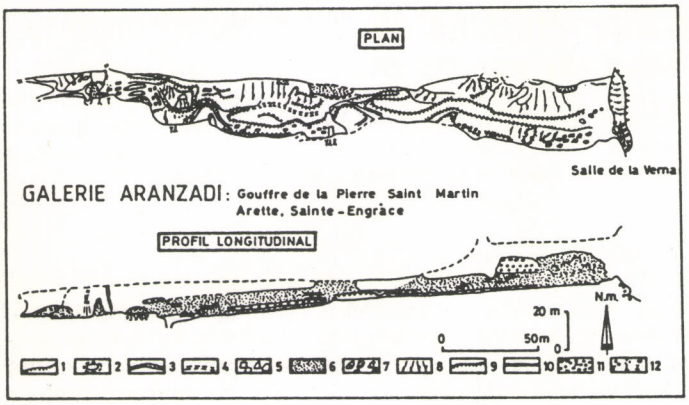
Réseau de haute montagne, le gouffre comprend une enfilade de galeries et de grandes salles sous 400 m de calcaires crétacés au contact du socle paléozoïque (fig. 1). Plusieurs gouffres dont l'orifice le plus haut se trouve à 2047 m d'altitude travesant les 40 m de calcaire pour donner accès aux rivières souterraines (Douat, 1976; Queffelec, 1976). L'épine dorsale du gouffre est constituée par une suite de salles géantes qui se termine avec la salle de la Verna, longue de 270 m, large de 230 m et haute de plus de 120 m. La galerie Aranzadi représente la suite du gouffre, lorsque la salle de la Verna n'était pas encore creusée et que le torrent qui actuellement s'y perd continuait sa course vers l'aval. Elle s'ouvre à 100 m de hauteur dans les voûtes de la salle de la Verna. Longue de 300 m, rectiligne, large de 20 à 30 m, la galerie Aranzadi, vu sa position perchée, est un remarquable piège à sédiments dont l'épaisseur dépasse la dizaine de mètres (fig. 2 et 3). Une coupe face au vide de la Verna témoigne de l'ancien passage du torrent avant la formation de la salle géante.

III. La séquence sédimentaire de la galerie Aranzadi

Les dépôts de la galerie Aranzadi se composent de 3 ensembles détritiques principaux discordants: l'ensemble inférieur, l'ensemble principal et les terrasses fluviatiles (fig. 4).

1) **L'ensemble inférieur** est essentiellement constitué de galets roulés centi- à décimétriques à matrice argileuse dans lesquels tranchent quelques strates sablo-argileuses. La calcimétrie de ces argiles est comprise entre 27 et 39 % de CaCO3. Il est épais de 5 m face à la Verna.

2) **L'ensemble principal** est une puissante série d'una dizaine de mètres à très large prédominance argileuse, présentant des discordances, des stratifications entrecroisées, des structures en chenaux avec lentilles sableuses, des slumpings. Les minéraux



2. Plan et coupe de la galerie Aranzadi. 1: Escarpement; 2: Cheminée; 3: Recreusement; 4: Talweg; 5: Eboulis; 6: Ensemble principal; 7: Blocs éboulés de l'ensemble principal; 8: Pentes dans les sédiments; 9: Terrasses fluviatiles (en plan); 10: Terrasses fluviatiles (en coupe); 11: Ensemble inférieur; 12: Stalactites, stalagmites, colonnes.

argileux sont exclusivement illitiques (plus de 90 %) et chloritiques. Les teneurs en carbonates détritiques sont élevées, variant de 64 à 83 %. Plusieurs niveaux sableux se dilatant par places en chenaux interrompent la monotonie des argiles. La proximité des parois rocheuses influence la granulométrie qui devient là plus grossière par contraintes géométriques. A 3 mètres du sommet de l'ensemble principal, vers le milieu de la galerie, une coupe naturelle montre une petite coulée stalagmitique interstratifiée.

3) L'ensemble principal est recreusé en gradins successifs garnis de **terrasses fluviatiles** étagées, constituées de sables et de galets roulés dont l'épaisseur varie de 10 cm à plus de 2 m. A l'encontre de l'ensemble principal, les argiles sont en proportion très faible et les teneurs en carbonates souvents nulles.

4) Des **stalagmites** scellent la plupart des terrasses fluviatiles.

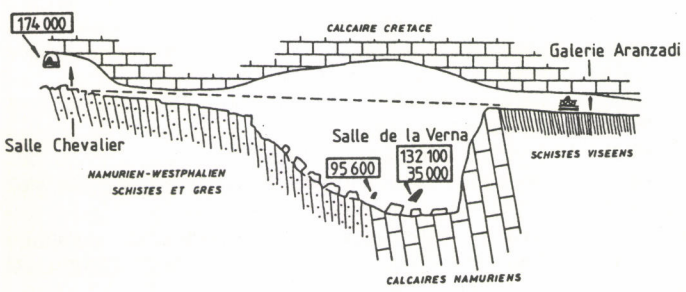
IV. Schéma évolutif du secteur étudié

1. Mise en place de l'ensemble inférieur.

La galerie Aranzadi faisait partie intégrante de l'épine dorsale du gouffre composée des salles géantes avant le creusement de la salle de la Verna. Le dépôt de l'ensemble inférieure s'est produit à cette époque: la présence des galets témoigne d'un circulation à haute énergie. Des étiages ou des modifications plus profondes ont permis la sédimentation des strates argileuses. Les circulations à cette époque, qu'il n'est pas encore possible de situer, devaient être proches de l'actuel torrent. Le contexte paléoclimatique reste obscur.

2. Mise en place de l'ensemble principal

La mise en place de l'ensemble principal marque une période charnière dans l'évolution du gouffre. Les eaux circulent lentement, sont très chargées et déposent des sédiments trés fins à médiane micrométrique. Ce sont essentiellement des dépôts de décantation totale, analogues aux dépôts océaniques profonds.



3. Coupe schématique de la salle Chevalier, de la salle de la Verna et de la galerie Aranzadi. La géologie est inspirée de Gilli (1984). On remarque la terrasse fluviatile suspendue dans la salle Chevalier et les deux croûtes stalagmitiques au fond de la salle de la Verna. L'escalade qui conduit à la galerie Aranzadi est haute de 100 m.

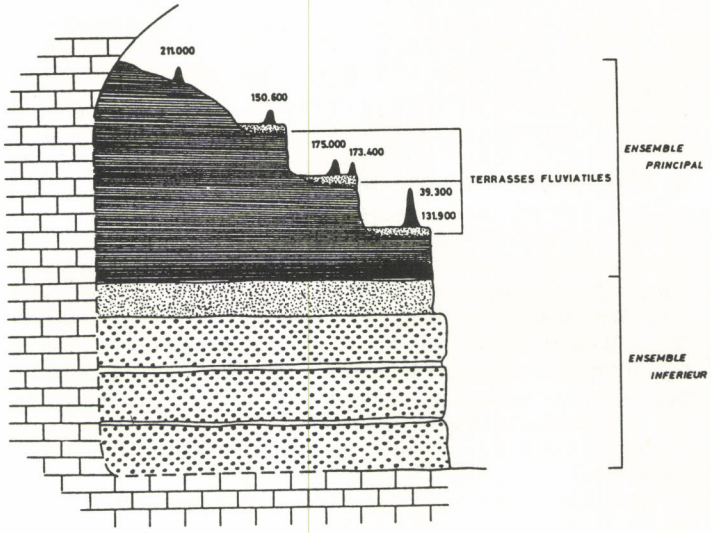
Les figures sédimentaires, notamment les petits chenaux sableux, témoignent par moment de perturbations hydrodynamiques. La haute teneur en carbonates détritiques et la fraicheur des minéraux argileux témoignent de la faiblesse des altérations et militent en faveur d'un climat glaciaire, l'ensemble principal étant en fait une «farine glaciaire».

Au moment de la sédimentation de l'ensemble principal, les pertes absorbaient des torrents proglaciaires ou sous-glaciaires qui innondaient la cavité en totalité. La brusque variation de granulométrie entre l'ensemble inférieur et l'ensemble principal peut être due à des facteurs climatiques uniquement ou à une modification dans la géométrie des écoulements souterrains: colmatages, ouverture de la salle de la Verna, etc... Néanmoins, la présence de galets sous l'ensemble principal et au dessus (les terrasses fluviatiles) s'oppose à l'existence d'un soutirage important en amont d'Aranzadi, confirmant ainsi les causes climatiques.

3. Mise en place des terrasses fluviatiles

A la fin du dépôt de l'ensemble principal, la galerie Aranzadi est complètement comblée. De nouvelles circulations recreusent alors les argiles sous forme de terrasses fluviatiles étagées. Le passage de la situation de comblement total à celle de circulation à haute énergie suppose l'ouverture d'un nouvel exutoire dans la galerie Aranzadi, le méandre Martine par exemple. De plus, la présence des remplissages de terrasses avec de puissantes séries de galets roulés pugilaires impose que le torrent venait du drain principal du gouffre. La salle de la Verna n'existait pas donc encore sous sa forme actuelle. Des petites pertes s'ouvraient peut-être en amont d'Aranzadi, qui auraient été bouchées par les argiles de l'ensemble principal. Cela suppose des vides beaucoup plus modestes que l'actuelle salle de la Verna.

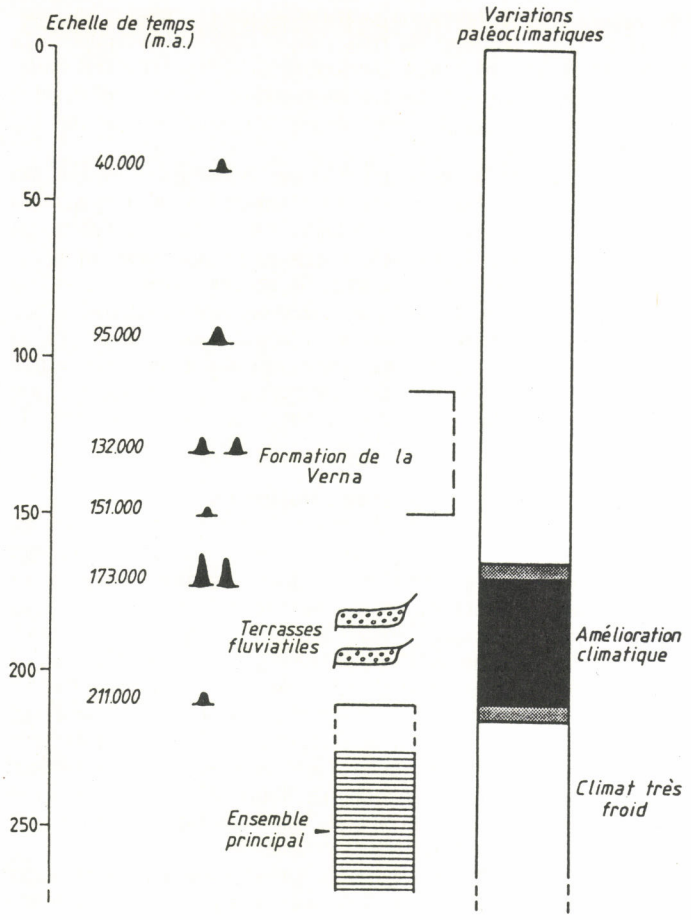
Le contraste entre les dépôts fluviatiles et l'ensemble principal est total. Nous avons maintenant affaire à des circulations à haute énergie. De plus, le contenu en carbonates détritiques des sables fluviatiles est nul. Une rupture climatique s'est produite vers un épisode plus tempéré. Cette question sera précisée avec l'etude du concrétionnement stalagmitique.



4. Log stratigraphique synthétique des dépôts de la galerie Aranzadi. Nous avons regroupé ici des stalagmites qui ont été prélevées à des endroits différents. Les épaisseurs des dépôts ne sont pas indiquées vu leurs fortes variations spatiales. L'ensemble inférieur est constitué de galets roulés et de quelques strates argileuses. Une couche de sable marque la transition avec les argiles de l'ensemble principal.

4. Fin de l'évolution fluviatile, creusement de la salle de la Verna

Aucun dépôt quantitativement important ne s'est mis en place aprés l'épisode des terrasses fluviatiles. Des concrétions stalagmitiques croissent. Les ruisseaux «Maria Dolorés» et «Martine» traversent la galerie Aranzadi en y incisant des recreusements dans



5. Echelle chronologique avec les principaux évènements enregistrés par les dépôts de la galerie Aranzadi. On soulignera surtout la période à climat tempéré qui se manifeste par un arrêt de la sédimentation de farine glaciaire (ensemble principal), les recreusements successifs avec le dépôt des terrasses fluviatiles étagées et les deux phases de concrétionnement stalagmitique.

les dépôts. La salle de la Verna s'est donc creusée peu après le dépôt des terrasses, soustrayant ainsi l'Aranzadi à l'érosion intense du torrent principal.

V. Chronologie et aspects paleoclimatiques

Les figures 4 et 5 indiquent les principales dates obtenues jusqu'à présent (Cantillana, Quinif, Maire, 1986). La stalagmite la plus vieille scelle l'ensemble principal. Les autres stalagmites d'Aranzadi scellent les terrasses fluviatiles. Les âges ne s'ordonnent pas suivant la stratigraphie des terrasses. Nous en concluons que la mise en place des terrasses s'est faite avant la plus vieille des stalagmites posées sur elles. Ceci est compréhensible vu que la galerie était parcourue par un écoulement violent lors de la mise en place des terrasses qui empêchait la croissance des stalagmites.

Nous définissons ainsi une phase morpho-sédimentologique complexe, se situant après le dépôt de l'ensemble principal et qui comprend une phase de concrétionnement (-211.000), les recreusements successifs avec dépôt des terrasses et un dernier épisode stalagmitique (-174.000). Le contexte paléoclimatique était tempéré. Il se peut que cet épisode soit complexe, avec des refroidissements secondaires mais il ne nous est pas possible de le prouver actuellement.

Nous avons découvert une terrasse fluviatile perchée dans la salle Chevalier qui précède la salle de la Verna. Une stalagmite scellant cette terrasse nous a livré un âge moyen de 174.000 ans ce qui corrobore parfaitement l'épisode stalagmitique défini dans Aranzadi.

Deux stalagmites ont été datées au fond de la salle de la Verna. Une petite coulée accuse un âge de 95.600 ans, une coulée plus importante a livré une date à 132.000 ans et 3 autres à 35.000 ans. Ces concrétions nous donnent un âge limite supérieur à la formation de la salle de la Verna que nous situons ainsi entre 174.000 et 132.000 ans.

Enfin, d'autres stalagmites de la galerie Aranzadi ont livré des âges de 150.600, 132.000 et 39.300 ans, visualisant des épisodes tempérés: un interstade dans le dernier épisode du Riss, l'interglaciaire Riss-Würm et un interstade dans le Würm.

VI. CONCLUSIONS

L'étude sédimentologique et radiométrique des dépôts de la galerie Aranzadi met en exergue le fonctionnement hydrogéologique de la cavité lors de deux ruptures climatiques dans le Riss. De plus, nous mettons en évidence une amélioration climatique à carectère interglaciaire dans les Pyrénées entre 211.000 et 174.000 ans, démontrant ainsi l'importance de ce type d'étude pour la géologie du Quaternaire.

Tableau 1: Résultats isotopiques et âges des stalagmites.

Echant.	U (p.p.m.)	U234/U238	Th230/U234	$(U234/U238)_o$	Ages (ky)
1. Aranzadi					
2ArSt1	3.79	1.107	0.871	1.194	211 (+38, −21)
2ArSt2	26	1.637	0.868	2.042	175.7 (+8.0, −7.5)
ArSt3	39	1.553	0.857	1.900	173.4 (+10.3, −9.3)
1Ar7	40	1.161	0.770	1.268	150.6 (+3.6−3.4)
1Ar12/bas.	6.4	1.352	0.734	1.509	131.9 (+27.4, −21.8)
1Ar12/som.	8.0	1.459	0.309	1.512	39.3 (+2.7, −2.60)
2. Salle de la Verna					
Vr5(1)	0.6	0.936	0.696	0.907	132.1 (+23.1, −18.5)
VR5(4)	0.77	0.870	0.289	0.855	37.3 (2.2, −2.2)
VR5(5)	0.77	0.870	0.286	0.856	36.9 (+2.2, −2.2)
VR5(6)	0.77	0.905	0.255	0.896	32.2 (1.2, −1.2)
VrSt1	0.35	1.059	0.590	1.077	95.6 (+56.8, −36.7)
3. Salle Chevalier					
1ChSt1/B	0.57	1.085	0.829	1.141	182.9 (+22.9, −18.5)
1ChSt1/C	0.80	1.057	0.779	1.089	159.8 (+177, −63.8)
1ChSt1/D	0.93	1.084	0.820	1.139	178.5 (+160, −62)
1ChSt1/F	0.82	1.214	0.829	1.349	174.5 (+24, −19.4)

A cause de la pureté de ces stalagmites, le rapport Th230/Th232 est plus grand que 100.

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On the interest of Speleochronological studies in Karstified Islands. The case of Mallorca (Spain)

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RESUM

Les illes carstificades són àrees geogràfiques excepcionalment apropiades per als treballs interdisciplinaris sobre espéleocronologia. Els estudis realitzats fins avui dia a Mallorca (España) sobre aquest tema, ens confirmen que diverses circumstàncies com el nivell oscil·lant de base controlat pel mar, que afecta al paisatge de les illes, o bé les tendències evolutives dels vertebrats fòssils endèmics que viuen en els paratges insulars, poden representar una valuosa font d'informació cronomètrica addicional de gran utilitat per a treballs de comprobació d'estratigrafies de coves. Aquest interès augmenta si tenim en compte que les coves de les illes es troben situades, sovint, en regions de clima o temperatures caluroses, i es caracteritzen per una deposició exhaustiva de concrecions, la qual cosa fa possible de dur a terme extensos programas de datació amb l'ajuda de mètodes físico-químics, com les sèries de l'urani, ESR i tècniques paleomagnètiques. A més, les fluctuacions pleistocèniques del nivell del mar són especialment significatives ja que els canvis en la situació altimètrica de la línia costanera poden establir-se dins les coves a partir de la formació de concrecions freàtiques i de l'acció de complexos canvis en les condicions geomorfològiques, hidrodinàmiques i geoquímiques que afecten dins les coves.

RESUMEN

Las islas karstificadas son áreas geográficas excepcionalmente adecuadas para la realización de trabajos espeleocronológicos interdisciplinarios. Los estudios desarrollados hasta la fecha en Mallorca (España) sobre estos temas muestran que diversas circunstancias, tales como el nivel de base fluctuante (controlado por las oscilaciones del mar) que afecta a las islas o las tendencias evolutivas de los vertebrados endémicos fósiles que vivieron en medios insulares, pueden proveer un marco cronológico adicional muy útil para trabajos centrados en la correlación entre estratigrafías de cuevas. Este interés viene acrecentado por el hecho de que las islas carbonatadas están localizadas muy frecuentemente en regiones de clima templado o tropical, siendo una característica de sus cuevas la abundante deposición de espeleotemas, que posibilitan amplios programas de datación con la ayuda de recientes métodos físico-químicos tales como las series de Uranio, las técnicas de ESR y el paleomagnetismo. Además, las fluctuaciones pleistocenas del nivel del mar son especialmente significativas debido a que los cambios altimétricos en la situación de la línea de costa pueden quedar registrados, en el interior de las cuevas isleñas, mediante la deposición de espeleotemas freáticos así como a través de la interacción de complejos cambios en las condiciones geomorfológicas, hidrodinámicas y geoquímicas que afectan a las cavidades.

SUMMARY

Karstified islands are geographical areas exceptionally suitable regarding interdisciplinary works on speleochronology. The up to date studies developed in Mallorca (Spain) on the subject show that several circumstances, like the pulsating sea-controlled base level that affects island landscapes or the evolutionary trends of endemic fossil vertebrates living in many insular environments, may provide additional chronometric framework very useful for cross-checking works in cave stratigraphies. This interest becomes enhanced by the fact that island-caves are located more frequently in regions of temperate or warm climate, being characterized by widespread speleothem deposition that allows the possibility of extensive dating programs with the aid of recent physico-chemical methods as U-series, ESR and paleomagnetic techniques. Furthemore, Pleistocene fluctuacions of sea-level are specially significant because changes in the altimetric location of the shoreline may be recorded, inside the caves, by phreatic speleothem deposition as much as by the action of complexchanges in the geomorphic, hydrodynamic and geochemical conditions that prevails in the caves.

Karstified Island and speleochronology

The islands whose geological constitution is mainly integrated by limestones offer an interesting variety of karstic phenomena. This fact encourages the successful speleochronological research; the following circumstances will contribute to the significance of these investigations.

The active morphogenetical processes operating on the coast line, as well as the discontinuous but progressive development of karstic phenomena whose base level is sea-controlled, produce a complicated range of interferences (Figure 1); most of these are specific of the karstic border which is located along the shore line. Obviously the karstified islands offer a wide spacial distribution of these geographical situations.

It is necessary to add that sea level has not remained static during the Pleistocene. On the contrary it has vastly fluctuated its altimetrical value, producing, besides other effects, periodical shifts of the coast line and also repeated immersions of karstic landforms that some time ago stayed above the sea level. A systematization of the complex range of interactions between sea level changes and coastal-karst areas is given on Table I.

Furthemore, insularity conditions stimulate the differential evolution of species living on the islands. Often, the evolutive trends of terrestrial fossil vertebrates are recorded with a certain richness of data in the stratigraphies accumulated inside some coastal caves; occasionally some bone breccias intercalate between sediments and morphologies of marine origin.

What is also essential to mention are the widespread processes of speleothems depositions. Interfering with the other mechanisms already referenced, they contribute to give complexity and larger possibilities to speleochronological research on limestone islands.

We will deal in detail with some of these morphosedimentary aspects of the karstified islands, as well as their chronological implications. In each moment, we will briefly refer to Mallorca as an example of what we intend to demonstrate.

Geomorphological data

Every oscillating movement of the sea level originates an extensive range of geomorphological, hydrological and geochemical effects that act upon coastal areas of karstified islands. When sea level changes, the underground water table

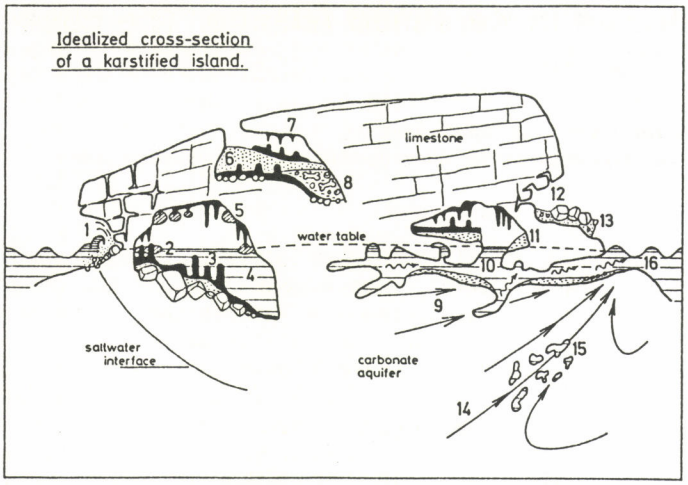

Figure 1. Geomorphic and stratigraphic effects of sea level changes that may be suitable for speleochronological studies.
1: Sea-cliff abrasion near a karstic cave. 2: Phreatic speleothems. 3: Submerged stalagmites. 4: Brackish pool. 5: Phreatic speleothems paleolevel. 6: Eolian sand. 7: Dripstone and flowstone speleothems. 8: Vertebrate bone breccia. 9: Groundwater flow. 10: Cave stream. 11: Cave clays. 12: Old sea cave. 13: Shelly gravels. 14: Mixing zone (freshwater-saltwater) subsaturated with respect to calcite. 15: Solutional cavities. 16: Submarine spring.

gets simultaneously adjusted to the new hydrological conditions in such a way that the altimetrical distribution of both the vadose and the phreatic zone is modified inside the karst. In this manner, previous vadose cave-features become drowned by sea level rises, whereas the phreatic zone retreats to lower heights with sea level fallings. As this hydrodynamic readjustment takes place the underground flow patterns tend to be reorganized, producing an intensification of the karstic erosion at the littoral springs belt. Though, this process results to be proportionally slow and for that reason it is common to find karst-outlets either perched over the sea level or transformed into submarine springs, according respectively with the descent or rise of the sea level.

Not only the water table and the outlets front considerably fluctuate its altimetrical position throughout the time; the mixing zone of freshwater with saltwater –that takes place in the surface of marine– water encroachment, near the shore line– undergoes the same alternations and reacts moving vertically in accordance with sea level oscillations. Recent researches (BACK & HANSHAW, 1983; BACK et al., 1984) have demonstrated that this zone of mixture is specially active from a geochemical point of view and dissolution processes may considerably increase in it.

The coastal karstic areas are subjected to intense erosive and sedimentary effects, wich are direct consequences of the waves action and the littoral geodynamics as a whole. These mechanisms affect in many different ways the development of coastal caves. For instance, gravels and sands of marine origin, either transported by the sea or wind-carried, may enter the caves and incorporate into its sedimentary record. At the entrance of the caves we can also frequently find morphologies of marine abrasion; it is even possible to verify that a great deal of cavities placed near the shore line are captures of caverns which, after their development by karstic dissolution processes, are being dismantled by littoral erosion mechanisms. An interesting classification of different types of coastal cavities was made by RIEDL (1966). It is pertinent to suppose that the phenomena of mechanical distension affecting the cliffs, as they was described by RENAULT (1967), might be involved in the easy way in which littoral erosion takes part in the progressive destruction of most of these caves, even occasionally transforming some of them in natural arches.

It must be added to the already mentioned arguments the fact that sea level fluctuacions during the Pleistocene introduce a chronological component, that has to be taken into account, since it can permit the datation of specific marine-abrasion paleoforms or littoral sediments whose faunistic content and altimetry were significant. This speleochronological approach is well showed on papers from KYRLE (1953), MONTORIOL-POUS (1961) and MONTORIOL-POUS & TERMES (1965). With similar criteria, GINÉS et al. (1975) relate some characteristics of two caves from the eastern coast of Mallorca with pleistocenic paleolevels of the Mediterranean sea.

Table I. Geomorphic and stratigraphic outcomes from sea level changes

Fluctuations of sea level		
	STAND OF SEA LEVEL	— Oceanic base level controls the location of coast line springs and groundwater flow patterns. — Active karstic erosion takes place in shore-effluent cave streams. — Limestone disolution occurs at the interface freshwater-saltwater. — Setting up of quiet brackish pools in coastal caves, roughly at sea level. — Development of conspicuous phreatic speleothem deposition. — Presence of shore abrasion morphologies and sediments.
	RISE OF SEA LEVEL	— Uplift of coastal karst water table. — Shift to higher levels of both coast line and phreatic zone morphogenetical factors. — Some karst-water outlets become submarine springs. — Brackish pools partially drown vadose cave-features. — Presence of submerged stalagmites below current sea level. — Uplifted water table becomes recorded in coastal caves as phreatic speleothems ledges. — Cave openings may be filled with marine sand. — Terrestrial vertebrates cannot be traped in submerged caves.
	FALL OF SEA LEVEL	— Drop of coastal karst water table. — Shift to lower levels of both coast line and phreatic zone morphogenetical factors. — Some shore-effluent caves become perched. — Retreat or removal of brackish pools in coastal caverns. — Phreatic speleothems are left above current sea level. — Sand of marine origin may only enter the caves wind-carried. — Coastal cave openings act as traps collecting remains of terrestrial vertebrates.

Speleothems

Speleothem deposition processes act widely and intensively in the karstic caves situated in zones of temperate or warm climates, where most of the karstified islands are placed. The final products of these chemical processes are included in the stratigraphies of coastal caves, remaining intercalated among sedimentary materials of extremely different characteristics, some of them of marine origin. For these reasons the possibility of obtaining absolute datings from speleothem samples (even from paleontological materials) by means of the use of recent physico-chemical technics as U-Series and ESR measurements, leaves a very suggestive field open to speleochronological studies on karstic caves of this type. The interest of these aspects is evidenced on several papers: GASCOYNE (1984); HARMON et al. (1975); HENNIG & GRÜN (1984); HENNIG et al. (1983); IKEYA (1978); IKEYA & MIKI (1980) among others.

Speleothem formation in coastal areas offer interesting particularities that must be taken into account. Specially its altimetrical relationship concerning past or present-day sea levels can supply worthy information. For instance, dripstone and flowstone speleothems can not develop in a coastal cave that has been drowned by eventual water table rises such as the ones produced during an interglacial stage. In that way, the presence of stalagmites submerged in the lakes of certain coastal caverns show the evidence of a partial flood of the cavity after a phase of aerial stalagmitisation belonging to a stage of lower sea level. This fact was already stated by JOLY & DENIZOT (1929) concerning the submerged stalagmites of the Coves del Drac (Mallorca).

More recently some authors have described phreatic speleothems that delimit old paleolevels of the water table in caves near the shore line. These phreatic speleothems, although they have a considerable morphological and mineralogical variety, appear as overgrowths more or less bulky that form horizontal ledges around the stalagmites, columns and walls of certain caves that were partially drowned by glacio-eustatical rises of sea level. These phenomena have been described, through observations in caves from different parts of the planet, in the publications of BALDUCCHI et al. (1956); HARMON et al. (1978); GINÉS et al. (1981 a, b); NÚÑEZ-JIMENEZ (1973), and some others.

In Mallorca, the great deal of informations available on the vestiges of pleistocenic beaches (see BUTZER & CUERDA, 1962; BUTZER, 1975) made possible to establish altimetrical, and even chronological, correlations between paleolevels of phreatic speleothems and Tyrrhenian beaches (GINÉS & GINÉS, 1974). Later researches, using U-Series techniques (HENNIG et al., 1981) and ESR measurements (GRÜN, 1986), have both confirmed and made accurate the datings of some samples of phreatic speleothems. Besides the absolute datations mentioned, in Mallorca we dispose of various isotopical datings on stalagmites and flowstones of the Cova de Muleta (WALDREN, 1982) and Cova de na Barxa (ANDREWS & SMART, pers. comm.).

Paleontological data

The progressive development of karstic phenomena, as well as the intense erosive activity taking place near the coast line, allow a considerable proportion of endokarstic cavities to communicate with the outside through penetrable openings. These entries can be used as a shelter for several vertebrate species. Sometimes the openings of vertical caves or some inner areas of the caverns can work as traps; the remains of the animals that had accidentally fallen into them are piled up at the bottom. In a way or another it is quite common that cave stratigraphies include bone breccias as a result of the accumulation of vertebrate remains that nowadays normally are extinguished. Sometimes these fossiliferous materials are associated with sediments of marine origin.

Making reference to the islands, we have to mention the possibility that fossil vertebrates have endemic forms which, if that is the case, increase the interest for the anatomical and morphometrical study of their remains. In that way, the evolutive tendences that can be deduced from the study on the vestiges of endemic vertebrates have an evident chronological value that has to be taken into account. As the knowledge on the fossil fauna of the islands increases we shall think that the age of each evolutive stage of the different endemic species will be fixed with greater accuracy.

Since most of the paleontological deposits in Mallorca have been formed inside karstic caves, it is not strange that some specially outstanding stratigraphies of majorcan caves as the Cova de Canet and the Cova des Fum had been interpreted from a chrono-stratigraphical point of view by PONS et al. (1979) and GINÉS & FIOL (1981) respectively.

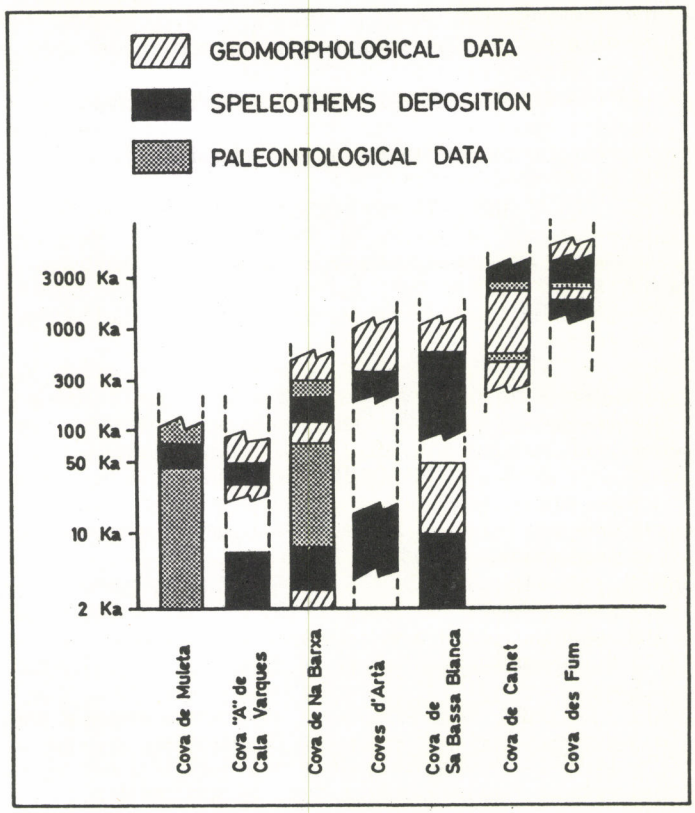

Figure 2. Schematic plotting of speleochronological data available from some significant Majorcan Caves.

At the same time a lot of datations made on materials from the Cova de Muleta, with C14 dating techniques and amino acid racemisation, have been published by WALDREN (1982). On the other hand, ALCOVER et al. (1981), taking the Balearic Islands as a geographical base, have made a conveniently up-to-date synthesis on the edemic forms of plio-pleistocenic vertebrates, paying special attention to the chronology which is confered to each of them according to the knowledge available now.

Conclusion

It is evident that morphological and sedimentological environments as the coastal caves of some karstified islands –and Mallorca is an example of them– are very adequate for making interdisciplinary speleochronological research (Figure 2), specially if we consider that with limited material resources it is frequently possible to achieve successful results. Most of these results can be contrasted by cross-checked datings in which different techniques and chrono-stratigraphical approaches are used.

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Datations^{14} C et ^{230}TH/^{234}U du concrétionnement stalagmitique de grottes belges.

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RESUM

Presentem ací els resultats d'unes 80 datacions amb ^{14}C i d'una cinquantena més amb ^{230}TH/^{234}U, efectuades a les concrecions estalagmítiques de coves belgues. S'ha efectuat una comparació dels dos mètodes de datació, basada en l'anàlisi de mostres idèntiques.

Histogramas construïts, integrant els errors associats a cada datació, permeten comparar les distribucions de les fases de concreció amb les fluctuacions climàtiques del Quaternari, tal i com apareixen en els registres isotònics dels fons marins.

Les coves estudiades presenten, de forma clara, dues fases més grans de concreció, corresponents als estadis isotòpics 1 i 5. Durant l'estadi isotòpic 3, s'observa igualment la formació de concrecions, però d'una manera menys intensa. En el transcurs del període comprès entre 40.000 i 10.000 anys B. P., aproximadament, sembla que la concreció s'hagi pràcticament interrromput per complet, cosa que està relacionada amb el període de màxima glaciació de l'estadi isotòpic 2. Durant l'estadi isotòpic 4, la formació de les concrecions sembla decréixer. Algunes concrecions han pogut també ésser datades, revelant edats que oscil·len al voltant dels 180-220 mil, 270-280 mil i 350 mil anys B. P.

RESUMEN

Presentamos los resultados de unas 80 dataciones ^{14}C y de una cincuentena de dataciones $^{230}Th/^{234}U$, efectuadas en concreciones estalagmíticas de cuevas belgas. Ha sido efectuada una comparación de los dos métodos de dataciones basadas sobre el análisis de muestras idénticas.

Histogramas construidos integrando los errores asociados a cada datación, permiten comparar las distribuciones de las fases de concreción con las fluctuaciones climáticas del Quaternario, tal como aparecen en los registros isotópicos de los fondos marinos. En las cuevas estudiadas, aparecen claramente dos fases mayores de concreción correspondientes a los estadios isotópicos 1 y 5. Durante el estadio isotópico 3, se observa igualmente la formación de concreciones, pero de manera menos intensa. Aproximadamente, a lo largo del período comprendido entre 40 y 10 mil B. P., parece que la concreción se haya prácticamente interrumpido por completo, en relación con el máximo glaciar del estadio isotópico 2. Durante el estadio isotópico 4, la formación de las concreciones parece decrecer. Algunas concreciones han sido también datadas sobre los 180-220 mil, 270-280 mil y 350 mil B. P.

RÉSUMÉ

Les résultats d'environ 80 datations ^{14}C et d'une cinquantaine de datations $^{230}Th/^{234}U$, effectuées dans des concrétions stalagmitiques de grottes belges; sont présentés. Une comparaison des 2 méthodes de datations, basée sur l'analyse d'échantillons identiques, est effectuée.

Des histogrammes construits en intégrant les erreurs associées à chaque datation permettent de comparer les distributions des phases de concrétionnement avec les fluctuations climatiques du Quaternaire telles qu'elles apparaissent dans les enregistrements isotopiques des fonds marins. Dans les grottes étudiées, deux phases majeures de concrétionnement, correspondant aux stades isotopiques 1 et 5, apparaissent nettement. Durant le stade isotopique 3, on observe également la formation de concrétions, mais de façon moins intense. Au cours de la période comprise entre 40 et 10 ka B. P. environ, il semble que le concrétionnement se soit pratiquement totalement interrompu, en relation avec le maximun glaciaire du stade isotopique 2. Pendant le stade isotopique 4, la formation des concrétions paraît ralentie. Des concrétions ont aussi été datées vers 180-220 ka, 270-280 ka et $>$ ***350 ka B. P.***

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$^{230}Th/^{234}U$ and $^{234}U/^{238}U$ dating of the stalagmite

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RESUM

Una estalagmita de 110 cm. d'altura es va extreure com a mostra de la cova de Dayan de Guilin. Es varen prendre 6 mostres, sistemàticament, de diferents nivells al llarg de l'eix central de l'estalagmita.

Es procedí a la datació d'aquestes 5 mostres pels mètodes $^{230}Th/^{234}U$ i $^{234}U/^{238}U$.

Els resultats obtinguts foren els següents:

N.º	per sobre de la base de l'estalagmita (cm)	$^{230}Th/^{234}U$ edad (Ka)	$^{234}U/^{238}U$ edad (Ka)
1	Top	41 ± 2	41^{+35}_{-30}
2	105	112^{+10}_{-7}	128^{+35}_{-30}
3	96	152^{+13}_{-10}	180^{+70}_{-40}
4	87,5	220^{+30}_{-25}	400^{+90}_{-60}
5	47,5	350	690 ± 100

D'acord amb això, podem afirmar que es varen produir dues interrupcions en el procés de deposició de l'estalagmita. Concretament a 112 i 220 ka B.P. L'autor suggereix la possibilitat que aquestes pauses poden reflectir unes condicions climàtiques molt seques.

RESUMEN

Una estalagmita de 110 cm de altura fue extraída como muestra de la cueva de Dayan de Guilin. Se tomaron 6 muestras sistemáticamente de diferentes niveles a lo largo del eje central de la estalagmita.

Se dataron cinco de estas muestras por los métodos $^{230}Th/^{234}U$ y $^{234}U/^{238}U$. Los resultados obtenidos fueron los siguientes:

N.º	por encima de la raíz de la estalagmita (cm)	$^{230}Th/^{234}U$ edad (Ka)	$^{234}U/^{238}U$ edad (Ka)
1	Top	41 ± 2	41^{+35}_{-30}
2	105	112^{+10}_{-7}	128^{+35}_{-30}
3	96	152^{+13}_{-10}	180^{+70}_{-40}
4	87,5	220^{+30}_{-25}	400^{+90}_{-60}
5	47,5	350	690 ± 100

De acuerdo con ello, tuvieron lugar dos pausas en el proceso de deposición de la estalagmita. Estas son 112-220 ka B.P. El autor sugiere que estas pausas pueden reflejar unas condiciones climáticas bastante secas.

SUMMARY

A stalagmite of 110 cm high was sampled from Dayan cave of Guilin. Six samples was derived systematically from various levels along the central axis of stalagmite.

Five of these samples are dated by $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ methods. The results are as follows:

NO	Above the root of stalagmite (cm)	$^{230}Th/^{234}U$ Age (Ka)	$^{234}U/^{238}U$ Age (Ka)
1	Top	41 ± 2	41^{+35}_{-30}
2	105	112^{+10}_{-7}	128^{+35}_{-30}
3	96	152^{+13}_{-10}	180^{+70}_{-40}
4	87,5	220^{+30}_{-25}	400^{+90}_{-60}
5	47,5	350	690 ± 100

Accordingly, two pauses had been took place in the process of deposition of the stalagmite. They are 112-220 ka B.P. The authors suggest that these pauses may reflect a rather dry climatic condition.

Introduction

As one know, a reliable result of measuring speleothem age by means of the $^{230}Th/^{234}U$ dating is obtained. Time scale was made for the speleothem of 350 ka B.P. but it has been studing for the speleothem of older than 350 ka B.P.

In this paper a result of $^{234}U/^{238}U$ dating of the speleothem is described. The age of the top of the stalagmite is 41 ka and the age of the bottom of the stalagmite is 690 ka measured by $^{234}U/^{238}U$.

Description of Samples

A stalagmite of 110 cm high was sampled from Guilin Dayan Cave of China. Five samples was derived systematically various levels along the central axis of stalagmite as shown in table 1.

Table 1. Description of Samples

Samples no	Above the root of stalagmite (cm)	Colour of Powder of samples	Annotate
8.457	top	light yelow	
82.110	103-107	milky white	
			–1 hiatuses
82.109	92-100	light yellow	
			–2 hiatuses
82.108	85-90	milky white	
82.106	45-50	milky white	

Table 2. Results of $^{230}Th/^{234}U$ dating of the stalagmite

Samples no	$^{234}U/^{238}$*	$^{230}Th/^{234}$ U	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$ Age (ka)
8.457	1,66 ± 0,06	0,32 ± 0,01	11	41 ± 2
82.110	1,52 ± 0,05	0,68 ± 0,03	95	112^{+10}_{-7}
82.109	1,45 ± 0,05	0,80 ± 0,03	20	152^{+13}_{-10}
82.108	1,24 ± 0,05	0,91 ± 0,04	50	220^{+30}_{-25}
82.106	1,11 ± 0,03	1,03 ± 0,04	> 500	> 350

* Activity ratio of isotope.

Table 3. Results of $^{234}U/^{238}U$ dating of the stalagmite

Samples no	U (/10^6)	$^{234}U/^{238}U$	$^{234}U/^{238}U$ Age (ka)
8.457	0,14 ± 0,005	1,66 ± 0,06	41 ± 32
82.110	0,07 ± 0,003	1,52 ± 0,05	125 ± 34
82.109	0,06 ± 0,002	1,45 ± 0,05	180 ± 43
82.108	0,04 ± 0,002	1,24 ± 0,05	400 ± 75
82.106	0,63 ± 0,020	1,11 ± 0,03	690 ± 100

Calculation of the age and results of the measured

1. The $^{230}Th/^{234}U$ age of the stalagmite T is calculated by following equation (1):

$$^{230}Th/^{234}U = (^{238}U/^{234}U) \quad [1 - \exp \quad (^{-\lambda}{}_0)T] + (1 - ^{238}U/^{234}U) \quad (\lambda_0/\lambda_0 - \lambda_4) \; [1 - \exp^{-} \; (^{\lambda}{}_0 - \lambda_4)T] \qquad (1)$$

2. The $^{234}U/^{238}U$ age of the stalagmite T is calculated by follwing equation (2):

$$^{234}U/^{238}U = 1 + [(^{234}U/\ ^{238}U)_o - 1] \; \exp^{-(\lambda_4)}T \qquad (2)$$

In equations 1 and 2, λ_0 and λ_4 represent respectively the decay constants of ^{230}Th and ^{234}U; ^{230}Th, ^{234}U, and ^{238}U are measured activites in a sample of T years old.

In equation 2, $(^{234}U/^{238}U)_o$ is the initial activity ratio, it can be calculated from the $^{230}Th/^{234}U$ known age of stopping growth part of the stalagmite. It is 1.7402 for this stalagmite.

3. The analytic results of $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ dating of the stalagmite is listed in table 2 and 3.

Conclusions

1. It is possible to obtain a systematic $^{234}U/^{238}U$ ages of a stalagmite if sampling along the axis of the systematically and rigorously is done and the geological condition of the speleothems is known. In table 3 it may be seen that the growth of the considered stalagmite began at 690 ka B.P. and stopped at 41 ka B.P.; the period *of grow* lasted for more then 600 ka.

2. Guilin Dayan Cave of China was formed at older than 700 ka B.P.

3. Based on the correcy analytic procedure, enough quantity of samples and careful long period measurement, the age of carbonate speleothems with U concentration even below 0.1 (to 0.04) ppm can be determined.

4. In this paper the initial ratio of the $^{234}U/^{238}U$ is estimated as 1.7402 for the top the stalagmite. It can be calculated from the $^{230}Th/^{234}U$ known age of the stopping growth part.

5. Two growth hiatuses can be clearly seen from the shell of this stalagmite. By means of the $^{230}Th/^{234}U$ dating, the hiatuses of (112-152) ka B.P. and of (152-220) ka B.P. are measured. It may reflect rather dry and cold palacoclimate existed over the period during the stalagmite formed.

6. This stalagmite obtained from Dayan Cave grew under a closed system condition, therefore it is a good material for $^{234}U/^{238}U$ dating. The ages of this considered stalagmite are of reliable. This result is a contribution to the dating of the carbonate speleothems older than 350 ka B.P..

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Cavidades relictas y paleokarst del plioceno en el área de Millares Tous (Provincia de Valencia, Spain)

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RESUM

L'enclavament geològic d'una sèrie de cavitats amb característiques morfològiques i espeleogenètiques comuns ha permès de situar, en el temps i en l'espai, l'existència d'un desenvolupament paleocàrstic d'excepcional importància dins del context regional valencià.

Les principals formes càrstiques, tant superficials com subterrànies, existents a la província de València, són l'herència d'un paleocarst que va aconseguir el seu punt culminant durant el Pliocè.

El nivell de base hidrològic actual, així com les superfícies piezomètriques dels diferents sistemes hidrogeològics existents a la zona, se situen al voltant dels 300 m. per sota de la seva antiga posició pre-quaternària.

RESUMEN

El enclave geológico de una serie de cavidades con características morfológicas y espeleogenéticas comunes ha permitido situar, en el tiempo y en el espacio, la existencia de un desarrollo paleokárstico de excepcional importancia dentro del contexto regional valenciano.

Las principales formas kársticas, tanto superficiales com subterráneas, existentes en la provincia de Valencia son heredadas de un paleokarst que tuvo su óptimo desarrollo durante el Plioceno.

El nivel de base hidrológico actual, así como las superfícies piezométricas de los distintos sistemas hidrogeológicos existentes en la zona, se sitúan alrededor de 300 m por debajo de su antigua posición precuaternaria.

SUMMARY

The most speleological interest of the Millares Tous region (holokarst developed in Cretaceous dolomites and limestones) is placed in a concurrence of horizontal caves which appear several hundreds meters upon present phreatic levels. These caves are the rest of an old karstical flow pattern (water-table zone) developed during the Pliocene.

The present hydrographic system instalation took place along the Cuaternary age and his most representative exponent is the karstical cannyon which crosses this regions from West to Est, beeing followed by the Jucar river.

Características generales del área

El cuadrante suroccidental de la provincia de Valencia está constituido por una amplia plataforma carbonatada que culmina en el pico Garoig (1.126 m sobre el nivel del mar). Su estructura geológica individualiza una serie de unidades hidrogeológicas de naturaleza kárstica, entre las cuales se encuentra, en su mitad septentrional, la de Millares-Tous, que comprende los relieves de la Muela de Cortes y la Sierra de Caballón-Campillo (fig. 1).

Los materiales acuíferos (fig. 2) corresponden exclusivamente a calizas, dolomías, margas y calizas arenosas del Cretácico, con una potencia superior a los 900 m. Bajo ellos se encuentra presente otra secuencia también carbonatada del Jurásico, aunque en probable desconexión vertical. Los límites laterales de esta unidad hidrogeológica están constituidos por materiales triásicos en facies Keuper (impermeable regional de base), por margas del Kimmeridgiense inferior y por areniscas y lutitas paleógenas (ELIZAGA et al., 1983).

La estructura general de esta unidad (fig. 3) corresponde a una plataforma subtabular: Muela de Cortes, que se prolonga hacia el SE por el anticlinal vergente del Caballón y la fosa de Tous. El límite septentrional lo constituye el Trías extrusivo de la Rambla de los Gallegos y el Paleógeno cabalgado de la Canal de Dos Aguas; por el NE constituyen barrera hidrogeológica las margas kimmeridgienses, que se elevan en el eje del anticlinal del Caballón; el límite O viene dado por el valle triásico de Ayora-Cofrentes; por el S limita con la falla del Caroig y la Canal de Navarrés, ocupada igualmente por el Trías; por último, el límite oriental es abierto y a través de él se produce una recarga lateral y oculta al acuífero miocuaternario de la llanura sublitoral de la Plana de Valencia.

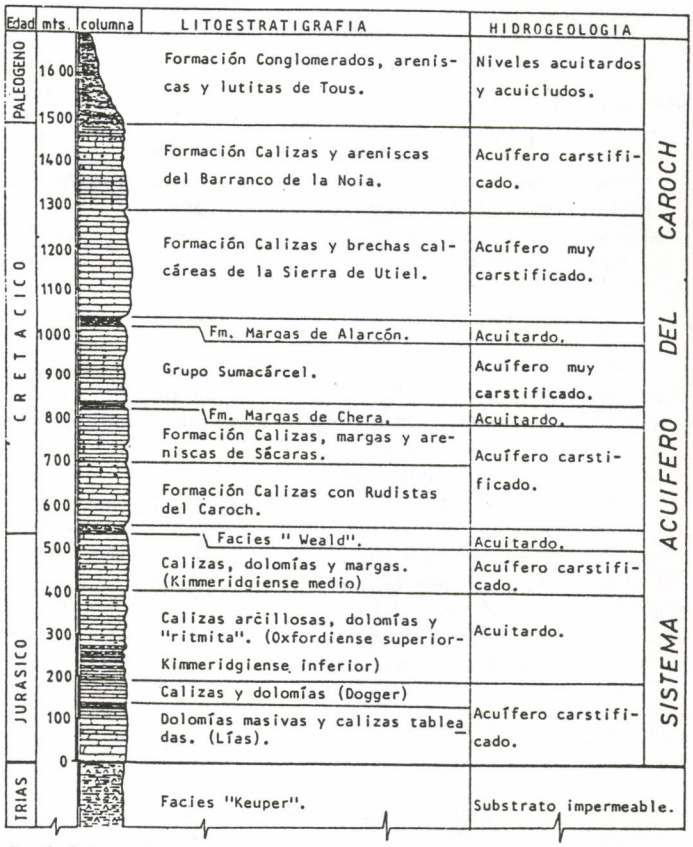

Fig. 2. Columna litoestratigráfica del Macizo del Caroig, tomada del ELIZAGA et al. (1983).

Geomorfología

Toda la unidad se encuentra atravesada de W a SE por el río Júcar que discurre profundamente encajado por un amplio cañón kárstico excavado a expensas de una serie de fallas de gravedad que configuran una pequeña fosa tectónica.

El encajamiento del Júcar ha condicionado el desarrollo de una relativamente densa red de drenaje superficial con profundos valles en V, la cual domina en el paisaje y es la responsable del desmantelamiento y captura de una morfología típicamente kársticas anterior a él, de la que quedan tan solo algunas formas relictas. En este sentido es destacable el valle elevado denominado La Canal (Dos Aguas), antiguo poljé desarrollado hacia los 500 m de altitud, con una cuenca vertiente de unos 10 km^2, en

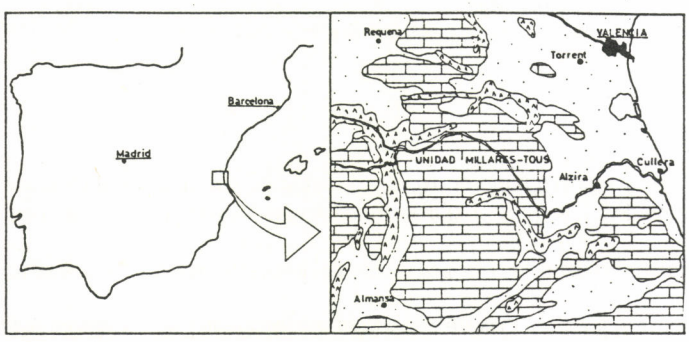

Fig. 1. Situación del área de estudio.

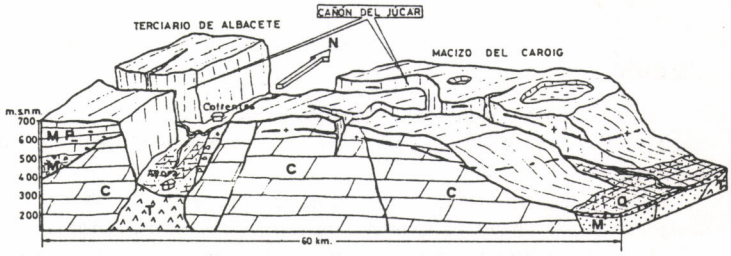

Fig. 4. Esquema tridimensional muy simplificado del área estudiada. Obsérvese la posición de las cavidades relictas (+).

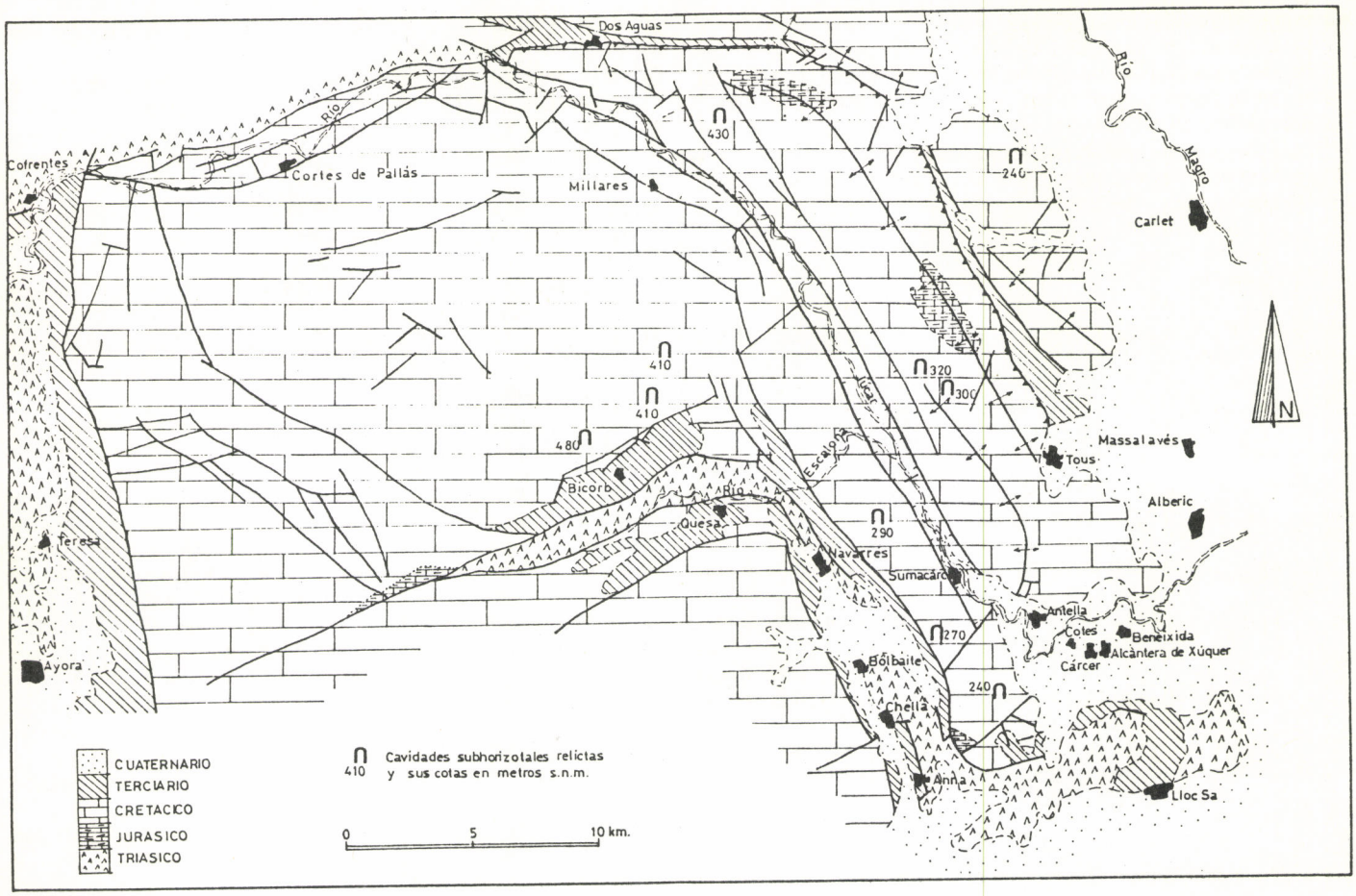

Fig. 3. Mapa geológico del karst de Millares-Tous.

la actualidad capturado por el barranco de Jalón, directamente tributario al Júcar.

Otras formas kársticas menores se reconocen dispersas por toda la unidad, destacando entre ellas la depresión endorreica de La Laguna (Tous), a 460 m de altitud.

La red hidrográfica actual, dentrítica y meandriforme, está caracterizada por pendientes entre 3 y 15 %, densidad de drenaje de 4 a 7 km^{-1} y densidad de frecuencia de 9 a 22 cauces por km^2.

Tipología de las cavidades

El conocimiento espeleológico de la zona, que arranca de finales del siglo XVIII (CAVANILLES, 1795-97 y 1803), ha puesto de manifiesto la existencia de diversas cavidades con unas características morfológicas y espeleométricas comunes. Se trata de antiguas galerías o tramos de éstas de desarrollo horizontal, con recorridos generalmente comprendidos entre 200 y 600 m y con anchuras y alturas medias comprendidas entre 3 y 8 m. Se encuentran situadas a cotas elevadas, muy por encima de la superficie piezométrica actual, aún cuando su origen está relacionado, en principio, con la pretérita presencia de antiguos niveles piezométricos entorno a ellas. Por consiguiente, en la actualidad no presentan actividad hidrológica alguna, salvo el encharcamiento perenne o estacional de sus gourgs.

En algunas de estas cuevas, además de su indudable morfología freática, se reconocen otras formas de indudable interés paleohidrológico como son las entalladuras de corrosión, canales de bóveda, cúpulas de corrosión remontante, marcas de corriente (flutes), etc.

Como prototipos de este conjunto de cavidades del área de Millares-Tous, se pueden citar la Cueva Dones (Millares), la Cueva del Candil (Tous), la Cueva del Alto de Tous (Tous) y la Cueva de las Maravillas (Dos Aguas).

Son importantes los rellenos litoquímicos y sedimentarios que contienen estas cavidades, los cuales son siempre los responsables de los límites de la exploración espeleológica.

Existe una buena correlación altimétrica entre éstas y otras muchas cavidades del área cuyas características morfológicas y topográficas siguen siendo comunes. Todo ello aboga por una formación y evolución conjunta de todas estas cavidades, en relación con una posición mucho más elevada de los niveles piezométricos que la actual.

Una visión más amplia y completa sobre los fenómenos espeleológicos de este área puede ser obtenida a través de las diversas publicaciones existentes: DONAT (1960, 1961, 1967, 1969, 1972 Y 1975), FERNANDEZ et al. (1980 y 1982), G.G.G. (1979), FERRER (1981), JORNET (1980, 1982A Y 1982B), etc.

Edad del paleokarst

El nivel de circulación paleokárstico que se acaba de definir, se encuentra en la actualidad completamente truncado y jalonado por la red hidrográfica, con una diferencia de cotas del orden de los 300 m. La plataforma superior del macizo, que se sitúa muy próxima y por encima del nivel de cavidades relictas, se prolonga hacia el W por los Llanos de Albacete, amesetados entorno a los 700 m sobre el nivel del mar e igualmente afectados por el encajamiento profundo del Río Júcar.

Los materiales que conforman estos llanos constituyen la denominada Formación Calizas del Río Júcar, de edad Mioceno Superior-Plioceno Medio, cubierta por la llamada Unidad Detrítica Superior, del Plioceno Medio-Superior (ROBLES, 1975; BASCONES et al., 1981; AGUIRRE et al., 1982; ALBERDI et al., 1982) (ver figura 4).

Con estos datos cronoestratigráficos es posible precisar que el encajamiento de la red fluvial no se produjo antes del Plioceno Superior. El límite superior de este encajamiento se sitúa en el Pleistoceno Medio, a juzgar por los materiales de esta edad (abanicos aluviales), en franca relación con los cauces actuales-subactuales (GOY et al., 1974).

La edad del paleokarst cabe situarla, en consecuencia, con anterioridad al encajamiento del Río Júcar. Es muy presumible

entonces que su desarrollo espeleogenético coincida con la formación de las calizas mio-pliocénicas de los Llanos de Albacete, sobre todo con su mited superior, dada la coincidencia de cotas entre colmatación y drenaje lateral a través de las dolomías y calizas cretácicas del Garoig. Por otra parte es lógico pensar en el intenso desarrollo kárstico que debe llevar implicado la colmatación de una cuenca carbonatada continental, con un notable aporte de calcita disuelta (GARAY, 1983).

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^{230}Th- ^{234}U Ages of Speleothems in Eastern Mainland of China and Paleoenvironment Studies

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RESUM

En aquest treball es comenten les edats de 40 espeleotemes a partir de 53 datacions amb ^{230} Th- ^{234}U de 18 sistemes de cavitats del Mainland oriental de la Xina. Amb l'estudi d'isòtops estables es pot arribar a discutir el paleo–ambient d'espeleotemes d'una antiguitat que es remonta als 350.000 anys

Els diferents episodis de sedimentació s'atribueixen a les époques interglacials, mentre que l'absència de sedimentació és pròpia dels períodes glacials.

Els períodes interglacials s'han pogut així conèixer i establir de la següent forma: 1) del moment actual fins a 20.000 anys; 2) de 75.000 a 120.000 anys; 3) de 170.000 a 230.000 anys; 4) de 250.000 a 310.000 anys. Aquests interglacials es corresponen amb períodes amb un nivell del mar alt i amb un clima càlid i hùmit, atès el que hom ha pogut registrar en els isòtops dels foraminífers marins.

RESUMEN

Se comentan las edades de 40 espeleotemas distintos a base de 53 ^{230} Th- ^{234}U, de 18 sistemas de cavidades del Mainland oriental de China y estudios sobre isótopos estables, se discute el Paleo–ambiente de espeleotemas dotados en 350.000 años.

Los episodios de sedimentación se atribuyen a los interglaciales y los de auséncia de sedimentación a los glaciares, los interglaciares se reconocen por: 1) presente hasta 20 ka; 2) de 75-120 ka; 3) de 170-230 ka; 4) de 250-310 ka. Estos interglaciares se correlacionan con períodos con el nivel del mar alto y un clima cálido y húmedo según lo que se ha registrado en los isótopos de los foraminíferos marinos.

SUMMARY

Based on 53 ^{230}Th-^{234}U ages for 40 different speleothems in 18 cave system from the Eastern Mainland of China and stable studies, the paleoenvironment of speleothems since 350.000 years is discussed.
Attributing episodes of deposition to interglacials and nondeposition to glacial periods, interglacials are recognized at 1) present to 20 ka; 2) 75-120 ka; 3) 170-230 ka; 4) 250-310 ka. These interglacials correlate with periods of high sea level and warm-wet climate observed on the isotopic record of marine foraminifera.

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Late Pleistocene Glacial Chronology in Crowsnest Pass, Alberta, Canada, as Evidenced by Uranium-Series Speleothem Dates.

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RESUM

S'han obtingut diverses datacions per les sèries de l'urani de mostres d'espelotemes de diferents coves de Crowsnest Pass (Alberta, Canadà). S'analitzen les implicacions paleoclimàtiques per a cada edat, identificant la cronologia dels períodes glacials i interglacials del Plistocè. Les datacions s'han correlacionat també amb d'altres cronologies del Plistocè. Una ámplia relació de cronologies d'espeleotemes per les sèries de l'urani de tot el globus, proporciona un excel·lent registre terrestre, el qual es troba en concordança amb la cronologia marina majoritàriament acceptada.

RESUMEN

Se han obtenido dataciones por las series de uranio sobre muestras de espeleotemas de diferentes cuevas de Crowsnest Pass, Alberta, Canadá. Se discuten las implicaciones paleoclimáticas de estas edades, identificando la cronología de los períodos glaciares e integlacialres del Pleistoceno. Las dataciones se han correlacionado también con otras cronologías del Pleistoceno. Una vasta colección de edades de espeleotemas por las series de uranio por todo el globo, propociona un excelente registro terrestre, que está en buena correlación con la cronología marina ampliamente aceptada.

RESUME

Une suite de datations par des séries uranium a été obtenue sur des échantillons de spéléothèmes de différentes grottes de Crowsnest Pass, Alberta, Canada. Les implications paléoclimatiques de ces âges sont discutées, identifiant la chronologie des périodes glaciaires et interglaciaires du Pléistocene. Les datations sont aussi corrélées avec d'autres chronologies du Pléistocene. Une grande collection d'âges de spéléothèms par les séries uranium à travers tout le globe, procure un excellent enregistrement terrestre, qui est bien corrélé avec la chronologie marine largement acceptée.

A suite of uranium-series dates has been obtained from speleothem samples from various caves in Crowsnest Pass, Alberta, Canada. The paleoclimatic implications of these dates are discussed, identifying the chronology of Pleistocene glacial and interglacial periods. The dates are also correlated with other Pleistocene chronologies. A large collection of uranium-series speleothem dates from across the globe provides an excellent terrestrial record which correlates well with the widely accepted marine chronology.

ESR-Dating Speleothems – Method and Application

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RESUM

Malgrat que l'espectroscopia – ESR s'hagi aplicat com a mètode de datació d'espeleotemes des de l'any 1975, és tanmateix poc coneguda en espeleologia. L'ESR es basa en la detecció dels electrons lliures, els quals seran capturats, amb el temps, per la malla cristal-lina. Aquests electrons lliures són el resultat de la radio-activitat natural (raigs α, β, γ i la radiació còsmica). El seu nombre augmenta constantment a través del temps, a l'igual que el senyal ESR, que és proporcional al nombre d'electrons emesos. Per a calcular l'edat d'un espeleotema podem aplicar la fòrmula següent:

$$\frac{\text{dosi acumulada (DA) Gray}}{\text{dosi anual (D0) mGray/ka}}$$

La dosi acumulada (DA) és la dosi que ha rebut la mostra des de l'època de la seva formació. Aquest valor es pot determinar mitjançant l'espectroscopi – ESR. Pel contrari, la dosi anual es desprèn de l'anàlisi d'elements radioactius (U, Th, K) de la mostra (taxa de la dosi interna i dels voltants), així com també de la radiació còsmica (taxa de dosi externa).

Descriurem breument el mètode, acompanyat d'algunes aplicacions en espeleologia.

RESUMEN

A pesar de que la espectroscopía -ESR sea aplicada como método de datación de espeleotemas desde 1975, es no obstante poco conocida en espeleología. El ESR está basado en la detección de los electrones libres, que son capturados en la malla cristalina con el tiempo. Estos electrones libres son el resultado de la radioactividad natural (rayos α, β, γ y la radiación cósmica). Su número aumenta constantemente con el tiempo, así como la señal ESR, que es proporcional a aquél. Se puede calcular una edad según la fórmula:

$$\frac{\text{dosis acumulada (DA) Gray}}{\text{dosis anual (DO) mGray/ka}}$$

la dosis acumulada (DA) es la dosis que ha recibido la muestra desde la época de su formación. Este valor está determinado por el espectroscopio – ESR, por el contrario la dosis anual deriva del análisis de elementos radioactivos (U, Th, K) de la muestra (tasa de la dosis interna y de sus alrededores) así como también de la radiación cósmica (tasa de dosis externa). Se describirá brevemente el método, acompañado de aplicaciones en espeleología.

RESUME

Bien que la spectroscopie-ESR soit appliquée comme méthode de datation des spéléothèmes depuis 1975, elle n'est pourtant que peu connue en spéléologie. L'ESR est basée sur la détection des électrons libres, qui sont capturés dans la maille crystalline avec le temps. Ces électrons libres sont le résultat de la radioactivité naturelle (rayons α; β; γ et la radiation cosmique). Leur nombre augmente constamment avec le temps, de même que le signal ESR, qui est proportionnel à celui-ci. Un âge peut être calculé selon la formule.

$$\frac{\text{dose accumulée (DA) Gray}}{\text{dose annuelle (DO) Gray/ka}}$$

la dose accumulée (DA) est la dose que l'echantillon a reçu depuis le temps de sa formation. Cette valeur est déterminee par le spectroscope – ESR, par contre la dose annuelle est dérivée de l'analyse d'éléments radioactifs (U, Th, K) de l'échantillon (taux de la dose interne, et de son environnement ainsi que de la radiation consmique (taux de dose externe). La méthode sera brièvement décrite accompagnée d'applications en spéléologie.

Although ESR spectroscopy is applied as a dating method to speleothems since 1975 it is not well known in speleology.

ESR is based on the detection of free electrons, which are captured in the crystal lattice during aging. These free electrons are created by the natural radioactivity (α –, β –, γ – rays and cosmic radiation). Their population increases steadily with time and so does the ESR signal, which is proportional to it. An age can be calculated according to the simple formula:

$$\text{Age (Ma)} = \frac{\text{accumulated dose (AD) [Gray]}}{\text{annual dose (DO) [mGray/ka]}}$$

where the accumulated dose (AD) is the dose a sample has received since the time of its formation. This value is determined by ESR-spectroscopy whereas the annual dose is derived from the analysis of the radioactive elements (U, Th, K) of the sample (internal dose rate) and its surroundings and the cosmic radiation (external dose rate). The method will be briefly describeb and applications in speleology will be given.

U-series dating and stable isotope studies of wall rocks and speleothems in Jewel Cave and Wind Cave, Black Hills, South Dakota, U.S.A.

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RESUM

La cova de Jewel (115 Km.) és la quarta més llarga del món i la cova de Wind és la onzena. Amdues coves s'estenen en les tres direccions en forma de laberints en la formació de Pahasapa, de 100 m. d'espessor, formada per calcàries i capes de dolomia. Les xarxes presenten formes associades a una dissolució en les aigües freàtiques que circulem lentament. No tenen relació amb la topologia actual. La cova de Jewel, conté abundants formes cristal·lines amb la forma del cap d'una agulla. La cova de Wind és coneguda per la seva caixa de calcita. Les dues coves compten amb nombrosos dipòsits carbonatats i sulfatats. El model genètic estàndart que s'ha proposat és el d'excavació per aigües meteòriques normals (dolces) que circulen en un medi artesià.

Nosaltres creiem que aquestes coves s'han format per aigües hidrotermals convergents en les fonts regionals. Barrejades amb aigua meteòrica, això hagués pogut tenir la seva importància. Els travertins de les fonts calents i modernes són escassos: de −2 a −7 % ^{13}C i de −3 a −18 % ^{18}O (en comparació amb el PDB). A tots els dipòsits hidrotermals que poden ser interessants succeeix quelcom semblant. La datació de les sèries de l'U ha demostrat que totes les aigües termals es van retirar de la cova de Jewel abans de 350.000 anys. Durant els últims 200.000 anys el nivell de les aigües ha sofert una oscil·lació de 40 m. a la cova inferior de Wind.

RESUMEN

La cueva de Jewel (115 kilómetros) es la cuarta más larga del mundo y la cueva de Wind (68 Km) es la onceava. Ambas siguen las tres dimensiones para su desarrollo, como laberintos, desarrolladas en los 100 m. de espesor de la formación de Pahasapa, formada por caliza y capas de dolomía. Las redes presentan formas asociadas a una disolución en aguas freáticas que circulan lentamente. No tienen relación con la topografía actual. La cueva Jewel, contiene abundantes formas cristalinas en forma de cabeza de alfiler. La cueva de Wind tiene fama por su caja de calcita. Las dos cuevas poseen muchos depósitos carbonatados y sulfatados. El modelo genético estandard propuesto para ellas es de excavación por aguas meteóricas normales (dulces) que circulan en un medio artesiano.

Proponemos que estas cuevas se han formado por aguas hidrotermales convergentes a las fuentes regionales. Mezcladas con el agua meteórica, eso habría podido tener su importancia. Los travertinos de las fuentes calientes y modernas son reducidos de −2 a −7 % ^{13}C y de −3 a −18 % ^{18}O (en comparación con PDB). Todos los depósitos hidrotermales que parecen interesantes se reducen de la misma manera. La datación por las series de U ha demostrado que todas las aguas termales se retiraron de la cueva de Jewel antes de 350 ka. Durante los últimos 200 ka las aguas han experimentado una oscilación de 40 m. en la cueva inferior de Wind.

RÉSUMÉ

La grotte de Jewel (115 kilomètres) est la quatriéme plus longue du monde et la grotte de Wind (68 kilomètres) est la onzième. Toutes les deux sont à trois dimensions, comme des labyrinthes, développées dans les 100 mètres èpais de la formation de Pahasapa, composée de calcaire et de couches de dolomite. Les réseaux exposent des formes associées à une dissolution dans les eaux phréatiques s'écoulant lentement. Ils n'ont pas de relation avec la topographie actuelle. La grotte Jewel contient d'abondantes formes cristallines en têtes d'épingles. La grotte Wind est renommée pour sa boîte calcite. Les deux grottes possèdent beaucoup de dépôts carbonatés et sulphatés. Le modèle génétique standard proposé pour eux est en creusement par des eaux météoriques normales (douces) coulant dans un environnement artésien.

Nous proposons que ces grottes aient été développées par des eaux hydrothermales convergeantes aux sources régionales. Mélangées avec l'eau météorique, cela aurait pu jouer un rôle. Les travertins des sources chaudes et modernes sont réduits de −2 à −7 % ^{13}C et de −3 à −18 % ^{18}O (en comparaison avec PDB). Tous les dépôts hydrothermales suspects sont réduits de la même manière. La datation par les series U a prouve que toutes les eaux thermales se sont retirées de la grotte Jewell avant 350 ka. Pendant les dernières 200 ka, les eaux ont oscillé de 40 mètres dans la grotte Wind inférieure.

SUMARY

Jewel Cave (115 km) is fourth longest in the world and Wind Cave (68 km) is eleventh. Both are three-dimensional mazes developed in the 100 m thick Pahasapa Formation of limestones with some dolomite beds. The passages display forms associated with dissolution in slowly flowing phreatic waters. They have no relation to the present topography. Jewel Cave contains abundant nailhead spar. Wind Cave is famed for calcite boxwork. Both caves contain many other carbonate and sulphate precipitates. The standard genetic model proposed for them is of excavation by normal (cool) meteoric waters flowing in an artesian environment.

We propose that these caves were developed by hydrothermal waters converging upon regional springs. Mixing with meteoric water may have played a role. Modern hotsprings travertines are depleted −2 to −7 % ^{13}C and −13 to −18 % ^{18}O (wrt PDB). All suspected hydrothermal precipitates are similarly depleted. U-series dating has established that all thermal waters had with drawn from Jewel Cave before 350 ka. During the past 200 ka waters have oscillated through a range of 40 m in lower Wind Cave.