The Contribution to the History of the Speleological Explorations of the West Indies - at 500-Anniversary of the Discovery of America

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PRISPEVEK K ZGODOVINI SPELEOLOŠKIH RAZISKAV ZAHODNE INDIJE - OB 500-LETNICI ODKRITJA AMERIKE

THE CONTRIBUTION TO THE HISTORY OF THE SPELEOLOGICAL EXPLORATIONS OF THE WEST INDIES - AT 500-ANNIVERSARY OF THE DISCOVERY OF AMERICA

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VSEBINA - CONTENTS

Zahodna Indija, kot danes imenujemo "Indijo", ki jo je odkril Krištof Kolumb pred 500 leti, so kraški otoki. Na njih je razvit tropski kras in nekatere morfološke oblike krasa, kot je stolpasti kras z "mogoti" na Kubi, depresije "cockpit" na Jamajki, tipični primeri tropskega krasa, ki nastopajo kot "locus typicus" v svetovnem krasoslovju in so dali svoj prispevek tudi k mednarodni krasoslovni terminologiji. V Ameriki je tudi drugod veliko najrazličnejšega krasa: sistem Mammoth Cave je s 531,069 km najdaljši na svetu, v Kanadi so najlepši primeri podledeniškega in periglacialnega krasa, kraški grezi na Floridi povzročajo prave gospodarske katastrofe, "cenotes" (sveta brezna) na Yukatanu so neprecenljive arheološke zakladnice, v Mehiki so orjaška brezna, kraške planote z ogromnimi udornicami v Južni Ameriki so resnični "izgubljeni svetovi".

Tudi Slovenci nismo brez stikov z ameriškim krasom: Valvasor, letos mineva 300 let od njegove smrti, omenja v svoji Slavi vojvodine Kranjske (1689) jame v Ameriki, med njimi tudi na otokih Zahodne Indije, brazilski kras je raziskoval naš rojak Peter Slavec, slovenska jamarska odprava je 1978 raziskovala kras na Galapaškem otočju in v Ekvadorju, 1984 pa v Kolumbiji.

Zato je uredništvo zbornika Acta carsologica z veseljem sprejelo pobudo našega zunanjega sodelavca dr. Trevorja R. Shawa, da se z vrsto razprav, posvečenih krasu Zahodne Indije, tudi mi s to številko pridružujemo počastitvi Kolumbovega odkritja, proslavitvi 500-letnice priključitve Amerike v krog zahodne civilizacije, obenem pa s tem tudi ponovno pokažemo, da Acta carsologica ni omejena le na Slovenijo, ampak je odprta krasu in krasoslovcem vsega sveta.

Urednik

West Indies, as is called "India", discovered by Christopher Columbus 500 years ago, are karst islands. Tropical karst and some morphological karst features, as is tower karst with mogotes on Cuba, cockpit depressions in Jamaica, typical examples of tropical karst, occur as "locus typicus" in the global karstology and give their contribution to the international karstological terminology. In America there are diverse types of karst developed: the Mammoth Cave Sytem, USA is the world's longest cave (531.069 m), in Canada there are the best examples of underglacial and periglacial karst, karst sinkholes in Florida cause virtual economic catastrophes, cenotes (the saint potholes) in Yucatan are invaluable archaeological treasury, in Mexico there are gigantic potholes, karst plateaus with immense depressions in South America are virtual "lost worlds".

The Slovenes did not remain without contacts with American karst: Valvasor, this year 300th anniversary of his death passes away, mentions in his Die Ehre des Herzogthums Crain (1689) the caves in America, among them one on the islands of the West Indies, the karst in Bresil was explored by our compatriot Peter Slavec, in 1978 the slovene caving expediton explored the karst of Galapagos and Ecuador and in 1984 in Colombia. a

This is why the Editorial Board of Acta carsologica accepted with pleasure the idea of our nonresident member Dr. Trevor R. Shaw to join, with a series of treatises, dedicated to the karst of the West Indies, the celebrations of the Columbus's discovery, the celebration of 500-years of incorporation of America to the circle of the western civilization and thus to show again, that Acta carsologica is not limited to Slovenia only but is opened to karst and karstologists of all the world.

Editor

CONTRIBUTION TO THE HISTORY OF CAVE STUDIES IN WEST INDIES (TO COMMEMORATE 500 YEARS OF COLUMBUS DISCOVERY OF AMERICA)

THE HISTORY OF CAVE STUDIES IN TRINIDAD, JAMAICA, THE BAHAMAS AND SOME OTHER CARIBBEAN ISLANDS

ZGODOVINA JAMSKIH RAZISKAV NA TRINIDADU, JAMAJKI, BAHAMIH IN NA NEKATERIH DRUGIH KARIBSKIH OTOKIH

TREVOR R. SHAW

Izvleček UDK 551.442 (729)(091)
591.542 (729)

Shaw, Trevor R.: Zgodovina jamskih raziskav na Trinidadu, Jamajki, Bahamih in na nekaterih drugih Karibskih otokih

Prisotnost tolstičnika je zbudila zanimanje za jame na Trinidadu v začetku 19. stol. V nadaljevanju so preučevali netopirje, višek raziskav je bil povezan s preprečevanjem stekline v 30-tih letih 20. stol. Geološke raziskave so bile drugotnega pomena (Geological Survey Memoir 1860). Tudi potniki so opisovali predvsem jame s tolstičniki, dokler po 1940 niso pričeli s pravimi speleološkimi raziskavami. Potniki in domačini so opisovali jame na Jamajki od 1688 dalje. Zanesljive geološke raziskave so se pričele 1824. Zaradi preučevanja netopirjev je bilo veliko obiskov jam okoli 1860. Jame na Bahamih so bile objavljene 1725 in kasneje so jih preučevali geologi in ljudje, ki so se zanimali za izkoriščanje guana. Jamske slike na Arawaku so bile opisane 1889. Podmorske jame (Blue Holes) so bile objavljene okoli 1840, jame na manjših otokih pa 1749 (Antigua), 1773 (Caicos), 1813 (Barbuda) in 1878 (Grenadini). Najstarejše omembe so na pomorskih kartah, zemljevidih ali v navodilih za pomorščake.

Ključne besede: regionalna speleologija, zgodovina speleologije, netopirji, tolstičnik, guano, steklina, hystoplasmosis; Amerika, Zahodna Indija, Jamajka, Trinidad, Bahami.

Abstract UDC 551.442 (729)(091)
591.542 (729)

Shaw, Trevor R.: The History of Cave Studies in Trinidad, Jamaica, the Bahamas and some other Caribbean Islands

Interest in Trinidad caves arose early in the 19th century because of the presence of the the guacharo. Continuing study was supplemented on bats, which culminated in research to control the rabies in 1930s. Geological aspects took second place (Geological Survey Memoir 1860). Travellers' accounts were limited to guacharo caves until speleological explorations commenced in the 1940s. Caves in Jamaica were described, from 1688, by residents and travellers. Geological investigations of generally high quality began in 1824. Bat studies resulted in a number of cave visits about 1860. Caves in the Bahamas were noted in 1725 and studied later geologists and those interested in the exploitation of guano. Arawak petroglyphs were described in 1889. The underwater caves, or Blue Holes, were recorded about 1840. Caves in other small islands were recorded in 1749 (Antigua), 1773 (Caicos), 1813 (Barbuda) and 1878 (The Grenadines). All the earliest references are on charts, maps, or instructions for mariners.

Key words: regional speleology, speleological research history, bats, guacharo, guano, rabies, hystoplasmosis; America, West Indies, Jamaica, Trinidad, Bahamas.

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PREFACE

Despite the Caribbean being a single region there has been no common thread in the exploration and study of its caves and karst regions. Work in one part generally had little or no influence elsewhere. Indeed the individual islands or groups of islands, although some of them are close together, mostly have quite different histories of investigation.

In part this may have been due to the influence of the colonizing powers - Spain, Great Britain, France, the Netherlands and USA - which caused different languages and customs in the regions they ruled. This does not, however, explain the differences between one island and another. More, it seems, this was dependent on the specific concerns of each one - water supply, guano, edible birds, fossils, floods, picturesque caves, etc. - and on the interests and contacts of individual people living in each island.

Since World War II, i.e. after the period covered by this paper, the former links with Europe remained, and easier travel resulted in many study visits and 'expeditions' specially to the karst regions. Some of these were from central European countries which had not previously been involved there, but each with a long tradition of karst study. Research by Panoš and Štelcl (1968) was particularly important, and Czechs, Hungarians, Poles, Romanians and others have all done significant work there.

Some caves in the Caribbean islands were described quite early in the 17th century, and in Mexico in the 16th. Caves in the Yucatan peninsular of Mexico had been used by the Mayan Indian people much earlier.

Not surprisingly, Valvasor (1689) already knew of several caves in the Caribbean and Central America. Although he never visited the area, his extensive knowledge of the literature world wide enabled him to describe:

- a cave, in the island of Hispaniola, in which is a great crashing and roaring. Valvasor named his source as Petrus Martyr, and examination of the fuller description there shows that the cave was almost certainly the Boca del Infierno (also known as Cueva Fun Fun) on the edge of Bahia de Samaná in the north-eastern part of the island.
- a cave with a river in it near San Augustin in the Verapaz region of Guatemala. This is undoubtedly the Cueva de Lanquin. Valvasor's source was evidently the book by Dapper (1673, 305) which he includes in his published list of sources, but Dapper's description in turn is clearly taken from Johannes de Laet (1633).
- a cave near 'Kuertlavaka' (probably Cuertlavaca near Oaxaca) in Mexico. Valvasor cites Dapper's book (1673, p.287) but this itself is evidently based on the then unpublished description of 1629 by Antonio Vazquez de Espinosa (1942, 182)

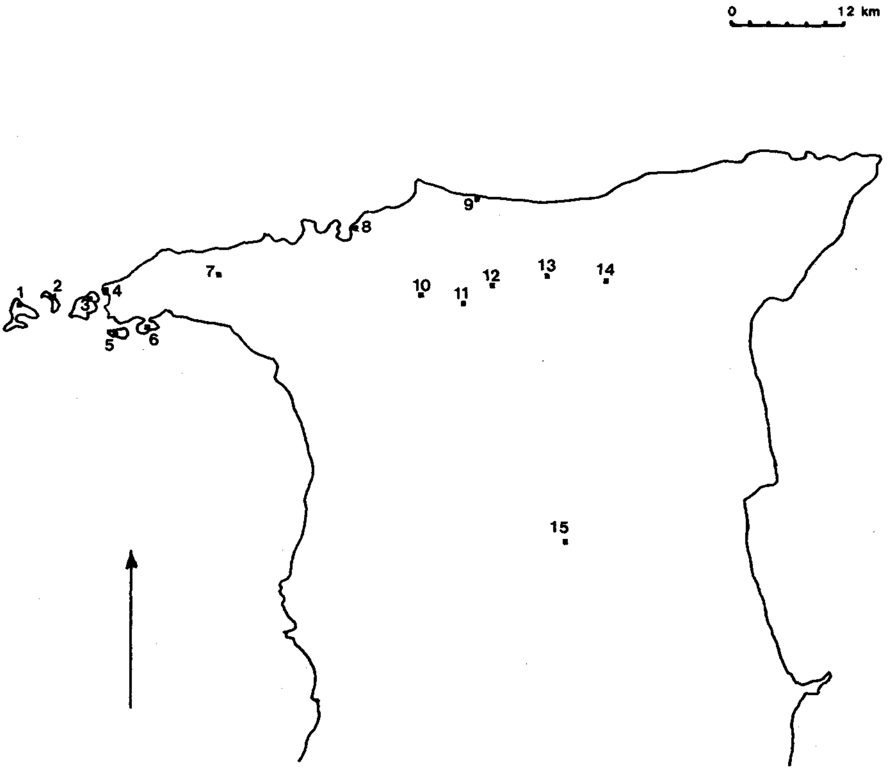

Fig. 1. Cave locations in northern and central Trinidad

Sl. 1. Lega jam na severnem in srednjem Trinidadu

1. Chacachacare Island	1. Chacachacare Island
2. Huevos Island	2. Huevos Island
3. Monos Island	3. Monos Island
4. Ance Paua	4. Ance Paua
5. Gasparee Cave in Gaspar Grande	5. Gasparee Cave in Gaspar Grande
6. Point Gourde	6. Point Gourde
7. Diego Martin	7. Diego Martin
8. Las Cuevas	8. Las Cuevas
9. Blanchisseuse	9. Blanchisseuse
10. Caura	10. Caura
11. Lopinot	11. Lopinot
12. Arima	12. Arima
13. Aripo	13. Aripo
14. Oropuche	14. Oropuche
15. Mount Tamana	15. Mount Tamana

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TRINIDAD TO 1950

Abstract: Interest in Trinidad caves arose early in the 19th century because of the presence in them of the cave-dwelling bird, the guacharo. Continuing study of the bird and its haunts was supplemented from the 1890s by work on bats, which later culminated in research to control the rabies epidemic of the 1930s. Geological aspects of the caves tended to take second place despite the Geological Survey Memoir of 1860. Travellers' accounts were usually limited to guacharo caves until cave exploration for its own sake commenced in the 1940s.

The principal caves in Trinidad, including most of those investigated during the period covered by this chapter, are in the Jurassic limestone of the Northern Range of hills and in the islands forming its continuation off the north-west corner of Trinidad. There are also a few caves on the coast of the northern part of the island. Those of Mount Tamana in the central range apparently remained unrecorded until the 1940s. The locations of caves referred to are shown in Fig. 1.

To describe the history of cave studies in Trinidad either in a strictly chronological sequence or by rigid regional demarcations would be unhelpful. Instead, the main division here is by the subject of investigation, e.g. guacharos, bats, bugs, or exploration per se, with regional sub-division within each. There are exceptions to these arrangement in two places. Because tourist visits developed to see the guacharo caves of the more or less accessible islands, guide-books and tourism are treated immediately after the main accounts of the birds there. Secondly, the Geological Survey Memoir of 1860, though referring very little to caves, is of such significance that it is considered separately at an early stage in the chapter.

The main divisions, therefore, are:

- guacharos in the north-western islands and adjacent coastal caves;
- tourist visits and guide-books;

- the Geological Survey Memoir;
- the guacharo cave of Oropuche;
- guacharo and other caves at Aripo;
- guacharos in the gorge known as Dunstan Cave at Arima;
- cave bats;
- other cave fauna;
- cave exploration for its own sake.

Guacharos in the North-Western Islands and Adjacent Coastal Caves

The cave literature of Trinidad is enhanced by the interest taken in the cave-dwelling Guacharo or Oil Bird (Steatornis caripensis), as well as the more usual concerns with guano, bats, other fauna, geology and casual sight-seeing.

Indeed the earliest reference to caves in Trinidad is also, not surprisingly, the first account of the guacharo living there. Dr. John Latham (1823, 366-368) writes as follows:

> [The Trinidad Goatsucker] Inhabits the Island of Trinidad, and adjacent parts, has a plump body, and [is] excessively fat, particularly the abdominal region and rump. I owe the above account to the kindness of J.V. Thompson, Esq. who informed me, that he first became acquainted with this bird at the regimental mess in Trinidad, in 1803, when they were served up without the heads or feet, under the name of Dumpy Ducks, or Diablotins, and said to be considered as one of the greatest delicacies afforded by the Island; but as they did not seem to be much relished by unassimilated palates, and wishing first to know what description of bird it was, at that time did not taste of them; but considered them of the greater interest, as no person could be found capable of furnishing the requisite information: and it was not till 1809 that he again met with them, although annually brought to market, which the little that could be collected of their history will in some measure explain.
>
> They inhabit coves* of the Islands forming the Bocases, an entrance into the Gulf of Paria, accessible only at the very lowest ebb tides, and in moderate weather; and as they are never observed on the wing in the day time, most probably, like the rest of the Genus, seek their food in the absence of the sun; here they breed, during the early part of spring, and it is at the time of new and full moon, in April and May, that the people, who are acquainted with these coves*, resort thither; when finding the young ones not sufficiently fledged to be able to fly, they speedily fill their boats; not, however, despising the old ones, many of which are knocked down with sticks, and constitute a portion of their cargo: but as such as happen to be killed, in this horrible affray, amid the screetches of the whole, and the attacks of the old ones, will not, in many instances, keep a sufficient time to reach the market; these are most generally packed on the spot, in barrels, with bay salt, after being plucked, gutted, and divested of their heads and feet: and are sold from about a shilling to as far as eighteen-pence a piece sterling; and it is astonishing with what avidity this noisy cargo is bought up by all classes of the people, the moment it reaches the town wharf; so that a boat load of many hundreds entirely disappears in the course of an hour or after two.
>
> We believe that the above species is not already known to ornithologists, unless the

* see comment in text below

> following extract from Monsieur Depens, in his **History of South America**, may allude to it. He says, 'In the Mountain Turmeriquiri, situated in the interior of the Government of Cumana, there is a cavern called Guacharo: it is immense, and serves as a habitation for millions of nocturnal birds, (a new Species of the Caprimulgus of Linnaeus), whose fat yields the Oil of Guacharo.'

In view of this uncertainty of identification, Latham does not venture a Latin name for the bird. The guacharo of Trinidad is in fact the same Steatornis caripensis as occurs in Venezuela.

John Latham (b. 1740; d. 1837) was a British ornithologist and Fellow of the Royal Society, who is perhaps best known for his 11-volume **A General History of Birds** in which this account appears. The word 'coves' he uses for the places where the birds were taken does in fact mean caves. The **Oxford English Dictionary** shows that the word was in active use with this meaning at least until 1849, and it survives still in the names of a few caves, such as Cleaves Cove in Scotland. Besides, comparison with later descriptions of the guacharo cave in Huevos island in the Bocas make it clear that it is of this that Latham is writing.

Although the guacharo may well have been taken from caves as food for centuries before it was first recorded in 1799 by Humboldt and Bonpland (1814) in nearby Venezuela in 1799, consumption in Trinidad was always relatively local. Thus as a delicacy for commerce the guacharo did not approach the swiftlet (Collocalia sp.) of south-east Asia, the widespread trade in which was recorded as early as 1600 or before and which still continues today.

It is important to point out that the name Diablotin, or Devil Bird, is also applied in the Caribbean to a totally different species, the Blackcapped Petrel (Pterodroma hasitata) which roosts in small holes in the ground like a martin or a rabbit. Thus it was this petrel which was referred to by Du Tertre (1654) and which gave its name to the highest mountain in Dominica, Morne Diablotin, where it used to occur (Feilden 1890). The distinction was first pointed out by Hautessier (in Bory de Saint-Vincent 1838).

Most accounts refer to the presence of guacharos in the island of Huevos. They are also recorded on the nearby mainland coast in a cave Anse Paua. Although bats are present in the caves of Gaspar Grande and Chacachacare, guacharos have not been seen there.

The next writer to refer to guacharos in Trinidad is more precise in stating where they were found. Hautessier (in Bory de Saint-Vincent 1838) was the first to see the birds in their natural environment there. His account is concerned principally with the birds themselves so only those parts of it relating to the caves where they occur is printed here (in translation):

> One of the largest and most visited by hunters is on the northern side of Huevos Island ... Without any doubt the caves owe their existence to the dissolving and destructive action of the sea, for all their entrances are at the height at which the waves break. It is because of this that problems arise in hunting out of season, and especially in January, the month of my visit ...
>
> To capture the young Guacharos, the fine weather of April and May is usually chosen,

when the sea is as smooth as glass, so as to be able to reach the caves without fear of damaging the boats... Once the dangers of landing are past, there are many others to overcome: much strength is needed to crawl in the very narrow passages, to climb the high rocks, and finally to get into the roof fissures in which the birds nest. But as the collectors hang on in some well-chosen place they seize hundreds of Guacharos of all ages with their bare hands and throw them down to the floor of the cave which is soon littered with them. Only the fear of the sea getting up and closing the entrance is capable of stopping the hunters' frenzy of destruction. They fill their boats and take them straight to the markets of Port of Spain where the birds are greatly sought after by gourmets despite the great quantities of unpleasant fat they contain, and their strong smell.

A preserved specimen of a guacharo taken by Hautessier, together with a nest and eggs, was presented to the Acad,mie des Sciences in Paris in August 1838. The Huevos cave, 'swarming with guacharos', is referred to by De Verteuil (1858, 293) and the bird is described by L,otaud (1866, 65-69) in his standard work on the birds of Trinidad. L,otaud lived in Trinidad and he was the first to state that the guacharo occurs also in caves inland; the one at Oropuche (see later) was on the family land (Darlington, pers. comm.) and he probably knew of their presence there.

The novelist Charles Kingsley (1871, vol. 1, 203-205) set out early in January 1870 to visit the guacharo cave in Huevos but the sea was running so high that the boat was unable to enter. His graphic description of the conditions, however, makes it clear how the birds there avoid human interference for much of the year. Kingsley's boatman was the same Mr. Morrison who is said (Chapman 1894, 60) to have discovered the cave.

A rather more professional, and successful, visit to the Huevos cave was made about 1883 by William Hornaday of the National Museum of Natural History in Washington, D.C. His own account of this is printed in **The Standard Natural History** (J.S. Kingsley 1885, vol. 4, 386) and provides the earliest description of the cave:

Half an hour's pull along the precipitous side of Huevos Island brought us to a tiny bay hemmed in by the same high wall of rock. A turn to the left around some half-sunken rocks and we were at the entrance of the cave, a black, semicircular hole at the base of the cliff, six feet high and twelve wide, into which the swells of the sea dashed every moment.

The oarsmen held the boat carefully in position until a big wave came rolling in, when they sent the boat flying forward on its crest. We passed safely over the sunken rocks, and the next roller, which lifted the boat so high that we had to crouch down in order that our heads might escape the roof of the tunnel, brought us to terra firma. Scrambling out upon the pebbly beach we found rising before us a huge dome-like cave. The moment we entered there arose a perfect storm of rasping cries coming from the throats of about two hundred guacharo birds that circled about the top of the cave.

The walls of the cave were smooth bare rock, but at one side a huge mass of fallen rock formed a series of ledges from the floor up to a height of thirty feet. Climbing upon this we found numerous nests of the guacharos. The rocks were covered with guano to a depth of several inches. Whenever a smooth spot offered a safe resting place the nests were placed like so many cheeses, while others were built half swallow-like on the slopes.

> As nearly as we could estimate there were about seventy or eighty nests, nearly all of which we searched for eggs. In different nests we found the number to vary from one up to four, so that we are unable to say what is the usual number laid.

A vivid account of the same visit was later published in a popular book by the same author (Hornaday 1925, 140-145). The guide was not Mr. Morrison but a David Basanta who lived on Monos Island.

Ten years after Hornaday's visit, Frank Chapman (1894, 60) entered the Huevos Island cave on 5 May 1893 with its discoverer Mr. Morrison as guide, and estimated the total number of birds present as 200. He collected debris of the birds' food, largely seeds and fruit pips, which were identified by McAtee (1922).

Chapman also visited a cave

> on the main island of Trinidad in the first Boca. It contained apparently not more than fifty birds. There is no beach or floor in this cavern; the water reaches to its innermost parts, and as the walls are precipitous I was unable to explore it for nests.

This is the cave in the cliffs about 400 m to seaward of the small bay locally known as L'Ance Paua (Williams 1922, 168). Williams himself entered the cave on 12 May 1918:

> About halfway back in the cave I climbed out of the boat and found the water about two feet deep, getting shallower to the back of the cave. About a dozen or twenty birds were nesting on ledges high up on the walls but all were out of reach so I cannot say if laying was taking place or not.

The cave is not in limestone. Guacharos were still present in 1945 or 1946 (Pawson, c. 1948, 5) but are not there now.

It is possible that guacharos may formerly have occurred in a cave in Monos island also. Two specimens obtained between January 30 and February 2 1884 by naturalists from the U.S. Fish Commission steamer 'Albatross' were recorded by Ridgway (1884) as from Monos, though they could have been supplied by Monos inhabitants who exploited the nearby colony in Huevos. The only other mention of a Monos cave being a guacharo site is by Carricker (1931) who reported the birds to be present there in 1930. There is no first-hand account of their being seen there and Snow (1962) does not record the island either as an active or a former location for the birds. Komisarcik (1979) does refer to their presence there but it is evident that his party did not see them. There is however a small inland cave where bats occur (Darlington, pers. comm.).

Commercial harvesting of the guacharos on Huevos has long since ceased, though some casual collecting for food continued at least until recently.

Tourist Visits and Guide-Books

> We started one morning for a cave which exists on a neighbouring island. It was beautifully hung with glittering stalactites, which gave it the effect of being supported on white marble arches and columns. In one place these rose direct out of the azure depths, which lay as motionless as a mirror around them. The vaulted roof, fretted, Moorish fashion, was prettily reflected in its bright surface, and looking down into its recesses, the rocky floor could be plainly seen four fathoms below. I undressed for a dip, swimming in and out among the Gothic transepts and aisles. The water was tepid. A more romantic bath can scarcely be imagined, and the Greeks of old would at once have assigned it to the nymphs, or pointed it out as the grotto where Diana took her morning plunge. It was partly lighted from the entrance, and partly by a torch which we had brought with us (Stuart 1891, 86-87).

This 1858-1859 account of a tourist visit, evidently to the cave in Gaspar Grande or Gasparee Island, clearly owes nothing to scientific investigation and fitly opens a consideration of early cave tourism and the guide-books and services provided for it.

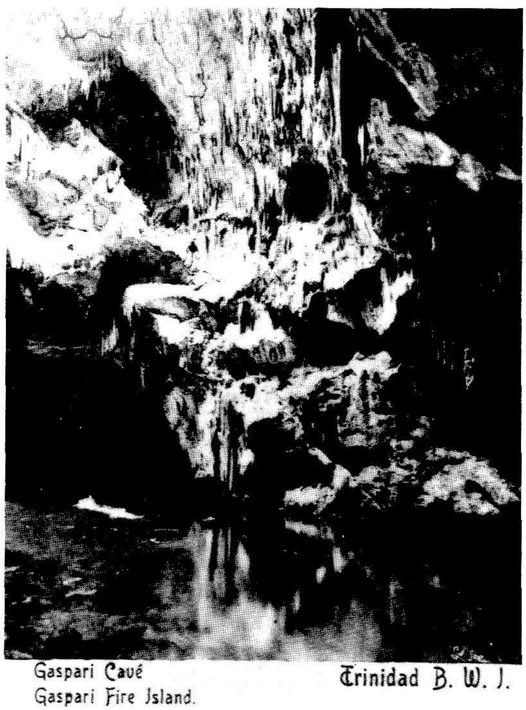

Fig. 2. Gasparee Cave about 1903 or before, on a postcard
Sl. 2. Razglednica Gasparee Cave okoli 1903 ali prej

Collens's **Guide to Trinidad** (Collens 1888, 225-226) mentions 'some curious limestone caves, containing singular petrifactions and swarming with ... bats, which may be explored at low water' in Gaspar Grande. To go beyond Monos 'you must engage a boat. I know of no better guide than Mr. Morrison if you can secure his services. He will pilot you to the celebrated cave at Huevos'.

By 1908 there were regular steamer services on four days a week to Gaspar Grande, Monos and Chacachacare (Ober 1908, 484-486) but a visit to the cave in Huevos still required a small boat to be hired specially. Houses were available for rent on Monos, Huevos and Chacachacare, though visitors had to take their own provisions with them (Aspinall 1907, 136; Ober 1908, 485).

It was about this time that tourist visits to Gasparee Cave on Gaspar Grande were promoted. A picture postcard (Fig. 2) was issued in the days when postal regulations allowed only the address to be written on the reverse side (i.e. before about 1903). A series of at least five photographic postcards, by 'HJB', were produced later; one of them has been seen with a postmark of December 30, 1921. Other postcards appeared towards 1930. Steps were built in the cave some time before 1936 to improve access and it is said (Pawson c.1948, 6) that the Trinidad Field Naturalists' Club held some of its meetings in the cave.

The attraction of the Gasparee Cave featured in the 1936 guide (Digby 1936, 182-184), and the same book (181) noted that 'boating excursions can be arranged and picnic parties made up for a visit to the Guacharo Caves at Huevos..., entrance being obtained at low tide'.

The Geological Survey Memoir

The Geological Survey Memoir on Trinidad (Wall and Sawkins 1860) is treated separately here, partly because of its intrinsic importance and partly because its point of view, unlike that of nearly all the other writers on Trinidad caves, is primarily geological.

The preface is dated December 1858 and the field work involved was no doubt spread over several years before that. Only a few pages (27-29) of the whole volume refer to caves, but in every case the information given is the earliest to be published on that cave.

First, and most prominent because it is accompanied by the engraving reproduced in Fig. 3, is a cave in the Diego Martin district. It 'has a considerable deposit of the latter substance ['crystallized spar'], and is resorted to by vast numbers of bats'. There are several caves at Diego Martin, but the only one listed by Goodwin and Greenhall (1961, 293) as containing bats is the La Fontaine Cave in Petit Valley, 2 km east of Diego Martin village. It is presumably 'the Diego Martin bat cave' visited in 1934 by Ditmars and Bridges (1935, 81) but it seems to have been destroyed since then (pers. comm. Greenhall to Darlington).

The part of the Memoir describing the Oropuche Cave is reprinted later, in the section dealing with that cave. Also, smaller 'cuevas de guacharos' are reported in the heights of Aripo and Arima'.

A guacharo cave 'at Acona [or Acono], is not in limestone at all, being produced by the

water having eroded a passage through very hard mica slates which arch over the stream'. Williams (1922, 171) 'made a close search of the Acono valley (a branch of the Maracas Valley)' and found, not a roofed cave, but a cave-like gorge 'exactly similar to the Arima Valley locality and apparently quite suitable for the guacharos, but none were present.'

The second cave illustrated in the Survey Memoir is labelled as 'Cavity in schist near Blanchisseuse' but is not referred to in the text. Blanchisseuse is on the north coast of Trinidad, and the picture appears to show a small natural bridge or tunnel open to daylight at both ends. Somewhat similar wave-cut caves at Las Cuevas, some 10 km west of Blanchisseuse, had earlier been mentioned by Dauxion Lavaysse (1813, vol. 1, 47).

The Guacharo Cave of Oropuche

Guacharos in Trinidad having been first recorded, first collected and first studied in the caves of Huevos and Monos islands, the history of those caves has been considered first and followed up until the 1940s.

Nevertheless it was as early as 1860 that another major cave site of the guacharo was recorded (Wall and Sawkins 1860, 27-29):

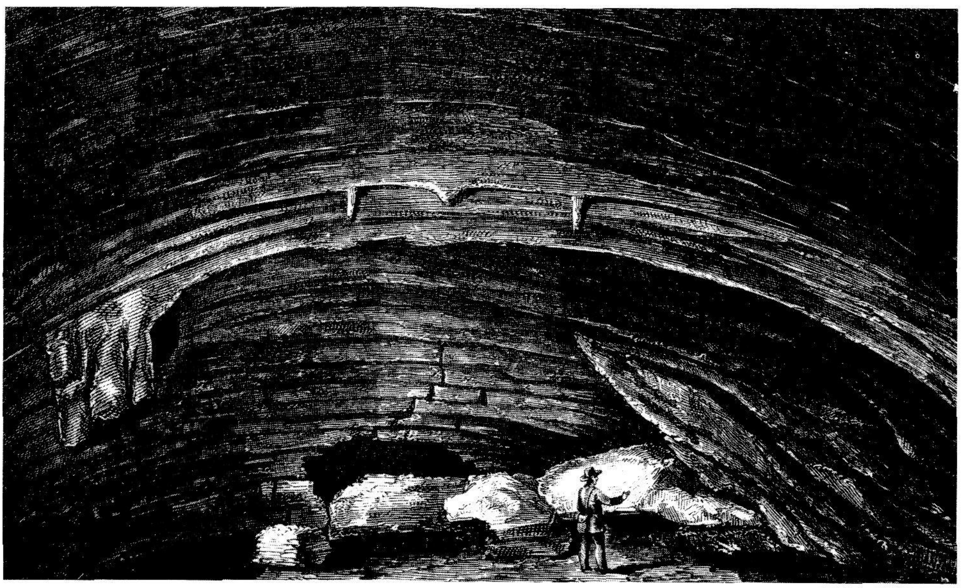

Fig. 3. A cave at Diego Martin, probably La Fontaine Cave, from an engraving in the Geological Survey Memoir (Wall & Sawkins 1860)

Sl. 3. Jama pri Diego Martin, verjetno La Fontaine Cave, na risbi v Geological Survey Memoir (Wall in Sawkins 1860)

> Perhaps the most remerkable cavern is situated at the base of the hill of Oropuche. This mountain rises to over 2,000 feet, and consists of calcareous rocks, which are extensively fissured. That circumstance facilitates the accumulation of a considerable body of water in the upper part of the cave, whence it flows in a constant and abundant stream, forming the origin of the river Oropuche. At the entrance the dimensions are about 30 feet high by 14 feet wide, and these are preserved for 100 feet; after which the area contracts. The cavern is distinguished as the habitation of the curious nocturnal bird termed guacharo...

As has been seen already, the cave was probably the source of L,otaud's statement (1866) that guacharos were to be found in inland caves as well as in those by the sea.

A visit to Oropuche cave on 2 March 1895 by F.W. Urich was described in detail in the **Journal of the Trinidad Naturalists' Field Club,** of which Urich was a prominent member.

> The Guacharo cave is pierced in the vertical side of the wall of crystalline limestone a hundred feet high, the entrance is about 25 feet in height and about 15 feet broad. Strewn about it are some huge boulders. The first thing to greet us was the smell of the birds and their deposits. They were of a decided "cockroachy" aroma. There are numerous rocky ledges and cavities in the sides. It is difficult for me to judge the distance I penetrated as progress was very slow but I should say that about 150 yards is not over estimated. In the bottom of the cave is a clear running stream in which we waded, reaching as a rule to above the ankle and sometimes above the knee. The bottom is composed of white quartz pebbles and sand; strewn about the bed are large boulders with jagged ends which make progress very slow. At the sides of the river, out of the current, there is a large accumulation of guano and seeds of, so far as I could judge, several kinds of palms. The roof of the cave slopes downwards and at the further end I could not stand erect, while the water was above my knees. Divesting ourselves of as much clothing as we could without running the risk of getting chilled, we each lighted a pavil and entered the cave. The scene which met our eyes and the noises we heard were of peculiar weirdness. Above our heads about a hundred birds fluttered, wheeled, darted, and screamed. The beating of their wings their shrill and piercing cries and croakings together with the rushing and murmuring of the stream created an impression which cannot be described but which was intensified by the vaulted rocks and repeated by the echoes in the depth of the cavern. Ped, by fixing a pavil at the end of a long rod bent at the end like a shepherd's crook, to which was attached a fish hook, showed me the nests of the birds some 25 feet above our heads. They were mostly in the holes and fissures of the rock, with which the sides of the cave are riddled. Feeling about the nest with the hook we managed to get two young ones, but they were very young and not yet fit for table. Most of the birds were still sitting on nests built of clay of a reddish colour. As we penetrated into the cave the noise increased, but when we got into the lower parts, no more guacharos were seen and we got into the region of the bats, which belonged to Chilonycteris rubiginosa species and were in numbers, treating us to a shrill concert which was answered by the plaintive cries of the guacharos in the distance. After securing a few specimens we retraced our steps and after various tumbles over the boulders emerged into daylight and seated ourselves at the entrance on the banks of the river and rested (Urich 1895).

The cave was visited by Urich again, in company with Freeman and Williams (1922, 168-169) on 23 April 1916. The birds were nesting at that time and there were some 30 or 40 nests on ledges from six feet above the river to the highest part of the walls.

It was the Oropuche cave that was visited by Theodore Roosevelt (1917), the former President of the United States, also with Urich and also in 1916. Roosevelt was a recognized naturalist of wide interests. He appears in the foreground of a photograph taken outside the cave by Urich and reproduced as Fig. 4. Roosevelt mentions the presence of bats in addition to the birds, and also noticed that seeds from the birds' food were germinating in the guano, though he mistook the growths for fungi.

Another quite detailed description of the cave resulted from a visit in June, probably of 1930, by M.A. Carricker (1931, 190-194).

Fig. 4. Theodore Roosevelt (front) and two companions outside the Oropuche cave in 1916 (photo by F.W. Urich, reproduced from Roosevelt 1917)

Sl. 4. Theodore Roosevelt (v ospredju) in dva tovariša pred Oropuche cave leta 1916 (foto F.W. Urich, reprodukcija iz Roosevelt 1917)

Guacharo and Other Caves at Aripo

A cave (or caves) at Aripo had been mentioned by Wall and Sawkins (1860, 29) as reputedly occupied by guacharos. Clearly the authors had not been there, so the earliest detailed report must date from 1922 (Williams) or possibly from 1911.

D.C. Plummer (1911) was an Agricultural Inspector in Trinidad who published in **The World Wide Magazine** how a neighbour of his, who remained anonymous, had fallen while trying to descend the entrance shaft of 'the Bottomless Pit' near the entrance of a famous guacharo cave some miles from Arima. His wife had fallen too, but they had landed on sponge-like moss which broke their fall. Eventually they reached another entrance above the coast near Blanchisseuse. The title page of the magazine describes it as 'an illustrated monthly of true narrative' but whatever in this story may be truth is so obscured that it is impossible to identify the cave concerned with certainty. However, Dr. Johanna Darlington (pers. comm.) suggests that it might be based partly on Soho Cave at Aripo.

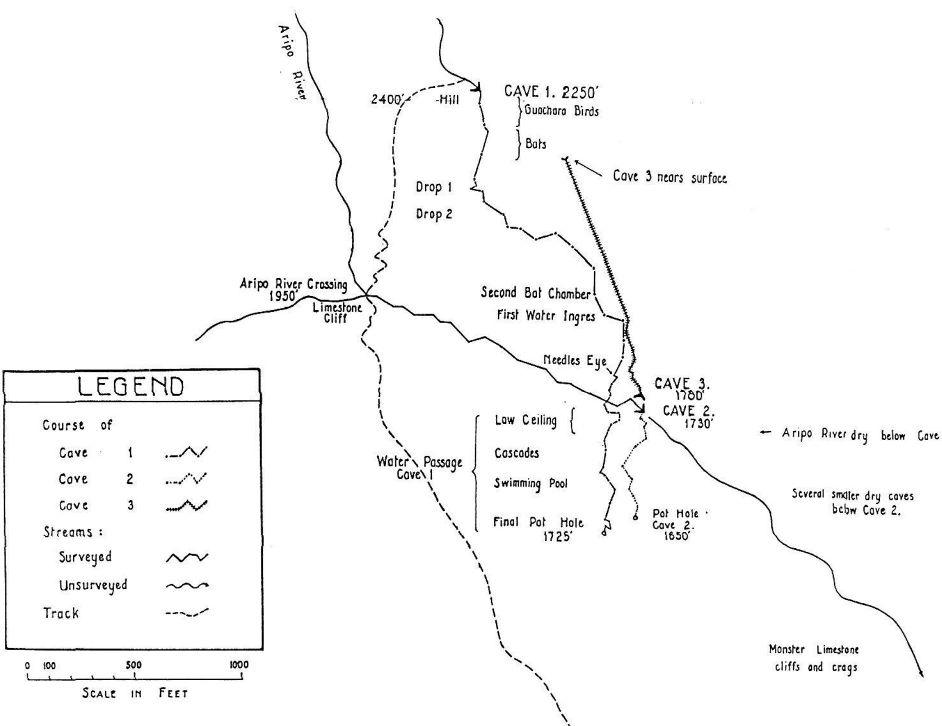

Fig. 5. A previously unpublished plan of Aripo Caves No. 1, 2 and 3, surveyed in 1940 by Gunther and Chenery (reproduced by courtesy of Trintoc)

Sl. 5. Neobjavljen načrt Aripo Caves No. 1, 2 in 3, meritev 1940, Gunther in Chenery (reproducirano z dovoljenjem Trintoca)

C.B. Williams (1922, 169), already cited so often, mentions a guacharo cave at Aripo very briefly. He had not visited it but had heard that it contained the largest guacharo colony in the island; this is certainly not so now. 'It has been visited on several occasions by Mr. E. Andre but so far as I am aware no account of it has ever been published.' Nor is anything known now of Mr. Andre.

In 1922 also a Major D.R. Latham, who had been in charge of the Government's survey, penetrated for 610 m in Aripo Cave No. 1 (Gunther 1940). The initials GLA were painted on the wall at this point. The exploration is apparently unpublished and, surprisingly, it has not been possible to trace any information about Major Latham.

It was probably in 1929 that M.A. Carricker (1931, 187-189) explored what he called the Shagramal Cave, now known as Aripo Cave No. 1. It is a stream cave containing both guacharos and bats. Nearby, Carricker (189-190) used a rope ladder to descend another cave in the same district, entered by an 18 m shaft - perhaps the original or inspiration of the **Wide World** cave. Two more caves were also noted, one of them with 6 m shaft near the entrance.

In 1937 the naturalist and popular writer Ivan Sanderson (1939, 35-77) was combining his honeymoon with a collecting expedition when he visited Aripo Cave No. 1, where he noted that the guacharo guano was 5 m deep, and also another cave which contained some vampire bats as well as other species.

The Aripo Caves No. 1, 2 and 3 were surveyed in 1940 by A.E. Gunther and Dr. E. Chenery. A detailed description, with a location map, was published in **The Trinidad Guardian** (Gunther 1940) and gave passage lengths of about 853 m, 152 m and 305 m respectively for the three caves. The survey of the caves referred to in the text was not printed with the article but an unpublished copy was traced in the files of the Trinidad and Tobago Oil Company by their archivist, who has provided the copy reproduced here (Fig. 5).

A rather more accessible description of Aripo Cave No. 1, written in 1948, has been publishe by Pawson (1974).

Guacharos at Arima

The Arima valley was the site of another of the guacharo caves heard of but not seen by Wall and Sawkins (1860, 29).

Williams (1922, 170-171) describes the place:

> ... on searching in company with Mr. Urich on June 2, 1918 we found that it was not a cave but a deep narrow canyon that had been chosen by the birds. The river has cut a deep ravine, forty to fifty feet deep and less than ten feet wide in the soft schist that forms so much of the northern range and in the semi-gloom near the bottom of this, and ten to fifteen feet above the level of the water seven nests were found.

This 'cave' is sometimes called Dunstan Cave (e.g. on the modern tourist maps), Asa Wright Cave or Spring Hill Cave. It was visited on 17 April 1926 by Gloria Hollister, in company with Urich, and she described it in a popular article (Hollister 1926).

Bats

The subject of cave bat research provides a convenient place to introduce the Trinidad Field Naturalists' Club, the president and other members of which studied bats and explored caves and whose journal published their findings.

The Club was founded in 1891 and its journal first published in 1892. Already the name of one of its members - F.W. Urich - has appeared often in these pages. The Society, though, like most scientific societies, was more than the sum of its members and its publications. It provided stimulation for work appropriate to its aims and, by meetings and publication, encouraged its progress,

Of the members one of the most prominent in cave work and over the longest period was Frederick William Urich (b. 1879, d. 1937) (Fig. 6), whose exploration of the Oropuche

Fig. 6. F.W. Urich, probably in the 1920s (from Howard 1930)
Sl. 6. F.W. Urich, verjetno okoli 1920 (iz Howard 1930)

Cave has already been noticed. He was appointed a government entomologist in 1909 (Wolcott 1938) and in 1934 he was put in charge of bat studies as a part of the government's anti-rabies programme. From 1926 to 1935 he was Assistant Professor of Zoology at the Imperial College of Tropical Agriculture in Trinidad.

Although his publications on cave matters were limited, Urich was repeatedly acknowledged as the catalyst who encouraged and made possible cave visits by others, including specialists from abroad. It was he who accompanied Williams and Freeman at the Oropuche Cave in 1916 and also Theodore Roosevelt in the same year, C.B. Williams at Arima in 1918, Gloria Hollister at Arima in 1926 and R.L. Ditmars and his colleagues in Caura Cave in 1934. A new species of blind cave fish was named after him in 1926.

Early in the 1890s, Henry Caracciolo, President of the Society and another entomologist, had many mammal specimens sent to the British Museum (Natural History) and the resulting report by Oldfield Thomas (1893) included three species of bat from caves. These had been collected in 1889 by Sir William Robinson, from the Point Gourde Caves and from a 'Cave in First Boca', which was probably the cave in Monos island.

In March and April 1893 Frank M. Chapman of the American Museum of Natural History collected specimens of Noctilio leporinus from the cave in Huevos, to which he was taken by the Mr. Morrison already mentioned. By this time the cave in Monos Island seems to have been deserted by the bats (Allen and Chapman 1893).

Caracciolo (1895) had watched these fish-eating bats in Januray 1892 and described how they caught their fish by swooping to the surface of the water with one foot lowered.

Specimens were taken in the Gasparee cave in 1934 by Raymond L. Ditmars (1935, 218), Curator of Mammals and Reptiles of New York Zoo. A shot gun was used to obtain them (Ditmars and Bridges 1935, 178)! In the same expedition Ditmars and Bridges (1935, 81) went to the Diego Martin bat cave (probably La Fontaine) and also made a more enterprising visit to the 'Jumbie Cave' at Caura (Caura No. 1 Cave), further east in the Northern Range, where they saw many bats but none of the vampires they were particularly seeking (Ditmars and Bridges, 1935, 78-103). Urich was with them but, now aged about 64, he did not go far into the cave.

It was in the 1930s that search for and research on bats was given impetus by an epidemic of paralytic rabies. The first incidence was in animals in 1925, with the first human case in 1929, and by 1935 eighty-nine humans had died of the disease which was spread by the vampire *Desmodus rufus* and other species of bat. Urich was appointed in January 1934 to investigate the relation of bats to the disease and to develop methods for their control. Much cave exploration and bat study resulted and the last human death from rabies was reported in 1937 (De Verteuil and Urich 1935; Goodwin and Greenhall 1961). Such work has continued since.

Other Cave Fauna

Although cave entomology has played such an important part in Trinidad cave studies since 1950, and though Urich was an entomologist, almost no one was working on invertebrate cave fauna in the period under review. Some occasional collecting took place, however.

Urich, together with C.B. Williams (the English entomologist trained in the United States whose cave work has been referred to several times) collected in the Oropuche Cave on 23 April 1916 (Williams 1922, 171). A new species of centipede, *Pselliophora cavincola*, was taken from the cave wall 'far in' (Chamberlin 1918, 168-169). Two new diptera (Edwards 1918) were *Trichobius caecus* from a bat and *Erioptera troglodyta* from the cave walls.

On March 1942 D.K. McE. Kevan found a new species of gryllid, *Aclodes cavicola*, in one of the Aripo caves (Chopard 1954). D.J. Billes collected two species of earwig from there in 1941 or 1942 (Kevan 1951).

The Oxford zoologist Dr. Peter C.J. Brunet (1921-1991) was in Trinidad in 1945 while serving as a Royal Navy officer. His collecting, in the caves of Aripo, Caura, Lopinot and Oropuche, included Opilionids and Pseudo-scorpions and he made a special study of the sub-order Schozonotidae (Brunet, pers. comm.)

A new species of blind catfish was obtained in 1924 by Urich and named *Caecorhamdia urichi* after him (Norman 1926). The location is given simply as 'a pool in the interior of the Guacharo Cave, Trinidad'. As, however, the pool 'becomes connected with a rivulet running out of the cave' in times of heavy rains, and the species is a fresh water one, the sea caves of the islands are precluded. Oropuche Cave, often referred to as 'the Guacharo Cave' in zoological literature, was well known to Urich and is almost certainly where the fish was found. It still occurs there and is not known anywhere else.

Cave Exploration for its Own Sake

With the increased number of foreigners working in Trinidad in the 1940s, both for oil companies and for the military, the circumstances that had led to cave exploring being a popular amateur occupation elsewhere in the world became applicable in Trinidad. People of varying backgrounds having no professional need to work in caves, but linked by their enjoyment of exploring the unknown, began to visit the caves and discover new ones. In some cases a professional approach led to surveying, but rarely were the results properly published.

Good work done by Gunther (1940) and Chenery at the Aripo Caves has been described earlier. It was in Aripo Cave No. 1 that an American airman, one of an exploring party of six, fell and broke his back on June 23, 1943 (Freitag 1943). The rescue involved a medical officer and seven others, all but one of whom subsequently suffered symptoms that are now recognizable as those of the lung infection histoplasmosis (Brown 1988).

The most comprehensive cave explorations known to have occurred before 1950 were those of Ken Pawson in 1945 and 1946 when he was in the Royal Air Force. A 61-page typed report was written, mainly in 1948. Of this, 56 pages, including three location maps, deal with Trinidad, the rest being about caves in Barbados. The typescript was never published, apart from the description of Aripo Cave No. 1 (Pawson 1974). The full report (Pawson, c.1948) has been cited from time to time as authority for statements earlier in this chapter. The full extent of Pawson's work can be seen by a list of the caves he explored: the main cave and others in Gaspar Grande, Biogowa [?Begorrats] Cave at Diego Martin, Caura No. 1 Cave, three caves in the Lopinot Valley, the Aripo Caves, Oropuche River Cave, and the caves on Mount Tamana in the Central Range (Pawson, c. 1948).

After 1950

Although this chapter covers only the period up to 1950, it is right to indicate the main directions in which cave work has developed since then, much of it driven by the need for more information on cave bats, guacharos and other cave fauna.

The anti-rabies programme of the 1930s, already mentioned, continued (Goodwin and Greenhall 1961) and led also to extensive work on bat ectoparasites and blood-sucking flies (Jobling 1949).

The recognition of the fungus *Histoplasma capsulatum* as the cause of histoplasmosis resulted in a widespread survey of guacharo and bat habitats, including caves (Ajello et al. 1962a, 1962b). Snow (1962) made a detailed study of the guacharo.

The ecology of bat guano was studied by Hill (1981) in the Tamana Caves, and Darlington (1970) worked on the cave-dwelling cockroaches in the same caves. New genera and species were named as a result.

In the 1970s the Government sponsored a survey of the Lopinot Caves with a view to developing them for tourism (Aquing 1974).

Cave explorers from USA reported on the main Trinidad caves while seeking new ones in 1978 (Komisarcik 1979),

Acknowledgements

Biographical information has been taken from the **Dictionary of National Biography** and the **Dictionary of American Biography** unless otherwise stated. Dr. Johanna Darlington, formerly of the University of the West Indies in Trinidad, drew my attention to several important references and I am particularly grateful for her helping me to tell which 'Guacharo Cave' was which in the 19th century literature. She also made helpful comments on the manuscript. Chris Howes, FRPS, copied the postcard used as Fig. 2 and has critically read this paper in manuscript. I am also grateful to the late Dr. Peter Brunet for information.

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JAMAICA TO 1940

Abstract: Caves in Jamaica were described, from 1688, by residents and travellers who were interested in anything unusual and were in effect cave tourists. Geological investigations of generally high quality began in 1824. Bat studies resulted in a number of cave visits about 1860.

Awareness of caves in Jamaica followed a very different pattern to that in Trinidad.

Firstly, caves and rivers flowing underground were noticed earlier, in descriptions of the island from the late 17th century onwards. Partly, no doubt, this is due to the fact that there are more of them in a larger island; partly because they are more prominent as so much of Jamaica is karst; partly, too, because several of the sinking rivers and caves are relatively accessible to people going about their normal business. Another factor affecting the notice taken of karst phenomena was the presence, in an island of considerable size and economic importance, of a high proportion of professional people - in government, as local residents, and as visitors. Some of these were geologists, attracted by the need to resolve the geology of an important island.

Secondly, there were no guacharos present, with all the attraction they presented to zoologists, collectors, curious visitors, and the catering industry. Nor, in Jamaica, has much research on bats been reported.

A study of the karst literature of Jamaica falls conveniently into the sections adopted in this chapter:

- a) travels, 1688-1866
- b) geologists
  - (i) De la Beche, 1824;
  - (ii)The Geological Survey Memoir of 1869;
  - (iii) Hill and Daneš, 1899-1914;
- c) popular and guide books 1877-1908;
- d) prehistoric and quaternary remains;
- e) bats and guano;
- f) cave fish and other fauna.

The locations of the caves referred to are shown in Fig. 7.

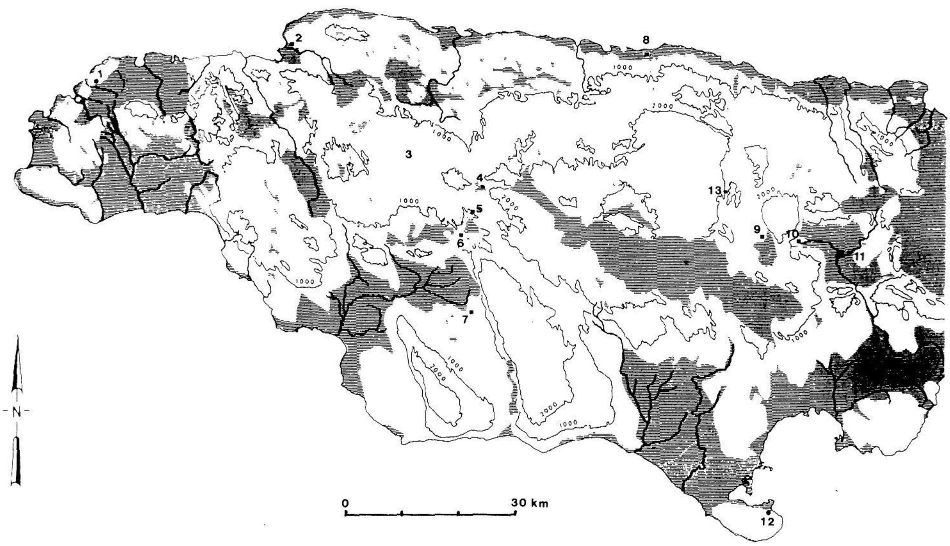

Fig. 7. Cave locations, etc. in Jamaica (adapted from the map in Peck, 1976)
Sl. 7. Lege jam itd. na Jamajki (prirejeno po karti v Peck, 1976)

1. Cousins Cove Cave No. 2	1. Cousins Cove Cave No. 2
2. cave at Montego Bay	2. jama pri Montego Bayu
3. Cockpit Country	3. Cockpit Country
4. Hector's River Sink	4. Hector's River Sink
5. Oxford Cave	5. Oxford Cave
6. Wallingford Caves	6. Wallingford Caves
7. Peru Cave	7. Peru Cave
8. Runaway Bay Caves	8. Runaway Bay Caves
9. Swansea Cave	9. Swansea Cave
10. Riverhead Cave	10. Riverhead Cave
11. junction of Rio Cobre and Rio Doro	11. sotočje Rio Cobre in Rio Doro
12. Portland Cave	12. Portland Cave
Dallas Castle Cave (off the map to the east, c. 7 km E. of Kingston)	Dallas Castle Cave (izven karte na vzhod, približno 7 km E of Kingstona)
Three-fingered Jack's Cave (off the map to the east, c. 10 km E. of Kingston)	Three-fingered Jack's Cave (izven karte na vzhod, približno 10 km E of Kingstona)

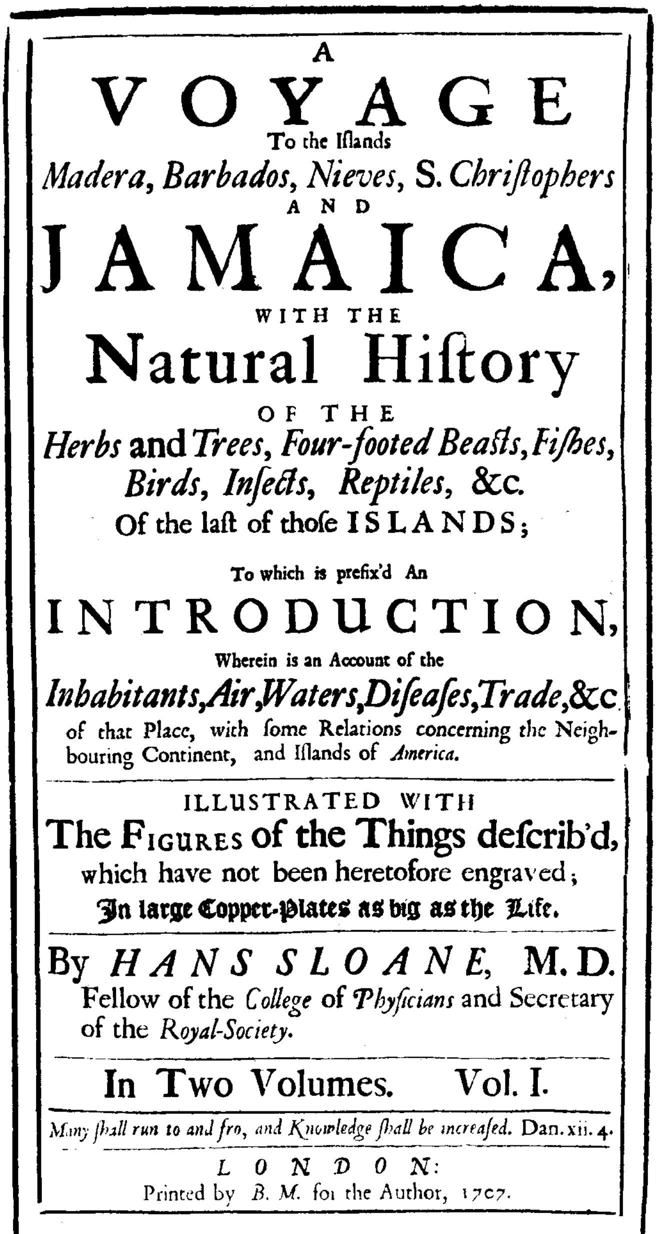
A
VOYAGE
To the Iſlands
Madera, Barbados, Nieves, S. Chriſtophers
AND
JAMAICA,
WITH THE
Natural Hiſtory
OF THE
Herbs and *Trees, Four-footed Beaſts, Fiſhes, Birds, Inſects, Reptiles,* &c.
Of the laſt of thoſe ISLANDS;
To which is prefix'd An
INTRODUCTION,
Wherein is an Account of the
Inhabitants, Air, Waters, Diſeaſes, Trade, &c.
of that Place, with ſome Relations concerning the Neighbouring Continent, and Iſlands of *America*.
ILLUSTRATED WITH
The FIGURES of the Things deſcrib'd, which have not been heretofore engraved;
In large Copper-Plates as big as the Life.
By *HANS SLOANE*, M.D.
Fellow of the *College* of *Phyſicians* and Secretary of the *Royal-Society*.
In Two Volumes. Vol. I.
Many ſhall run to and fro, and Knowledge ſhall be increaſed. Dan. xii. 4.
LONDON:
Printed by *B. M.* for the Author, 1707.

Fig. 8. The title page of Sloane's book of 1707
Sl. 8. Naslovna stran v Sloanovi knjigi iz 1707

Travels 1688-1866

The classic first record of sinking streams in Jamaica was written by Hans Sloane (b. 1660; d. 1753) who spent fifteen months in Jamaica from December 1687 as physician to the Governor, the Duke of Albemarle. Sloane was later President of the Royal Society and his vast collection of books, manuscripts and natural history specimens went to found the British Museum. Sloane's book on his West Indian travels (Sloane 1707, 1725) (Fig. 8) is concerned mainly with plants and animals, but caves and underground rivers are referred to in the opening pages (vol. 1, ix-xii):

> Rivers here in the Mountains rise above and go under ground again in a great many places, as **Rio d'Oro** falls under, and rises above ground above **Sixteen Miles Walk**, three or four times, and so it is in many others.

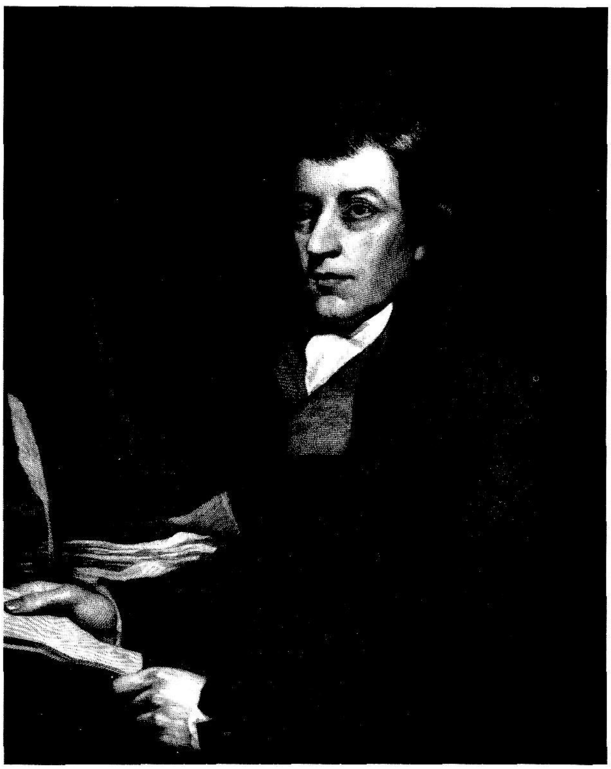

Fig. 9. Edward Long (1734-1813), engraved by W. Sharp after a painting by J. Opie (reproduced by courtesy of the trustees pf the British Museum)

Sl. 9. Edward Long (1734-1813), gravura W. Sharpa po sliki J. Opie (reproducirano z dovoljenjem pooblaščencev British Museum)

The Rio Doro flows from the north-east towards Bog Walk where it joins the Rio Cobre. Although the Rio Doro flows through some limestone country, and under a well-known natural bridge about 10 km from the junction, it does not constantly sink underground. It does sink in its lower reach, however, and it also twists and turns a lot, frequently in deep gullies, and this might lead to an impression of sinking and rising.

Unspecified caves are mentioned by Sloane in connection with saltpetre:

> What Saltpetre is to be had here, is from the Earth dug out of Caves where Indians were buried, or where Bats, and their Dung, are in great quantities. This I am certain of, because the Duke of Albemarle carried several people to Jamaica on purpose to try to make Saltpetre, having had a Patent for that Design.

He describes also the formation of tufa by the lime-bearing surface streams and refers to stalactites as the underground equivalent:

> Spring water is reckon'd preferable to other kinds: there are fine, large Springs here, many of them as well as Rivers, petrify their own Channels, by which they sometimes stop their own Courses, by a Sediment and Cement uniting the Gravel and Sand in their bottoms. When this petrifying water falls drop by drop, it makes the **Stalactites**. Several caves have their bottoms and tops united by this Stone, so that they appear Pillars.

There is no indication which caves he had seen these in. The most probable sites are those described later in the 18th century (though not Runaway Bay Caves, in view of Long's remarks on their discovery).

The next account of underground rivers, towards the middle of the 18th century, is by Charles Leslie of whom nothing is known except that he visited the island. He writes (Leslie 1740, 18-19):

> ... some [rivers] run for many Miles under Ground, particularly the **Rio Cobre,** in **St. Thomas's in the Vale** [which runs underground for nine miles] and the **Rio Pedro** in the same Precinct [which] runs about two Miles thro' a Mountain; it falls in with a mighty Noise, and rushes forth with no less. The **Negroes**, when they go a Fishing, stop the Inlet of the Water, and enter with Ease in the Cavity on the other Side, where they fish a little way with good Success.

More important, more lengthy, and more subterranean are the remarks of Edward Long (b. 1734; d. 1813) (Fig. 9). His father had lived in Jamaica and he himself went there from England in 1757 as a lawyer, and became a judge there. Ill health caused his return to England in 1769 and he spent the rest of his life writing, including his three-volume **History of Jamaica** (Long 1774), which contains descriptions of three caves.

The first of these is Riverhead Cave, in which the Rio Pedro rises:

> The cavern at River-head in the North-West part of the vale extends near a quarter of a

> mile under a mountain, or perhaps more, it being impossible to explore the whole length, on account of the river Cobre, which occupies the inmost part of it, and, running for a considerable way, suddenly shoots through a hole in the rock on one side, and continues its current under ground for a considerable distance from the cave. That this river draws its origin from some large stream in the mountains, far beyond the cave, seems evident, by its rising or falling in exact proportion as the rains are heavy or otherwise in the mountains. After very heavy rains, the river is so swelled, that, unable to vent itself at the hole, the superfluous water disembogues through the mouth of the cavern. An ingenious man attempted, a few years since, by fixing a flood-gate across the hole, to force the current of the river into a regular channel by the mouth of the cavern, and conduct it from thence to turn water-mills on the neighbouring estates. The undertaking had all the appearance of being practicable, but was laid aside after the death of the projector (Long 1774, vol. 2, 57).

The remains of a stone-built dam are still present about 400 m inside the cave. The stream is believed to come from the Worthy Park Sinks, more than a kilometre away, or perhaps from even further (Fincham 1977, 3, 124).

The whereabouts of the next cave is no longer known:

> In a rocky hill, on the Northern side of Old Woman's Savannah, is a cavern which runs a great depth under the earth. Upon examination, a few years since, it was found to contain a great many human bones, which were probably either Indians, or the relics of some of the wild or rebellious Negroes, who formerly infested this part of the country, and made it their place of concealment (Long 1774, vol. 2, 65).

After describing various tufa deposits and cascades in surface streams, Long (1774, vol. 2, 95-100) gives a detailed account of what is now known as Runaway Bay Caves, near Dry Harbour where Columbus landed. This description is printed here in its entirety, being the earliest detailed one of a visit to any Jamaican cave:

> The grotto in this parish, near Dry Harbour, and about fourteen miles West from St. Anne's Bay, is situated at the foot of a rocky hill, under which it runs for a considerable way, and then branches into several adits, some of which penetrate so far, that no person has yet ventured to discover their ending. The front is extremely Gothic in its appearance. It is the perpendicular face of a rock, having two arched entrances about twenty feet asunder, which look as if they had anciently been door-ways, but sunk by time or accident to within two or three feet of their lintels. In the centre of the rock, between these portals, is a natural niche, about four feet in height, and as many from the ground, which might well be supposed intended for the reception of a madona, especially as at the foot of it is a small excavation, or bason, projected a little beyond the face of the rock; which seems a very proper reservoir for holy water. Excited by the accounts I had heard of this celebrated curiosity, I made one among a party to visit it. After providing ourselves with several bundles of candlewood, split in small pieces, we crept on our hands and knees under the larger of the two apertures in the front of the rock, and immediately found ourselves in a circular vestibule, of about eighteen feet diameter, and fourteen in height. The cieling [sic!] (an irregular concave), as well as the sides, was covered with stalactic and sparry matter, interspersed with innumerable glistening

particles, which, reflecting the light of our torches from their polished surface, exhibited the most rich and splendid appearance imaginable.

This roof seemed to be supported by several columns of the same matter, concreted by length of time; whole chaptrels, and the angular arches above, appeared in the true Gothic taste. The pillars surrounded the vestibule; the open spaces between them led into avenues which diverged away into different parts of this subterraneous labyrinth. On one side we observed a rock, which by the continual dripping of water upon it from the cieling, was covered with an incrustation, and bore a very striking resemblance of some venerable old hermit, sitting in profound meditation, wrapped in a flowing robe, his arms folded, and a beard descending to his waist. The head appeared bald, and the forehead wrinkled with age. Nothing was wanted to complete the figure, except the addition of features, which we immediately supplied, in the theatric manner, with a piece of charcoal. The graceful, easy folds and plaits of the drapery, and the wavy flow of the beard, were remarkably well expressed. Roubilliac, the rival of nature, could not have executed them in a more finished and masterly style. After we had sufficiently contemplated this reverend personage, we pursued our route through one of the largest adits. We found the passage every where of good height, in general from twelve to fifteen feet; but so totally excluded from day-light, that the gloom, together with the hollow sound of our trampling, and dismal echo of our voices, recalled to our minds the well-imagined description of Aeneas's descent into the infernal regions...

That the comparison might have appeared more just, I ought to have premised, that the grotto is surrounded with a thick wood, and that at a small distance before the entrance is a large lagoon of stagnant water... The soil beneath our feet we perceived was deep, soft and yielding, and had a faint, cadaverous smell. Upon examination, we imagined it to be a congeries of bat's dung, accumulating perhaps for ages past; and were further confirmed in this opinion by the multitude of these creatures, which, upon the disturbances of our torch-light, and the unusual noise of so many visitors, flitted in numerous swarms over our heads. It is probable this soil is strongly impregnated with nitre; but we had not time to search for it. After walking a considerable way, we observed many new adits branching from the sides. Our guide informed us they led several miles under ground; and that one half of them had never been explored by any human being. Soon after, we came all on a sudden to a little precipice, of about four or five feet; and some of the party would have hurt themselves very severely, if it had not been for the soft stratum of bat's dung which lay below ready to receive them. Our guide, and two or three of the foremost, disappeared in an instant, having tumbled one over the other; but soon recovered from their surprize, when they found themselves unhurt. The rest, who followed at some little distance, being put on their guard, descended with somewhat less rapidity. We continued our walk without further interruption, till we hailed the day-light again, in an open area environed on all sides with steep rocks covered with trees. This area, as nearly as we could conjecture, lies about a quarter of a mile from the entrance of the grotto. We remarked several adits leading from different parts of this little court; but our guide was acquainted with one of them only, into which we walked, and came into a magnificent apartment, or rotunda, of about twenty-five feet diameter, and about eighteen to the dome, or vaulted cieling; from the centre of which descended a strait tap-root of some tree above, about the size of a cable, and pretty uniform in shape from top to bottom. This had made its way through a cleft in the rock, and penetrated downward quite into the floor of the apartment. On one side was a small chasm, opening like the door-way of a closet into a narrow passage; which our guide endeavoured to dissuade us from entering, on account of a deep well, which he informed us lay a few paces within. However, we ventured in

a little way with great caution, and found his account very true. The passage grew more and more contracted, till we met with a thin, upright ledge of rock, rising like a parapet-wall, almost breast-high, which seemed to decline gradually lower as we advanced. We therefore thought it prudent to halt, and soon discovered the ledge of rock separated us from a vast cavernous hollow or well. Having no line, we could not sound the depth of the water, nor how far it lay beneath us; but, by the fall of some stones we threw in, we judged the distance to the water about thirty or forty feet. The stones in their fall produced a most horrid, hoarse noise, as loud as hell's porter uttered from his triple jaws, primis in forcibus orci. Our guide informed us it was unfathomable, and communicated with the sea. The latter is probable, as the entrance of the grotto is very near the coast. We returned across the area by the way that we came, only peeping into a few of the other avenues as we proceeded, which we found very little different. They had the like rude cielings incrusted with stalactites, here and there interspersed with the radical fibres of trees and plants, and their walks strewed with various seeds and fruits, particularly the bread-nut in great abundance; and even some reptiles, all curiously covered over with incrustations, but still preserving their original shapes. The structure and furniture of these various cloysters and apartments, at the same time that they excite the utmost curiosity, baffle all description. In some we saw, or fancied we saw, sparkling icicles, and beautifully-variegated foliage, gemmy canopies, festoons, thrones, rostrums, busts, skulls, pillars, pilasters, basons, and a thousand other semblances of such objects as struck our different imaginations. Most of the arches and columns seemed to be composed internally of a greyish, sonorous marble, and were extravagantly wild and curious. Some are perfect, and sustain the massy superstructure; others half formed; and some in their very infant state. Several of the apartments are cellular; others, spacious and airy, having here and there an eyelet-hole to the world above. These aerial communications are of signal service; for, although not in general large enough to admit much light, yet they introduce sufficient fresh air to expel noxious vapors, and afford a convenient respiration, except in those parts which are most recluse. The exterior summit of the cave is a greyish rock, honey-combed all over, full of crannies, and thick-set with various species of trees, whose roots having penetrated wheresoever they could find an opening, they flourish without any visible soil, an appearance which is extremely common in this island. We were anxious to investigate further: but, upon examining our stock of torch-wood, we found scarcely sufficient left for conducting us back to the entrance, and we were obliged to use dispatch in regaining it, for fear of rambling into some one of the numerous passages opening to the right and left, where, puzzled with mazes and perplexed with errors, we might have rambled on without the probability of ever finding our way out again: and in such a distressful event we could not reasonably have expected any human assistance. The famous Cretan labyrinth did not, I am persuaded, contain half the turns and windings which branch through every part of this infernal wilderness; and which even Theseus, with the help of his clue, would have found difficult to unravel. Whoever may have the curiosity to examine these meanders with more attention, and to discover their extent and termination, ought to furnish himself with the implements necessary for striking fire, a portable mariner's compass, a proper quantity of wax tapers, and some provision for the stomach. Thus equipped, he may pervade them without fear of being lost, if he walks with due circumspection: the impression of his feet on the soft mould, which is thick-strewed in these passages, might enable him to re-trace his own tract almost without the assistance of a compass; though to avoid the possibility of being bewildered, it will be advisable to carry one.

> There are the most remarkable curiosities as yet discovered in this parish; but it may probably contain others, the grotto not having been found out, or at least generally known, till within these few years. We are uncertain whether it was known to the Spaniards; but it is supposed that run-away Negroes were not unacquainted with so convenient a hiding-place.

A curious little book, whose author is not known, appeared a few years later, in 1790, and contains a short account of the same cave, apparently by then the most visited cave:

> There is a very curious cave on the North side of the island, which I have been visiting with my friend Philanthropos, - the chambers are very lofty and spacious, but the passages are so intricate, that none have yet ventured to explore the extent of the grotto. - Trusting to our guides we wandered from chamber to chamber, till the decrease of our wooden torches, warned us to return in time to the Sun.
>
> The ground we walked upon was uneven, and our feet sunk half over our shoes into a kind of soft black dust like soot: we met vast numbers of bats.
>
> In some of the apartments there were small clefts that admitted day-light and after proceeding a considerable way, we got out into a curious large area, in which there were trees growing.
>
> Entering by another cell on the opposite side of the area, we were told by our guides to walk with caution, as we were approaching a deep well - at which we shortly arrived, and throwing down a large stone, heard it strike repeatedly against the sides, till at last it dashed into the water, after taking near a minute in its descent.
>
> As we returned we passed thro' one apartment, where we were struck with a number of extraordinary figures; some in the shape of tombs, others of various bodies and faces, but one image was so nearly perfect, that we could scarcely resolve upon its being a lusus naturae [sport of nature]. - It was the figure of an old man with a long beard, cloathed in a robe sitting on a stone, and reclining his head upon his hand, his elbow resting on his knee: - the folds of his robe fell over his feet, and above his head was (if I may so express myself) a large concave sheet of the rock, under which he sat as under a canopy - his posture was that of pensive melancoly, which furnished Philanthropos with the subject of the following ode (Anon. 1790, vol. 2, 126-129).

The author's friend 'Philanthropos' was Robert Charles Dallas (b. 1754; d. 1824) and his poem, of 15 verses, is called 'The Grotto: or melancholy. An ode'. Its author is known because the poem was reprinted in the **Miscellaneous Writings** of Dallas (1797, 59-66). He was born in Kingston but left the island as quite a young man, as the climate affected his wife's health. Fincham (1977, iv), who quotes one verse of the poem, states that he was still in Jamaica in 1778 so the date of the cave visit that inspired it, and his anonymous friend's description, may have been as early as that.

A few years later Dr. Thomas Coke (1808, 352) described the same cave but his account is merely adapted from Long's book, without acknowledgement, the parts that are not shortened being almost word for word copies of Long's text. In its turn, Coke's description was quoted by the Baptist missionary James M. Phillippo (1843, 43-44).

The naturalist Philip Gosse lived in Jamaica from 1844 to 1846 and visited two caves, neither of which can now be identified. They are 'Hallow-well' near Grand Vale,

Westmorland, and 'a singular little grotto close by the road side' at Mount Carey, St.James (Gosse 1851, 198-199, 253-254).

A remarkable exploration was made in 1895 when the Governor of Jamaica and a Mr Davis were lowered to the bottom of Hutchinson's Hole, a shaft now known to be 98 m deep (Fincham 1977, 85). Sir Henry Blake (b. 1840; d. 1918) was 55 years old at the time. The cave gets its name from a tradition that the highwayman Lewis Hutchinson used to throw his victims' bodies down the shaft.

Sir Henry's descent, on 19 or 20 July 1895, is described in some detail in one of the Jamaica's main newspapers (Anon. 1895).

> Telegraphing yesterday morning our correspondent says: Yesterday His Excellency the Governor and Lady Blake drove to the historical 'Hutchinson's Hole' on the property of Edinburgh Castle in the Pedro district[.] Preparations had previously been made by Mr. Davis, Superintendent of Public Works, for a descent into the hole into which he first went, after which His Excellency descended and remained for some time. No bones or other relics of Hutchinson's reported victims were found. The bottom of the cave opens into a rather large hall and appears to have been flooded at some not very remote period; this might possibly account for the absence of such relics. The depth of the hole as ascertained by actual measurement is 256 feet and not 6 or 8 hundred as previously supposed.

Geologists

De la Beche

Like several of the people already mentioned, Thomas Henry De la Beche (b. 1796; d. 1855) had some family connection with Jamaica, and it was to see the family estate that he visited the island in 1824. For most of his life, however, he was concerned with British geology, initiating the Geologiocal Survey of Great Britain and becoming its director.

Two main papers resulted from his Jamaica visit. The second of these is the more wide-ranging but the first (De la Beche 1825) includes a description of his visit to Portland Cave No. 1 which he called the 'most celebrated' one at that time. 'Portland Cave has been visited by hundreds of persons, most of whom have written their names on almost every accessible portion of it'. Imbued with the then fashionable writings of Buckland (1823) on the presence of mammal bones in cave earth beneath a stalagmite layer, he comments 'I did not observe any bones beneath it [the 'crust of stalagmite'], and am now sorry that proper search was not made, as the depth of the silty clay has not been ascertained, and as it might contain bones.' Indeed it might; in 1920 H.E. Anthony found bones there (Koopman & Williams 1951, 2) but his excavation has not been published.

Although the other paper (De la Beche 1827) is 52 pages long, it aims to cover the geology of the whole island so the underground rivers, while noted, are not given prominence. Indeed it is surprising to find a quite lengthy footnote describing the Swansea Cave:

> The entrance to this cavern is highly picturesque, and is concealed from a distant observer by dense tropical vegetation. The first part of the cave varies in height, and is, in some

places, lofty; this portion is covered with grotesque stalactites and stalagmites, and some of the columns are very beautiful. It terminates in a small open space surrounded by cliffs, where some negroes cultivate plantains and cocos. The lenght of the first cavern is about 76 paces allowing for all inequalities. After crossing the small open space above mentioned, (probably only a portion of the cave that has fallen in,) we entered a cavern forming a winding chamber, about 89 paces in length, the sides, roof, and floor of which are covered with stalactites and stalagmites. We then crept through a low communication about three paces long, and entered another chamber about 34 paces in length, containing grotesque stalactites and stalagmites. We then came to a small space, through which we crept upon our hands and knees, for about the distance of two paces; and this opened into a lofty cavern 54 paces in length, where bats were clustered in considerable numbers on a portion of the roof. This chamber was separated from another by a small division. The space now entered was tolerably lofty and about 21 paces long: at the end, the roof had fallen in, and admitted the light of day; and the rubbish formed a rough ascent and descent, occupying about 60 paces of the cavern's length. We then entered a chamber 14 paces long, which is succeeded by a low passage, where we could not stand upright, 21 paces in length. After passing this low place, we found ourselves in a chamber 14 paces long, and we then entered a low place where the bed of limestone that formed the roof gradually approached the clay floor and prevented further progress.

Near this cavern is another, from which the people on Swansea estate obtain their supply of water, which remains at a greater or less depth in it according to the seasons. Sometimes, when heavy rains have fallen in certain parts of the neighbourhood, with which it must have communication, it rushes out of the cavern with great noise and impetuosity into a gully, but is soon swallowed up among the sink-holes (De la Beche 1827, 185-186).

The cave referred to in the final paragraph is now called Sand Hole Gulley Cave.

The Geological Survey Memoir of 1869

The Gelogical Survey Memoir on Jamaica (Sawkins 1869) has 340 pages devoted to an island about 70% of which is limestone, so it cannot be expected that this section can give an adequate r,sum, of all there is in it relating to caves. It is not the intention to trace the development of geological interpretation of Jamaica karst from De la Beche, through Sawkins, Hill and Daneš. To do so would require a lengthy chapter to itself. The purpose here and in the next few paragraphs is to note the existence of such work and to show how it led to a greater knowledge of the caves themselves.

Most of the book consists of reports on individual regions, parish by parish, by five separate authors, some of them writing as early as 1863. There is thus a vast amount of detailed information, not only on the rocks but on the hydrology of the island, mentioning caves primarily in this connection. The value of the volume is in its comprehensiveness, including as it does the more remote areas. Thus the Cockpit Country is described for the first time in some detail (216-219, 242-243). By providing information on individual places, it allows the hydrology to be seen as a whole. The dolines or 'cockpits' of the Cockpit Country, as well as 'light-holes', are attributed to collapse (242-243). The Geological Sur-

vey Memoir made the karst of Jamaica known world-wide and was cited by Cviji- (1893, 244) and Martel (1894, 548; 1896, 40).

Hill and Daneš

Thirty years after the publication of the Geological Survvey Memoir a lengthy reassessement of the geology of Jamaica was produced by Hill (1899). There is little of descriptive interest on the karst, but the cockpits are explained as being products of solution, not of collapse (25-27).

Daneš (1914 and earlier) was aware of Hill's views and he also favoured solution for the formation of cockpits. His principal contribution to the study of karst was that he was able to add his observations of tropical karst in Jamaica and Java to the European investigations which had hitherto been the basis for karst theories. Sweeting (1972) has pointed out that it was mainly because of Daneš's work that Grund (1914) was able to put forward his scheme of evolution of karst areas, in which the doline karst of temperate regions evolved towards the type of tropical karst seen in Jamaica.

Popular and Guide Books

In a country where the caves had been as well researched and reported as they had in Jamaica. one would not expect the popular books to contain new information. Nor do they, but they are significant in that they show how the public would learn about the caves and to what extent they were regarded as tourist attractions. It will be seen that they were given much less prominence than those in, say, Trinidad.

Considered first, as the earliest, is a series of a large size photographic reproductions of scenes in the island by Dr. V.P. Parkhurst (1887), photographer and publisher, with a short accompanying text. Not popular in the sense of a large-scale production, it was nevertheless aimed at the lay public, not the scientist. It would have been a magnificent production had it been completed, measuring 35,5 cm by 27,5 cm, but the author died when only five parts had been issued. The very high quality photographs included ones of the river sinking at Luidas Vale and the rising at Riverhead Cave.

The guide-book by Bacon and Aaron (1890) mentions the main Hector's River Sink. Both Gardner (1893) and Stark (1898) refer in identical terms to Three-Fingered Jack's Cave on the Cane River and the latter book goes on to describe Runaway Bay Cave and the Cockpit Country. Ober (1908) has no more than 16 lines on caves but he does say that 'Peru Cave ... is noted for its fine stalagmites', the first written intimation that the public might go there, though names on its walls indicate that it had been visited for a long time already (Fincham 1977, 3).

Prehistoric and Quaternary Remains

Rock carvings made by aboriginal Indians in or near cave entrances are known at several sites, suggesting that some caves were sacred and perhaps used for burial. In 1895 the

small Dallas Castle Cave was discovered by removing the boulders that blocked the entrance and at least 24 human skeletons were found there, together with the remains of a canoe and of food animals (Duerden 1895).

In 1919 and 1920 H.E. Anthony investigated 18 caves, finding and collecting bones in 10 of them. He himself published only a popular article (Anthony 1920a) and one note on new genera of rodents from a cave at Wallingford (Anthony 1920b). The fossil bats he collected were subsequently studied by Koopman and Williams (1951) and the fossil monkeys by Williams and Koopman (1952). Anthony's work at Wallingford has been reviewed recently by McFarlane and Gledhill (1986). With these exceptions, his work in Jamaica remains unreported (A.P. Currant, pers. comm.).

Bats and Guano

Cave bats, among others, were studied from 1858 to 1860 by W. Osburn who died suddenly while working on them, leaving extensive manuscript notes. From these a paper was prepared for publication by the Secretary of the Zoological Society of London (Osburn 1865). The caves he visited included Mahogany Hall Cave and Sportsman's Hall Cave in 1858; and, in 1859, Oxford Cave (an 'immense cave, whose winding galleries cannot be less than a mile in length'), a 'magnificent' cave in Portland Ridge, Runaway Bay Caves, two caves on the Harmony Hall estate in Trelawny parish, and a 'picturesque little cave' close to the town of Montego Bay, perhaps Sewell Cave. The Portland Cave referred to may be the same one (No. 1) that De la Beche saw, or it may be the more 'magnificent' and longer cave (No. 2) which is more difficult to explore but nevertheless contains dates from the mid 18th century. The locations of Mahogany Hall Cave and Sportsman's Hall Cave are not known exactly, but they are not far from Oxford Cave and Balaclava (S.J. Walker, pers. comm.). In Mahogany Hall Cave 'The floor of the cave was strewn here and there with the kernels of bread-nut (Brosimum), which had sometimes germinated into young blanched trees on the thick deposit of dung'.

Bat guano was used locally as a fertilizer in the 19th century and analyses of 35 samples were published by Cousins (1903) when export to U.S.A. was being considered. The largest deposits occurred in what is now known as Cousins Cove Cave No. 2 (Fincham 1977, 214-215) and it was from there that at least some of his samples were obtained.

Cave Fish and other Fauna

Eigenmann (1909, 188) wrote that blind fishes related to the Stygicola and Lucifuga species found by Poey in Cuban caves in 1856 'are said to occur in Jamaica'. This statement may derive from a newspaper report (Anon. 1909) that an English researcher had found blind fish in Wallingford Cave (now known as Wallingford Sink).

Other fauna seem to have attracted little attention in the period under review. Chopard (1923) describes a Uraroviella, a new genus of gryllid, from specimens taken by Major A. C. Clarke in a cave in Trelawny parish, 'nearly a mile from daylight', in September 1921.

Acknowledgements

Biographical information has been taken from the **Dictionary of National Biography** and from the **Bibliotheca Jamaicensis** of Cundall (1895). Dr. Alan Fincham, formerly of the University of the West Indies in Jamaica, and Chris Howes read the manuscript of this chapter and made several helpful suggestions which I have adopted. I am also grateful to A.P. Currant of the Natural History Museum in London and S.J. Walker of St. George's College, Kingston, Jamaica, for information.

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THE BAHAMAS TO 1950

Abstract: Caves in the Bahamas were noted in 1725 and studied in the 19th and 20th centuries by geologists and those interested in the exploitation of guano. Arawak petroglyphs in a cave were described in 1889. The underwater caves, or Blue Holes, were recorded on charts about 1840 and attracted much attention in the 1890s.

The Bahamas are today perhaps better known for their underwater caverns or Blue Holes than for conventional caves. Both have been recorded over the years, together with numerous pits on land which the high water table cause to be water-filled. In the days before cave diving, observations on the underwater caves were limited to their surface appearance and depth.

Whilst it was the 'curious' nature of the water-filled holes that attracted attention to them, many of the caves were recorded because of the considerable trade in bat guano. The presence of aboriginal petroglyphs in one cave was also noted.

As many of the caves are small and have few distinguishing features, it is often difficult to determine their precise location from contemporary descriptions. For this reason the map accompanying this paper (Fig. 10) names the islands only, as well as some of the Blue Holes in the ocean.

The peculiarly porous nature of these low-lying islands is demonstrated by the presence of pits or dolines in which the water level rises and falls with the tide (though not in phase with it). These were the first karst phenomena to be noticed in the Bahamas and were seen in 1725 by the English naturalist Mark Catesby (b. 1679?; d. 1749). He was a friend of Hans Sloane, noticed in the chapter of Jamaica, and many of his plant specimens went to the latter's museum and thence to the British Museum. Catesby had travelled extensively in America from 1710 and in 1725 he visited the Bahamas, staying with the governor in [New] Providence and visiting several of the other islands.

> Many of the Islands, particularly **Providence**, abound with deep Caverns, containing salt Water at their Bottoms; these Pits being perpendicular from the Surface, their Mouths are so frequently choaked up, and obscured by the Fall of Trees and Rubbish, that great Caution is required to avoid falling into these unfathomable Pits (as the Inhabitants call them) and it is thought, that many Men, which never returned from Hunting [,] have perished in them: in **Providence**, and some other [i]slands, are extensive Tracts of low level Land, or rather spongy Rock, through which, at the coming in of the Tide, Water Ooses, by subterraneous Passages from the Sea, covering it some Feet deep with Salt Water, which at the Return of the Tide sinks in, and is no more seen, 'till the Return of Tide again, so that there is an alternate Appearance of a Lake and a Medow every 12 Hours; One of these Lakes being visible at a Distance of about four Miles from the Governor's House, surprised me at its appearing and disappearing several Days successively, 'till I was truly inform'd of the Cause. The Caverns before mentioned, I make no doubt of, are supplyed with Salt Water from the Sea, in like manner with these Lakes, but because of their Depth and Darkness, the rising and falling of the Water may not have been observed; ... (Catesby 1731, vol. 1, xl).

More than a hundred years later Captain Richard John Nelson made a detailed geological study of the islands (Nelson 1853). Captain Nelson (b. 1803; d. 1877) was in the Royal Engineers of the British Army and later became a major-general, studying the geology of many of the areas where he was stationed. Like Catesby, he noticed the dolines with their fluctuating levels of brackish water on the lower ground. It was he who first recognized that the fresh ground water formed a lens, floating on top of the salt water in the ground and

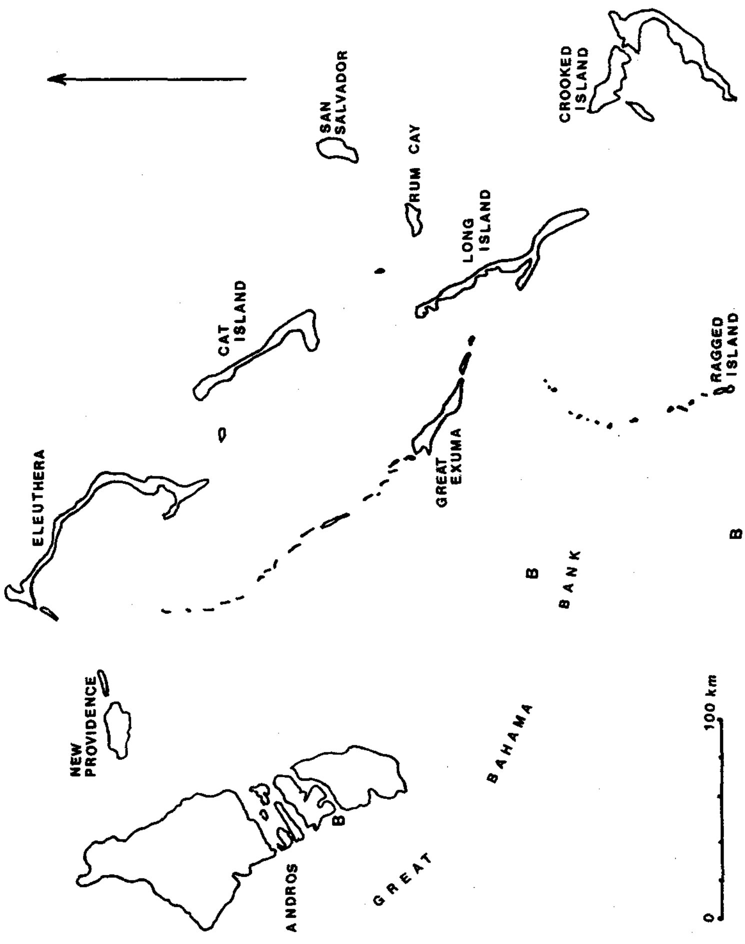

Fig. 10. Part of the Bahamas, showing places mentioned in the text. B: Blue Holes on Admiralty Charts surveyed 1836-1844

Sl. 10. Del otoka Bahamov, ki prikazuje kraje, omenjene v besedilu. B: Blue Holes na Admiralty Charts izmerjene 1836-1844

resupplied by rainfall. The practical importance of wells therefore being dug no deper than necessary did not escape him.

Blue Holes

One of the characteristics of the Bahamas is the presence of Blue Holes or deep underwater caves. Some of these have entrances on land but most of them open as shafts in the sea bed where the blue colour of their deep water, contrasting with the green of the shallow sea, gives rise to their name.

Blue Holes are of particular interest today, when they are being extensively explored by cave divers. Their history goes back more than a hundred years before the 1950s underwater explorations of George Benjamin, who is credited in a widely read reference book (Courbon et al. 1989, 43) as being the first to describe them.

Although they have probably been noticed for centuries, the earliest record of Blue Holes (as distinct from Catesby's tidal dolines), so far located, is their presence on the Admiralty Charts surveyed in 1843 and 1844 by Commander Edward Barnett and Lieutenant G.B. Lawrance, Royal Navy. One of these holes, at 2306'15" N, 76038'45" W, is marked as '38 fms [69.5 m] hole 10fms diameter. in c[o]r[a]l patch', with the surrounding sea bed about 9 m deep; another, at 2209'25" N, 76029'53" W, is labelled 'Blue Hole', and shown as 13 fathoms (23.75 m) in a surrounding 11 m; yet another, at 220 14'30" N, 76028'50" W, is 24 fathoms (44 m) deep. All these occur on the Great Bahama Bank; the first is some 150 km west of Long Island and 120 km south-east of Andros; the others lie about 80 km west of Ragged Island. Another, shown on an Admiralty Chart of 1844, is a 2.5 fathom (4.5 m) 'Deep Hole' in water otherwise only half a fathom (1 m) deep off the west end of South Bight in Andros; it was recorded during surveying between 1836 and 1842.

Nelson (1853) did not remark on Blue Holes but they received considerable attention in the 1890s from those who recorded their position, described their behaviour, and attempted to explain their origin.

The geologist Dr John I. Northrop (1890) spent a little over six months in the islands, two of them in new Providence and the rest in Andros. One hole he saw, on land but nevertheless 'known as the "Ocean-hole"', was near Nicholl's Town at the northern end of Andros. The pit 'was about one hundred feet in diameter and perhaps forty feet in depth, and contained a pool of brackish water... The name "ocean-hole" is also applied by the natives of Andros to deep holes **under** the water' and Northrop lists the following, all of which he saw himself;

- Mangrove Cay, close to the shore, 30 m diameter and said to be over 33 m deep.
- Andros, close to the northern bank of Fresh Creek, about 16 km from its mouth. 30 m diameter, and 5.5 m deep in water that is otherwise only 0.6 m deep.
- Andros. Near Grassy Creek, the shore forming one edge of the hole. About 50 m diameter and more than 37 m deep.

In addition, he was told of one over 55 m deep in the 'Pine Yard'.

Northrop uses the term 'Boiling-Hole' to distinguish those holes where the water could be seen moving with some velocity.

> The first of these I was shown on Andros in a small creek that runs into Conch Sound. The top of the hole was about a foot under water at low tide, and close to the mangroves that formed the side of the creek. It was about seven feet in length and about two or three wide. Below the diameter increased, forming an overhanging ledge. When the tide was low in the creek, but rising outside, the clear sea-water could be distinctly seen ascending, thus producing the same appearance at that presented by a mixture of sulphuric acid and water. Suspended particles could also be seen rising.
>
> While sailing past Rat Cay, near Mastic Point, another "boiling-hole" was seen that was apparently about ten feet in diameter, and from a distance we could see a perceptible "boil" on the surface that was undoubtedly caused by the rising water. Our captain said that when the tide was falling the water in the hole went "down and round" - which statement I believe, as the water was rising with some force, and probably ran out again with sufficient rapidity to cause a small whirlpool. In another boiling-hole near Mangrove Cay the water was seen ascending.
>
> These facts prove not only that an underground connection exists between these holes and the ocean, but that the connection is an open one, so that the water can flow freely through it, and thus the pressure resulting from the passing tidal wave is shown before the tide commences to rise on the shore. The ocean-holes, I believe, can be explained by supposing them to be old boiling-holes in which the connection has been stopped up, and their greater size caused by the falling-in of the ledge on the edge, which would aid in the stoppage. I regret that I have no fact to offer on the depth of the boiling-holes, for the only one I stopped to examine was at Conch Sound, and this one ran under the ledge, so that its depth could not be determined. The ocean-hole at Nicols Town, described above, is also, I believe, an old ocean-hole now elevated.

'Ocean-holes' were also examined by Alexander Agassiz (b. 1835; d. 1910), oceanographer and zoologist and son of the better-known Jean Louis Agassiz. He studied the Bahamas and the surrounding sea bed in the early part of 1893 and was interested in the evidence that the holes provided for subsidence of the land.

> May we not to a great extent measure the amount of subsidence which must have taken place at certain points of the Bahamas by the depth attained in some of the so called ocean-holes, as marked on the charts? Of course we assume that they were due in the aeolian strata to the same process which has on the shores of many islands formed potholes, boiling holes, banana holes [i.e. small solution holes], sea-holes, caverns, caves, sinks, cavities, blow-holes, and other openings in the aeolian rocks. They are all due more or less to the action of rain percolating through the aeolian rocks and becoming charged with carbonic acid, or rendered acid by the fermentation of decomposed vegetable or animal matter or by the action upon the limestone of sea water or spray under the most varying conditions of elevation and of exposure. None of them have their upper openings below low-water mark [i.e. none that he knew of], though some of them may reach many feet below low-water level. Ocean-holes were

formed in a similar way at a time when that part of the bank where they exist was above high-water mark, and at a sufficient height above that point to include its deepest part. The subsidence of the bank has carried the level of the mouth and of the bottom of the hole below high-water mark.

...

The principal ocean-holes, Blue Holes, are the following: one five to six miles from Hawk's Bill Rock; three, of eighteen, twenty-four, and thirteen fathoms [33, 44 and 23,75 m], a little east of north of Blue Hole Point, each about five miles apart on a northerly line; and two, of seventeen and thirty-eight fathoms, in the extension of the line of Blossom Channel leading from the Tongue of the Ocean upon the bank [This last is probably the one shown on the chart of 1844].

...

At other places on the banks ocean-holes are said to exist. Among those not on the charts, I may mention a fifteen fathom [27 m] hole at High Point, Andros, and a twenty fathom [37 m] hole in the Middle Bight, between Gibson Cay and Big Wood Cay (Agassiz 1894, 41-42).

The 'fifteen fathom hole at High Point, Andros' might be Stargate, a hole near the highest point of Andros, and now known to be 80 m deep overall (Palmer 1986a; 1989), though the name High Point was applied in the 17th century to what is now called High Point Cay, further to the south on the sea coast.

Thus Agassiz considered that the underwater caves were formed originally by water action when they were at higher level. Northrop had stressed the flow of sea water through the passages, caused by the tide, though he does not explicitly link this with development of the caves. As will be seen, this was the contribution made by Maynard in 1894.

In order to see these 19th century statements in perspective, it is well to summarize the present-day explanation of the origin of Blue Holes (from Palmer 1986b). The caves in the islands originally formed just below sea level, at the interface of the lens-shaped mass of fresh water ground water with the salt water below. Corrosion is particularly great here in the chemically aggressive mixing zone of fresh and salt water, aided by bacteria living at the interface. Tidal movement as well as rainfall ensures movement of the water, removing corrosion products and restoring aggressivity. The caves formed some 100000 years ago when sea levels were not dissimilar to today's, and became dry during the ice ages, when speleothems formed in them, only to be submerged again since. The land levels of the time allowed the Ocean Holes far out on the Bahama Bank to form in the same way.

Charles Johnson Maynard (b. 1845; d. 1929) was a taxidermist and naturalist from U.S.A.. He made five collecting expeditions to the Bahamas and published on them in his **Contributions to Science,** one of the several books he published himself, setting the type and making his own woodcut illustrations.

Maynard was unconventional in many ways and his independence led him to conclusions about Blue Holes that in some ways closely approach the modern view. In a biographical note, Stone (1933) comments, 'while Maynard's observations were voluminous, often original, and covered a wide field, his lack of early scientific training was frequently evident in his publications and he fell short of the accomplishements that might have been his had had he had a thorough foundation in science. Nevertheless, as one of his biogra-

phers has said, "It is possible this would have spoiled his independence and originality, and made a narrow specialist of him".'

It was the reason for the flow of water in the submerged caves that particularly exercised Maynard's mind. He believed that the passages remained from spaces left when coral was forming into reefs and that they were kept open by the water flow or even enlarged by the 'dissolving away of the dead coral'. As will be seen, he invoked the movement of the Gulf Stream water, which is indeed largely channelled close to the Bahamas.

Because Maynard's (1894) account also gives locations and descriptions of some of the Blue Holes, and because copies of the original book are now excessively difficult to find, extracts are printed here at length:

> [A] coral reef, no matter how thick it is, is not a solid wall, but is honey-combed in all directions by passages which are either left through the irregular method of the formation of coral heads, branches etc., or from a dissolving away of the dead coral. With elevation of the reefs, many of these passages would remain much as they were, especially in that portion of the reef which still remained below sea level, for the water would still continue to flow through them.
>
> That such water ways do continue to remain, we have ample proof in many places in the Bahamas. On New Providence are three or four large lakes of salt water, which occur in old lagoon beds, and in which the water rises and falls with the tides of the ocean. The most distant of these bodies of water from the sea is Lake Cunningham, which lies south of Fort Charlotte and which is a little over a mile from the shore.
>
> But among the most remarkable of the remains of the ancient passages through the reefs are what are known as ocean holes. The first instance of this that I saw was at New Providence. About a mile south of the Government House, also in the lagoon bed, in a middle of a cleared portion of land, is a depression in the rock, which is occupied by a basin of water, somewhat circular in form and about ten feet in diameter. This basin is about six feet deep, but on the north-eastern portion opens into an apparently bottomless cavity, some four or five feet in diameter, in which the water, on account of its great depth, is as blue as indigo. Through this passage this ocean hole has direct communication with the sea, and the tide ebbs and flows regularly in the basin, rising and falling between two and three feet.
>
> There is a beautifully clear lake on the eastern side of Rum Key, the center of which is as blue as the water of the Gulf Stream, which is a huge ocean hole and which is said to be visited by turtles from the ocean.
>
> One day while my men were pushing my boat over the shallows of the great bank which lies south of Andros, on which the water is only a few inches deep, we suddenly glided over a large ocean hole in which the water was also blue, and gazing into its limpid depths. I could perceive no bottom. The current set into this hole with the ebb, and out of it with the flood, tides.
>
> On the south shore of Andros Island is a large ocean hole in the naked rock, about a half mile from the shore, which is some fifty yards in diameter, and which has a large spreading mangrove tree growing beside it.
>
> Further north on Andros, about opposite Green Key, is an ocean hole remarkable for its singular form. It occurs in the naked rock as a cleft which is about a hundred yards long, but which is nowhere over twenty feet wide. To all appearances the water is of great depth in this chasm, how deep, either in this or in others of the holes mentioned, I cannot say, as I had no

means of sounding them, but in this, as in others mentioned the tide rises and falls regularly with that of the neighbouring ocean.

These ocean holes, are, I think, of not unusual occurrence, throughout the Bahamas, and appear to connect, as seen, directly with the ocean, at perhaps no very great depth, but there is another class of subterranean water way which is even more remarkable than are the ocean holes, of which I know two only, one by actual observation and one by report. Both of these lie in Middle Bight, near the eastern opening, and from them both, as I can bear witness in one case, the water flows out constantly and with considerable force.

The one with which I am acquainted is situated on the side of a little islet known as Givens' Key that lies about a mile within the Bight towards the northern shore. The hole is quite near the island, about thirty yards from the beach, and being between tide-marks, the land about it is left dry by the falling water. This hole is somewhat circular in form and some ten feet in diameter, opening out of the solid rock, which it penetrates, without diminishing in diameter, for some twenty feet perpendicularly, then diminishing somewhat in size, passes obliquely under the rock to the eastward. From the mouth of this cavity the water flows with such force that it is difficult to stand upright in the stream which flows into the Bight on the north side at low tide, and it flows up to a considerable distance above the surface of the water at high tide. Just how much water is ejected by this singular orifice is difficult to calculate, but it must amount to several hundred gallons a minute.

The water is salt, and is evidently sea water, for gorgonias, especialy the Briarium arbestinium [a missprint for asbestinium], which is usually a deep water species, thrive well there, and several species of coral grow about the mouth of the cavity and in the stream that flows from it. None, however, grew far down in the cavity. I did, however, obtain the largest specimen of Briarium asbestinium that I ever saw, on the southern side of the cavity, from the top of a projecting shelf some two feet below the surface, and fine specimens of this gorgonia grew on all sides of the cavity as far as the water from the orifice flowed.

Before attempting to advance any hypothesis as to why the water constantly flows out of this singular cavity, I will explain its situation more fully by the aid of the accompanying diagram and also give a special idea of the formation of Andros Island.

In fig. 62 [reproduced here as Fig. 11] I have given a section of the mouth of this subterranean water way in which it will be seen just how and at what angle the passage bends to the eastward. By standing on the western shore one can see considerably further into the cavity than on the eastern side which I have marked with an E.

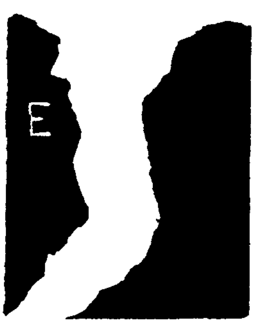

Fig. 11. 'Section of mouth of boiling hole'. The original Fig. 62 of Maynard's 1894 paper, showing a Blue Hole. E denotes east side

Sl. 11. 'Del ustja jame, ki "vre"'. Originalna slika 62 Maynardovega besedila iz 1894, prikazuje Blue Hole. E označuje vzhod.

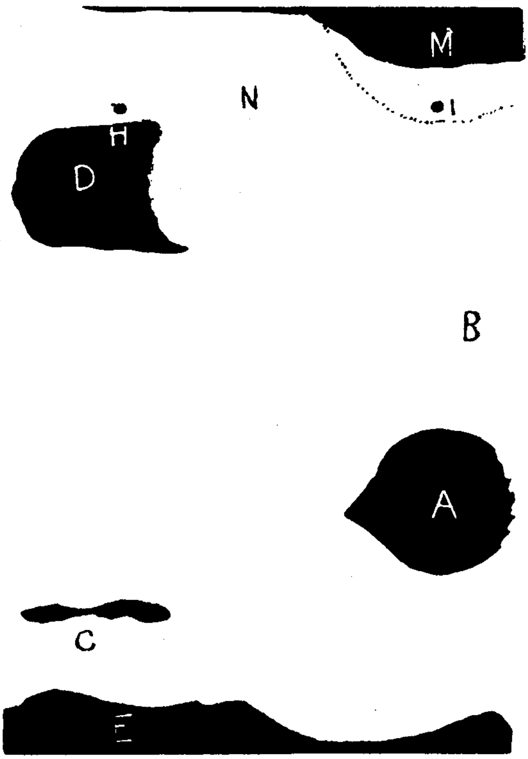

Fig. 12. The eastern entrance of Middle Bight, Andros, showing the position of two Blue Holes ('boiling holes'). The original Fig. 63 of Maynard's 1894 paper; the key is in the text

Sl. 12. Vzhodni vhod Middle Bight, Andros prikazuje lego dveh Blue Holes ('boiling holes'). Originalna slika 63 Maynardovega besedila iz 1894; razlaga v besedilu.

In the diagram, fig. 63 [Fig. 12], the white is water and the black land. B, is the entrance of the Bight; M, Mangrove Key on the north of the Bight;

A, Little Galden Key; C, Goat Key; D, Givens' Key; H, the cavity;

E, the south shore of the Bight; I, approximate position of the second boiling hole, and the dotted lines represent a shallow bank between it and the land. The scale of this diagrammatic chart is about two inches to the mile.

Andros Island, on the eastern shore of which these boiling holes are situated, is an island of somewhat peculiar formation as compared with the rest of the Bahamas. Along the eastern shore the land is quite high, often rising into cliffs. This line of cliffs is evidently an old barrier reef, similar to the barrier reef which now exists all along the eastern shore of the island, but of course the old reef has been elevated with the other of the Bahamas. West of this old line of reef, the land is low, that in the interior being rocky and covered by

pine woods, but west of this it gradually merges into marl flats that by degrees, through a network of creeks and lagoons, merge into the waters to the westward.

Between this low coast and the Gulf Stream, distant about seventy miles, are comparatively shallow banks which terminate quite abruptly on the borders of the Gulf Stream, but without the intervention, as yet, of any well-defined reefs. From this gradual lowering of the land from the eastward it is easy to understand that Andros has been formed by an accumulation from the western side, and that its greatest increase has been in that direction; in fact, it is highly probable that it is only a matter of time when all the bank between what is now the west coast of Andros and the Gulf Stream will become land. This is readily comprehended by one who has visited the southern coast of the island and seen the extremely shallow water there with little mangrove keys gradually forming and filling-in the watery area.

Now in regard to the constantly flowing water from the two boiling holes, this can be accounted for in two ways only. As shown, it is pure sea water, therefore cannot come from extreme depths, as does the sulphur water of Florida, which flows from the earth in a similar manner, as at Blue Springs, near the St. John's, and in other places. The Tongue of Ocean which lies only a little over a mile to the eastward is quite deep, and water under the pressure of considerable depths might, by being forced into a narrow passage, boil upward in that manner, but it would almost seem that the counteracting air pressure on the mouth of the passage would prevent any outward flow, and even if it came from a considerable depth would act exactly as we find it acting in the ocean holes, namely, rise and fall with the tide without any constant outward flow.

Then again, water from a great depth in the ocean would be cooler than surface water, which was not the case, or at least in any perceptible degree, and as seen it could not have been colder or corals would not have thriven in it.

After giving the matter much thought I can account for these boiling holes in one way only and that is by supposing that when the old reef was formed these passages were in it just as we find passages through the old reef which borders the everglades of Florida on its southern side, through which subterranean streams find their way into the ocean.

The elevation of the island does not appear to have broken the connection of these ocean holes with the sea and it did not break the connection which this boiling holes had with the ocean. We have seen that in case of the ocean holes their connection was with the neighboring ocean, to the eastward of the old reef, in an extreme case, not over three miles distant, but in order to account for the boiling holes we must consider that they were connected with the waters on the westward of the reef, which was, then as now, the Gulf Stream. Before the elevation of the land this stream had practically gradually receded to what is now the western border of the island, for it is clear that the whole western portion of the key is nothing but an elevated mud bank. In its retreat it carried the sea entrance and the passage to the boiling hole with it, until it not only reached the present western border of the island, but backward to the present border of the Stream a hundred miles from the mouth of the boiling hole.

Now it can be readily understood that the northward flowing current of the Gulf Stream, moving as it does with considerable velocity between the Bahama Bank and Florida reef, would cause the water to run into a narrow passage with such force as to cause it to emerge from the opposite opening especially if this were smaller than the entrance in the sea. To account for the two boiling holes we have only to suppose that they are both entrances to one passage, which would seem plausible, as they are not over a quarter of a mile apart.

Another class of subterranean water ways is a system of smaller passages, through which the water finds its way underneath all the land of the Bahamas, but always at sea level and

> below it. The evidence that the sea water does so penetrate beneath the land may be found in the fact that the water of the wells, no matter where situated, as far as I have examined them, rises and falls with the tide. To be sure this water is fresh, or but slightly brackish, but it is a well known fact that fresh water will float on salt, as it is lighter. The rain water falling upon the surface of the land finds its way slowly through the more or less porous lime stone until it reaches the level of the underlying sea water, after which it can go no further. Hence all wells excepting those of which I have spoken, as being Indian wells and rock holes, in which the surface water is retained for a time, must be sunk to sea level. Thus we find that the well at Fort Charlotte, which stands on the top of a hill, is over ninety feet deep, but other wells, situated in the old lagoon bed, are much shallower, while in the pine woods, where the land is quite low, water occurs within about three feet of the surface.
>
> It is scarcely probable that the sea water thus penetrates to all parts of the underlying strata of the keys by simply percolating through the aeolian lime stone, even though this is softer at considerable depths than on the surface, for the water rises and falls in the wells nearly or quite uniformly with the tides, as regards time, and at extreme low water the wells are dry. This fact renders it probable that there are larger channels through which the water ebbs and flows and that such channels occasionally break out into the light of day in the form of the ocean holes, of which I have spoken.

A few years later Shattuck (1905), although he added no new information of significance, made the subject of Blue Holes more widely known, for his work was reported also in the French journal **La Nature** (Anon., 1906), one of whose editors-in-chief was Martel, and was later cited by Martel (1921) himself.

Caves

Turning now from submarine caves to more readily accessible ones, the earliest description appears to be by Daniel McKinnen (1804, 161-163), of a cave containing bat guano in Crooked Island:

> ... you are obliged to enter it by descending from an aperture in the rock above. Within this cave the devastation of the water, evident in various places throughout the island, has left more remarkable traces. In some spots, the top appears as if completely demolished, in others it is worn and fretted into regular cavities and shapes, giving it an air of Gothic ceiling, and the stalactites and incrustations on the side walls (if they may be so called) have a damp and mouldy appearance, tinged with occasional hues of green and light blue. In various parts the wild fig-trees, which are particularly fond of moisture, have penetrated into the recesses, and shot their bearded roots like clusters of columns on the sides or through the holes in the roof, which admit the light and in some places the sun's rays. It extends in a variety of capricious and romantic figures to a distance which has never been yet traced; and the imagination, prone to the marvellous, has led some persons to believe that it runs nearly across the island. The bottom was covered with a concretion, many feet deep, of some elastic substance resembling mould, but which is not possessed of any vegetative power. A philosophic gentleman conceived it was an accumulation for many ages of the dung of the bats which swarm in the dark recesses of this singular cave.

Captain Nelson (1853), already mentioned, explored a cave near Delaport (New Providence) in 1849 and found guano there. Some of it still contained recognizable insect remains but the rest was so decomposed that it was only by the presence of ammonia that it was identified. He also noted that,

> There are large caverns* in Long Cay and Rum Cay; and probably caverns are as numerous in the Bahama Islands as in the Bermudas; but so few extensive excavations have been made, that they cannot be positively affirmed.

The petroglyphs in the Rum Cay cave are discussed later. Caves in Long Island, probably those referred to by Nelson, were described more fully in 1891 in a guide-book (Stark, 1891, p. 236):

> Fine specimens of stalagmite are to be found at the Long Island caves. These caves are the finest in the Bahamas; they extend almost across the island. At the entrance is the Cathedral, seemingly prepared by nature for the officiating priest. A broad stalagmite makes a good pulpit, and near it the font, three feet high, with a hollow basin at the top always overflowing with water, then a number of pillars reaching to a roof with many arches. A test applied to one of the stalagmites used by geologists gave it an age of 90000 years.

It has not been possible to trace the source of this information on stalagmite dating. The Challenger expedition did not call at the Bahamas and Agassiz's investigations on the island were after 1891. The age given is different to that calculated for the Admiral's Cave stalagmite in Bermuda, thus precluding possibility that the two were confused.

Moseley (1926, 83-84) describes what is almost certainly the same cave, adding that 'A skeleton of a very large man, thought to be a Lucayan, was found some years ago in this cave'. Lucayans (Arawaks) were the now extinct inhabitants of the islands before Europeans arrived, and their remains have been found in several caves, including Hartford Cave discussed later.

A cave in New Providence Island, known unimaginatively as 'The Caves', is in a former sea cliff near the coast to the north of Lake Killarney. Though modified by the action of the sea it is basically a karst cave (Shattuck 1905, 18). Charles Ives (1880, 46) mentions bats there and writes:

> In quite a number of instances the ceilings of the rocky chambers had partially fallen in, and, through the openings, the roots of wild fig trees had made their way, dropped from ten to twenty feet to the bottom, where, entwined among and running over the rocks, they seemed in the dim light like huge anacondas, whose repose it might be dangerous to disturb.

It was in this cave that Maynard, on 2 June 1884, discovered for the first time the bat *Phyllonycteris plainfrons* which is known only from the Bahamas (Shattuck, 1905, 382). In describing the bats of the islands, Shattuck (1905, 380-383) refers to specimens from

* Some of these are remarkable for the rude Indian pictures drawn on their walls.

Hamilton Cave and a cave 2,5 km from Clarence Harbour (both in Long Island), a cave at Sandy Point (San Salvador), a 'large cave' about 6,5 km south of Georgetown ('Eleuthera', but perhaps Great Exuma was intended), and The Caves in New Providence. Caves known in 1935, and from which bats were collected for the Field Museum of Natural History in Chicago, were Hamilton's, McKinnon's and Miller's Caves, in Long Island, and James Cystern Cave and Sheep Hill Cave, in Cat Island (Allen & Sanborn 1937).

The trade in bat guano was extensive in the 19th century. An anonymous (1876) report states that an estimated 400000 tons of guano existed in the Bahamas at that time. It is not named as bat guano, but that is the only sort referred to in the literature. Ives (1880, 47) notes exports of bat guano, principally to the United States, of about 20000 USD per year at around 15 USD per ton, and Voelcker (1878) says that 'Most of the Bats' guano which is actually imported into England as an article of commerce is derived from numerous caves frequented by bats on Guanahani Island (St. Salvador) and on other islands belonging to the group of Bahamas'. He gives the composition of nine samples of such guano.

The existence of petroglyphs in Hartford Cave (Rum Cay) has been mentioned already. A detailed description of these, together with the illustrations reproduced here as Fig. 13, is provided by Maynard (1889). According to the Department of Archives in Nassau (Dr Gail Saunders, pers. comm.), 'Maynard's 1889 work, although dated, remains the seminal printed source for the Hartford Hill assemblage.'

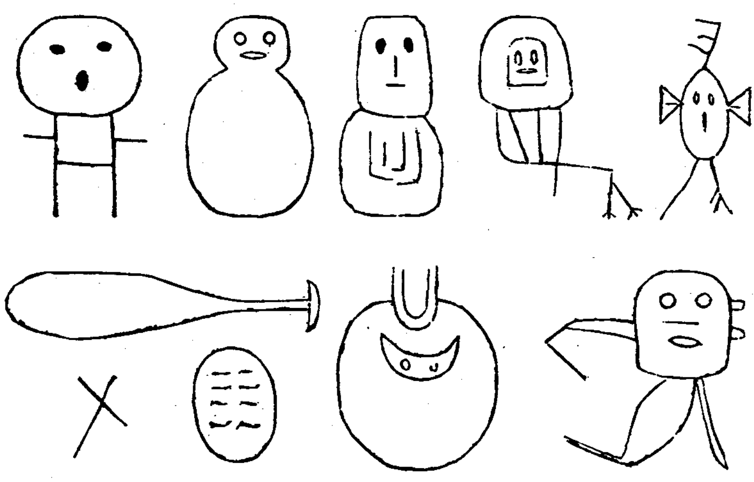

Fig. 13. The petroglyphs of Hartford Cave, Rum Cay, as drawn by Maynard in his 1889 paper

Sl. 13. Petroglifi v Hartford Cave, Rum Cay, kot jih je narisal Maynard leta 1889

Maynard visited the cave on January 20, 1888.

> ... we took a creole as a guide and he conducted us along interior road, to the north shore to what is known as Hartford Hill, one of the highest elevations on the key. ... At the foot of the hill we dismounted and made our way across the elevation, being somewhat retarded by the thick growth of shrubbery that everywhere covers the ground. Reaching the shore, here a rugged mass of rocks, we turned to the westward, proceeding till we came to a narrow sand beach, midway on which is the opening of the cave, in a limestone cliff which is some fifty feet high.
>
> The entrance to this ancient domicile was a low arch not over twelve feet high, but some fifty feet in long diameter. Just as we entered, the sun was nearing the water in the western horizon, and by reflection shone directly into the interior, illuminating it much more thoroughly than it would have done even at noon day. I found a rounded chamber about fifty feet in diameter, with smooth, evidently water worn walls, rising some fifteen feet nearly perpendicularly from the white sandy floor to the arched roof. There were a few gray stalactites, evidently forming slowly in wet weather and crumbling in dry, so that the rate of decrease was nearly equal to that of increase.
>
> The walls were of lime rocks, grayish in color, and covered with distinct, though rude figures of human beings and other objects, formed by lines cut in the stone to the depth of half an inch. As the sinking sun gave me comparatively little time for observations I hastily sketched ten of the principal figures, which I have given in the accompanying cuts.

He interprets the petroglyphs as representing white men and their equipment and concludes that they 'were placed there in commemoration of the landing of Columbus, on either this, or a neighbouring island'. Alternatively, he says, the figures may represent natives of some other island who recorded their visit in this way.

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ANTIGUA, BARBUDA, CAICOS ISLANDS, CAYMAN ISLANDS AND THE GRENADINES TO 1950

Abstract: Caves in these small islands were recorded in 1749 (Antigua), 1773 (Caicos), 1813 (Barbuda) and 1878 (The Grenadines), but apparently not until the 20th century in the Caymans. All the earliest references are on charts, maps, or instructions for mariners.

ANTIGUA

Bat's Cave or Bat Cave, in the south of the island of Antigua (Fig. 14), has a history of respectable antiquity. The first definite record of it is in the map surveyed by Robert Baker (1749) in 1746 to 1748, where it is named Balls Hole (Fig. 15). Gurnee (1961) refers to its presence on 'charts made in 1710', but no details are given and his notes have been destroyed by fire so this cannot now be confirmed (Gurnee, pers. comm.). The cave is not shown on Thornton's map made in 1701 and nothing earlier than the 1749 map is known in Antigua. The name Balls Hole was repeated on maps into the next century, for it appears on those Thomson (1814) and Philip (1856).

Early in the 19th century the cave was mentioned briefly, without naming it, in a book by a Methodist bishop, Dr Thomas Coke (1810, 417):

> In the vicinity of the Ridge, in a wild sterile spot, overgrown with false Acacia, Cactus, and dwarfy Psidium, intermixed with innumerable huge masses of spar, there is a curious cavern, in which an immense quantity of beautiful petrifactions are found, besides **Stalactites**;

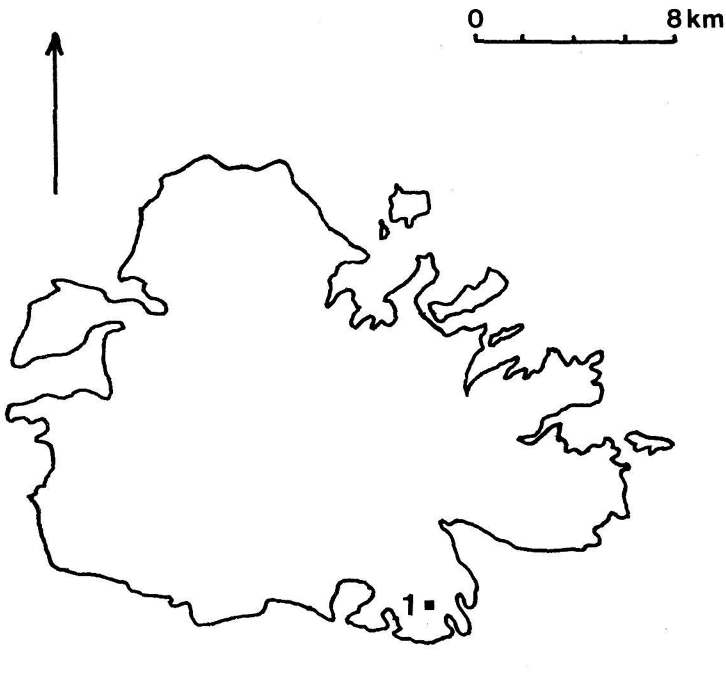

Fig. 14 - Antigua, showing Bat's Cave
Sl. 14. Antigua, prikaz Bat's Cave

Fig. 15 - The cave now known as Bat's Cave, on the map surveyed in 1746-48 by Robert Baker. The inlet of the sea at bottom left is English Harbour, with Indian Creek to the right. In the scale at the top each small division, 5 mm on the original map, represents one tenth of a mile. (reproduced by courtesy of the trustees of the British Library)

Sl. 15. Jama, znana kot Bat's Cave, karta, ki jo je izmeril Robert Baker 1746-48. Zaliv v spodnjem levem kotu je English Harbour, Indian Creek na desni. Po merilu na vrhu vsak delček predstavlja 5 mm na osnovni karti kar je desetina milje (reproducirano z dovoljenjem pooblaščencev British Library)

He says also of such petrifactions that 'in many other parts of the island they are met with, detached in forms infinitely varied'. Where they came from is not stated.

Some thirty years later a Mrs Lanaghan (1844, vol. 1, 281-282) provided a detailed description of the cave. She walked to it from the naval dockyard at English Harbour.

> After leaving the Ridge, we turned down a slight declivity, by the victualling offices, on our way to Bat's Cave, and the Savannah.
>
> ...
>
> Scrambling, as best we could, over a huge bed of prickly pear, (one of the cactus family), we

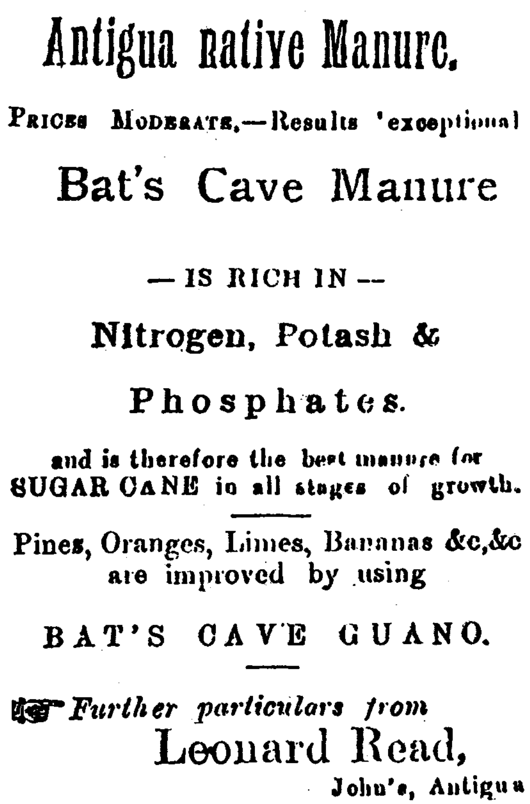

Fig. 16 - An advertisement for guano from Bat's Cave, which appeared in The Antigua Observer from 19 August 1897 until 17 March 1898. Height of original 10 cm.

Sl. 16. Oglas za guano iz Bat's Cave, objavljan v The Antigua Observer 19 augusta 1897 do 17 marca 1898. Višina originala je 10 cm.

gained an opening in the copse, and stood before the mouth of the cave. Two large trees, which grew on each side, extended their gnarled roots (from which the earth had been washed) across the opening, forming natural steps, by which we descended, and stood within the cave.

Huge masses of the rock which forms the cavern have fallen in, and in great measure blocked it up, so that it now only presents an arena of about 50 feet in circumference, although in time past it was of considerable extent. From the main cavern, two passages branch off in opposite directions. They are perfectly dark, the only means of exploring them being by the use of flambeaux; but to what length they extend has never been discovered. Mr. M. Lane, a late resident of English Harbour, (now of Canada,) has made several attempts to that purpose, all of which proved fruitless; the greatest distance he ever proceeded was to the extent of two sea-lines [i. e. sounding lines], about 120 yards. The only known occupants are bats, which breed there in immense numbers, and often attain the size of a common pigeon. A dark unhealthy vapour is emitted from these openings, proceeding, no doubt, from the carbonic acid gas they contain. This vapour soon extinguishes the light of a torch, which is one reason this cavern has never been further explored. [It is supposed that these passages extend to the sea-shore, a distance of about a quarter of a mile.] A streak of dank green runs down one side of the cave, which was pointed out to me as indicating the existence of copper; but upon examining a portion of the rock I brought away with me, I found that the colour was occasioned only by a vegetable substance adhering to the stones.

In former times, Bat's Cave was a great place of concealment for the tribes of erratic Caribs, when visiting Antigua on their predatory excursions; and tradition still points it out as the scene of a barbarous carousal among that wild and savage race, in one of their attacks upon this island.

At the end of the century an attempt was made to sell bat guano from the cave as a fertilizer. An advertisement (Fig. 16) in **The Antigua Observer** of 19 August 1897 was accompanied by an article (Anon. 1897) encouraging planters to use this inexpensive local fertilizer instead of chemical ones from abroad which were said to be less effective. An analysis by the Government Analyst gave 12,3% of phosphates in the guano. The advertisement appeared weekly for exactly seven months, until 17 March 1898, but whether its cessation indicated failure is not known.

A location map is provided by Gurnee (1961), together with a modern cave plan which agrees quite closely with the description of nearly 120 years earlier. The cave is in a small patch of dark Seaforth Limestone resting on the igneous rocks which form most of the southern part of the island (Reed 1949, 259).

BARBUDA

Two caves are marked on the 1814 Admiralty Chart of this island, the result of a survey made in the previous year by Captain Deckar. Both are in The Highlands (see Figs. 17 and 18), the more northerly one being named as Darby's Cave. A third cave in The Highlands is shown on an undated manuscript chart which appears to be of slightly later date (C 284 in the archives of the Hydrographer of the Royal Navy at Taunton, England). Darby's Cave is a flat-bottomed doline about 100 m long (Wagenaar Hummelinck 1979, 170-171) and the

unnamed caves may well be the ones now known as Dark Cave and Bryant's Cave, both of which contain pools of water. It would be these, or others like them, that Ober (1908, 350) referred to as the 'rude cisterns' from which the inhabitants collected their water when he was there between 1876 and 1880.

Ober also states that 'there are several caves, one of which is large enough to serve as a shelter for a band of lawless men, and was probably used by the wreckers when they plied here their nefarious calling'. This is likely to be Bat Hole, a cave some 25 m long and about 10 m above sea level at Gunshop Cliff on the east coast (Brasier and Donahue 1985).

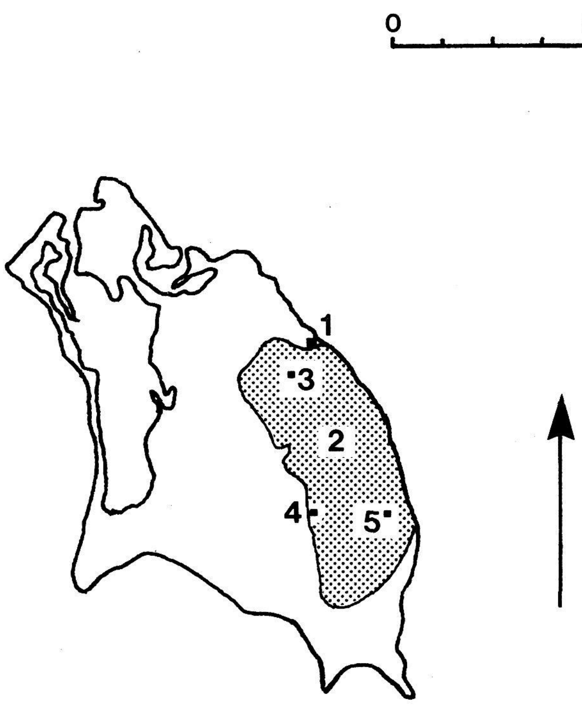

Fig. 17 - Barbuda
1. Bat Hole
2. The Highlands
3. Darby's Cave
4. other cave in 1813 survey
5. cave in later 19th century map

Sl. 17. Barbuda
1. Bat Hole
2. The Highlands
3. Darby's Cave
4. druge jame na načrtu iz 1813
5. jame na kasnejši karti iz 19. stoletja

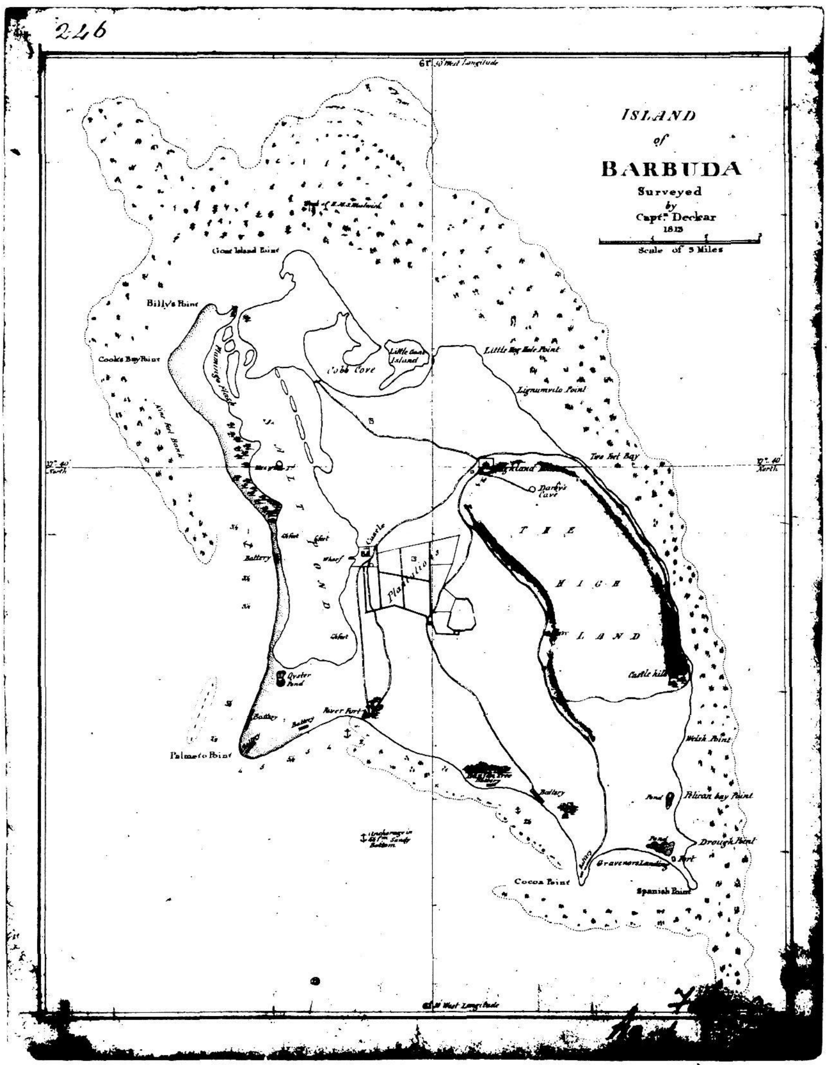

Fig. 18 - The original 1813 survey of Barbuda by Captain Deckar, Royal Navy, showing Darby's Cave and one other cave. (reproduced by courtesy of the Hydrographic Office, Royal Navy)

Sl. 18. Originalni načrt Barbude iz 1813 avtorja Captain Deckar, Royal Navy, prikazuje Darby's Cave in še eno jamo (reproducirano z dovoljenjem Hydrographic Office, Royal Navy)

CAICOS ISLANDS

Limestone caves exist in many of the Caicos Islands. Although the one best known to visitors today (Conch Bar Cave) is in Grand, or Middle, Caicos, it was those in the western and eastern islands that were noticed in earlier times. Their location is not known, so no map is provided.

First in date is the statement by J. N. Bellin (1773, 57), referring to the west coast of West Caicos:

> There are some caves, and good anchorage occurs opposite these pools and caves a quarter of a league [1 km] from Pointe de Nord Ouest.

Bellin's map confirms that the Pointe de Nord Ouest is indeed in the northwest corner of the island but it does not mark the caves. They are likely to be sea caves, either raised or still at sea level.

Even less precise is the remark of Daniel McKinnen (1804, 133):

> In a cave some sculls, I was informed, had been recently taken up, which on being touched, immediately mouldered to dust.

He does not say in which island the cave is, but it might be the one that Sharples later described as containing aboriginal drawings.

S. P. Sharples (1884) visited the guano caves of South Caicos about 1882 and his report is still cited in the standard publication on guano (Hutchinson, 1950). He writes:

> The main object of our visit, was not to see the Grand Turk, but an island to the west of it which is called Cape Comet, on the charts, but which is known locally as Breezy Point. This island lies about twenty miles to the west of the Grand Turk.
>
> ...
>
> The guano caves, which it was our special object to visit, are situated at the western end of the island on a beautiful bay, which is large enough to afford anchorage for vessels drawing nine or ten feet of water. The caves are in a low range of hills which form the principal elevation on the island. These hills are never very high: the principal one being about 150 feet in height, and is called by the negroes "Filamingo Hill", otherwise Flamingo, from a pond at its base where this bird is frequently seen. The hills in which the main deposits of guano have been found do not exceed fifty feet in height. These hills have been most thoroughly honey-combed by the action of the waves at a date that must be comparatively remote, since many of the caves are now half a mile or more inland. ... That they are true erosion caves, formed by the waves and not like the caves in our limestone stone valleys formed by under ground streams, is shown by their general character, and their great resemblance to the caves that are now being formed wherever the sea has access to a limestone bluff. ... In one of the largest of the caves the water still ebbs and flows, although it is at least a quarter of a mile from the shore. The caves are remarkable for the almost entire absence of stalactites and stalagmites although they may occasionally be seen. This is accounted for by the compactness of the roof and its thinness, for it rarely exceeds a few feet in thickness. Access to these caves as a general rule is obtained through openings in the roof, where the

> thin roof has broken away. Many of these openings are not over a foot in diameter, and seem in many instances to have been caused by the growth of roots through crevices of the rocks.
>
> At the largest entrance, where we made our first descent the opening is about ten feet across and is partially blocked up by the rocks from the roof;
>
> ...
>
> The opening in the first cave led into a large, roughly circular chamber which in former times had evidently been a place of considerable resort, as the walls were blackened in many places by smoke and the fireplaces and ashes were plainly to be seen. On the walls of this chamber are a number of rude drawings, which in most cases are evident attempts to imitate the human figure. In one of the branches of this cave the first explorers found two bowls and a chair. They were evidently of aboriginal manufacture, being similar to those described by the early visitors to this region as in use by the inhabitants, and they must have been in the cave upwards of three hundred years, since it is about that time since the Spaniards took the Indians to the happy hunting grounds and depopulated the islands.

The cave contained what Sharples regarded as fossil guano, without smell and almost free of recognizable remains:

> The entrance to the second cave that we visited was in a hillside. At this place we descended over broken rocks to the water level where we found distinct evidence of the ebb and flow of the tide, though the cave is at least half a mile from the shore. We entered a boat and were rowed into the cave for about a hundred yards, through a channel from fifteen to twenty feet wide. By burning magnesium wire from time to time we could get some idea of the size of the cave and could see passages opening off from it on either side. Near the end the cave made an abrupt turn and opened into a large vaulted chamber, about forty feet in height, and fifty feet in diameter; at the apex of the vault there was an opening which admitted the light, so that it was well illuminated. The entire floor of the chamber was covered to the depth of twenty-five feet above water level with guano. It was estimated that there were at least one thousand tons in this one heap. ... The enormous extent of these caves may be imagined from the fact that it is estimated that there is at least three hundred thousand tons of guano in them.

CAYMAN ISLANDS

Caves exist in all three of the Cayman Islands - Grand Cayman, Little Cayman and Cayman Brac. No mention of them has been traced before 1900 and even those in the first half of the 20th century are vague as to location. These references are reprinted here and are followed by discussion of the probable cave locations.

> There are a few caves [in Cayman Brac], but not large, and though stalactites and stalagmites are to be found they show to no advantage (Rutty, 1907, 67).
>
> All around the [Cayman] islands are vast fishing-grounds, and natural caves of great extent extend from the land under the sea. These were once the abodes of pirates and buccaneers... (Ober 1908, 195).
>
> The flat plateau [of Cayman Brac] is a waterless karst country in a rather advanced stage of development. Its rough rocky surface is corroded into fingerlike pinnacles and is cut up

> everywhere by hollows, cracks, and fissures. Sink-holes abound, some of them having the form of deep circular or elliptical well-like pits with vertical sides. Many caves must be hidden in the mass of the plateau, and I saw one on the surface which contained a fine assemblage of stalactites and columns. Although the plateau supports a dense growth of forest or 'bush', it is almost bereft of soil, as the insoluble residue of dissolved limestone and the decomposed vegetable matter are rapidly washed away into the fissures and sink-holes; (Mattley 1926, 359-360)

H. W. Rutty was a magistrate and Collector of Customs resident in the Cayman Islands so he had probably seen some of the caves. Although Frederick Ober had spent several years further south in the Caribbean, he was writing this part of his guide without personal knowledge. Dr Charles Mattley, on the other hand, devoted four days to geological field work in Cayman Brac in January 1924.

Rutty's sentence is about Cayman Brac, on which the 1979 1:50 000 Ordnance Survey map marks seven caves. Both Rutty and Mattley refer to stalactites and they may well have visited the same caves. Local knowledge of which caves are the most prominent or easy of access, or which show signs of much visiting, might suggest where these two authors had been.

Ober's pirate caves under the sea are unlikely to exist as such but there may be some real caves to which the undersea extension has been attributed (like cave routes supposed to be taken by hairless dogs in other lands). Ober does not indicate which island the caves are in but Aspinall (1954, 296) says 'Among the natural curiosities at Boddentown are a cave which extends for some hundreds of yards under the sea...' Boddentown is on the south coast of Grand Cayman but too far (6 km) from Bats Cave for the two caves to be confused. Both Ober and Aspinall may have heard the undersea story of the same cave.

THE GRENADINES

Caves not in limestone are rare in the Caribbean, and even less common is any mention of them before 1900. One such cave, a fissure cave, occurs in Battowia Island, one of the most northerly of the Grenadines and lying 16 km south of St. Vincent (Fig. 19).

Frederick Ober (b. 1849; d. 1913) was collecting birds in the Lesser Antilles for the Smithsonian Institution from 1876 to 1878 and it was probably in February of 1878 that he visited Battowia. His own account (Ober 1880, 220-222, 224), shorn of details of the party's breakfast and journey, is as follows:

> In the eastern cliffs was the cave which some of the Indians had occupied, and which we desired to explore. ...
>
> After a light lunch, we scattered down the cliffs in search of the cave. A whoop from one of our attendants drew us half-way down the precipice, where we were introduced to a deep fissure-like hole in the rock, hidden by trees. Crawling carefully over the loose rock, three hundred feet above the surf beating at the base of the cliff, we entered the cave and prepared to explore it. A glance showed that it was not large nor deep, and we soon found that it led in

only a hundred feet before the crevice grew so narrow that it could not be followed; but we were satisfied that it led down to the sea as we could distinctly hear the booming of the waves.

Along each side of the cavern were hollows, evidently artificial, begrimed with smoke, as though they had been used as fireplaces. We found no living things but bats and tarantulas; the former flew about in great numbers. While my companions were engaged in the farther end of the cave, I groped among the loose fragments of stone near the mouth, where, one of the men told me, an Indian chair had been found some fifteen years before. Carefully displacing the stone chippings, I at last found what seemed to be an image of stone; but scraping with a knife revealed that it was of wood. It was a tortoise, four inches long and two and one-half broad, curiously carved. Two holes, a quarter of an inch in diameter, are bored through back and breast; the back, upper part of the head, and the throat, are covered with incised figures, and the eyes carefully carved hollows, as if for the reception of some foreign substance.There is little doubt that this image once belonged to an Indian living many years

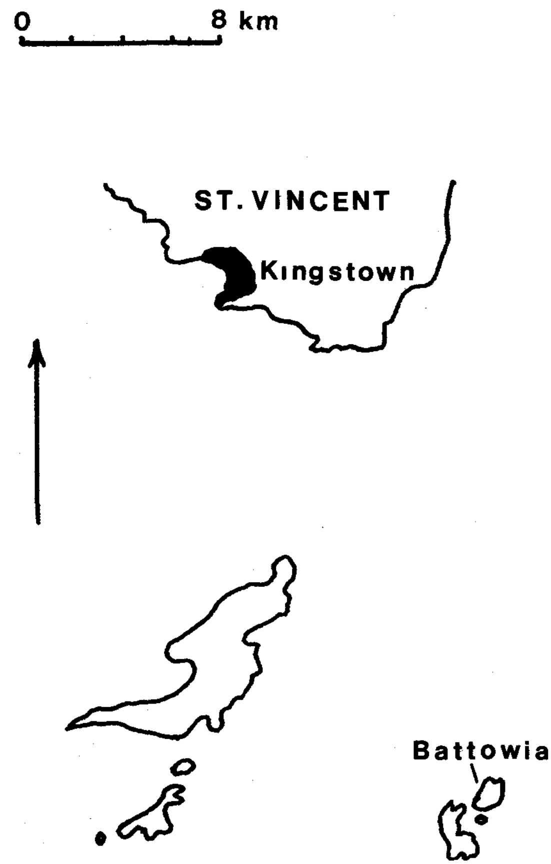

Fig. 19 - The northern Grenadines, showing Battowia in relation to St. Vincent
Sl. 19. Severni Grenadini, ki prikazujejo Battowio glede na St. Vincent

ago. Beneath the cave, a hundred feet farther down the cliff, was a grotto sparkling with lime crystals.

The exact location of the cave is not known but Ober's statements that it is in the eastern cliffs of an island only 1 km from north to south, accessible from the top of the cliffs and more than 30 m above the sea, narrows the area to be examined.

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ZGODOVINA JAMSKIH RAZISKAV NA TRINIDADU, JAMAJKI, BAHAMIH IN NA NEKATERIH DRUGIH KARIBSKIH OTOKIH

Povzetek

Večina jam na Trinidadu je v "Northern Range" (jurski apnenci) in v SZ delu otoka. Avtor je pregled raziskav razdelil po predmetu raziskav. Za speleološko literaturo Trinidada je najpomembnejši jamski ptič tolstičnik (guacharo, Steatornis caripensis) in tako je tudi najstarejša omemba jame na Trinidadu v vezana nanj (Latham 1823). Vsa najstarejša lieratura omenja jamo Huevos, iz katere je Hautessier prinesel tudi primerek živali, gnezda in jajca Akademiji v Parizu 1838. Ker so tolstičniki taka posebnost, so jame, v katerih živijo, omenjane tudi v prvih turističnih vodičih po otoku (Collens 1888). Eno izmed jam je obiskal tudi ameriški predsednik T. Roosevelt 1917. Razen za jamo Huevos, je obsežnejša starejša literatura še za jame Oropuche, jame v Aripu in v Arimi. V vseh živijo oziroma so živeli tolstičniki. Temeljno geološko delo o otoku, Geological Survey Memoir on Trinidad (Wall in Sawkins 1860) omenja tudi jame. Tako že slika 3 v tem delu prikazuje jamo iz okrožja Diego Martin. 1891 je bil ustanovljen Trinidad Field Naturalists' Club, katerega člani so se ukvarjali tudi z raziskavami netopirjev. Te raziskave so bile 1934 vključene v vladni program za zatiranje stekline. 1935 je zaradi nje umrlo 89 ljudi. V literaturi so tako omenjane številne jame, v katerih so preučevali oziroma lovili netopirje. Čeprav so bili člani omenjenega kluba tudi entomologi in drugi naravoslovci, so bila preučevanja ostale jamske favne pred letom 1950 zelo redka. Raziskovanje kraških jam na Trinidadu zaradi raziskovanja samega se je pričelo šele v 40-tih letih tega stoletja, ko je prišlo na otok večje število tujcev, pripadnikov naftnih družb in vojske. Ker je kras na Jamajki bolj opazen, kot na manjših otokih, in ima tudi reke ponikalnice, je bil tudi v literaturi omenjan bolj zgodaj. Najbolj znan je prvi opis izpod peresa H. Sloaneja (1707), ki je bil na otoku 15 mesecev kot guvernerjev zdravnik. Poleg ponikalnic omenja Sloane turi kraške izvire, stalaktite in soliter, ki so ga v jamah kopali Indijanci. Več potopisov in opisov iz 18. in 19. stol. omenja jame. Morda je najpomembnejši opisani dogodek spust samega guvernerja v 98 m globoko Hutchinson's Hole leta 1895. Tudi na Jamajki so prvi opisi jam vključeni v geološke okvire (De la Beche 1825; Geological Survey Memoir 1869). Zaradi tega so postale po vsem

svetu znane posebnosti krasa z Jamajke: "cockpits" in "light-holes", ki jih omenja tudi Cvijić (1893). Tudi v turističnih vodnikih s konca prejšnjega stoletja se pojavijo opisi kraških jam. Na Jamajki je prvi preučeval jamske netopirje Osburn 1858-1860, posebno pozornost pa je vzbujalo guano. Na prelomu stoletja so opravili 35 analiz, kot osnovo za izvoz guana v ZDA. Bahamsko otočje je s kraškega vidika znano predvsem po t.im. "blue-holes" - kraških breznih pod oziroma v nivoju morske gladine. Prve so omenjene v delu M. Catesbyja 1725, podrobneje opisane in locirane pa ob izdelavi Admiralitetnih pomorskih kart 1843 in 1844. Oblike in delovanje "modrih lukenj" je bolje pojasnjeno šele v novejšem času, ko so jih pričeli raziskovati potapljači z avtonomno potapljaško opremo. Kot na ostalih zahodnoindijskih otokih so tudi na Bahamih običajne kraške jame, ki so jih raziskovali predvsem v zvezi z netopirji in njihovim guanom. Tako naj bi že pred 1880 izvažali guano v ZDA za 20.000 USD letno. Tudi na manjših zahodnoindijskih otokih je razvit kras, ki je bil opisan v literaturi razmeroma zgodaj: na otoku Antigua 1749, na Caicosu 1773, na Barbudi 1813, na Grenadinih 1878 in na Caymanskih otokih v začetku 20. stol. Vendar v primeru teh otokov ne gre za krasoslovne ali podobne raziskave (guano), ampak za pojave in oblike, zarisane ali omenjane na pomorskih kartah, na zemljevidih ali v navodilih za pomorščake, čeprav je tudi na teh otokih kasneje postal pomemben vir dohodkov ravno guano jamskih netopirjev.

RECENT WORK ON THE CAVES OF TRINIDAD AND TOBAGO

NOVEJŠE PREUČEVANJE JAM NA TRINIDADU IN TOBAGU

JOHANNA P.E.C. DARLINGTON

Izvleček UDK 551.442 (729)
591.542 (729)

Darlington, Johanna P. E. C.: Novejše preučevanje jam na Trinidadu in Tobagu

Večina danes znanih jam na Trinidadu in Tobagu je bila odkritih do 1950, raziskane pa so bile predvsem v zadnjih treh desetletjih. Zaradi izbruha stekline je bila posebna pozornost posvečena preučevanju netopirjev, v zvezi z njimi pa tudi podzemeljskim jamam. V šestdesetih letih se je pojavilo vprašanje histoplasmose tudi v trinidadskih jamah. Po 1960 pa so pričenjali preučevati ptice tolstičnike (guacharo) iz znanstvenih in naravovarstvenih nagibov, kar je vzpodbudilo raziskave jam, med drugimi tudi deset let trajajočo ekološko študijo jamskega spleta Tamana.

Ključne besede: speleologija, regionalne raziskave, netopirji, histoplasmosa, tolstičnik, zgodovina raziskav; Amerika, Zahodna Indija, Trinidad in Tobago

Abstract UDC 551.442 (729)
591.542 (729)

Darlington, Johanna P. E. C.: Recent work on the caves of Trinidad and Tobago

By 1950 most of the Trinidad caves known today had already been discovered but the majority was explored in the last three decades. Due to an outbreak of paralytic rabies special atention was given to bats and thus, consequently, to cave exploration. In the 60s the problem of histoplasmosis appeared in the caves of Trinidad too. After 1960 the study of guacharos started mostly from scientific and natural conservation point of view arousing an interest for cave exploration, among others ten years lasting ecological study of Tamana cave system.

Key words: speleology, regional researches, bats, histoplasmosis, guacharo, history of explorations; America, West Indies, Trinidad and Tobago.

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INTRODUCTION

By 1950 most of the Trinidad caves known today had already been discovered. The process of exploration was far from continuous. Indeed a number of quite well-documented caves have become lost, as their locations have been forgotten.

No systematic list has ever been published. Pawson, a sport caver stationed at Piarco Airport in 1945-46, wrote descriptions of all the caves known to him, but his draft was never published in full (two short excerpts were published in 1974). Komisarcik (1979) made an independent attempt to list the better known caves, reaching a total of 21. This is far fewer than were listed by de Verteuil and Urich (1936) for one small part of the island, but they were counting any activity that contained a bat roost, whereas Komisarcik only included caves large enough for people to enter.

CAVE SURVEY AND EXPLORATION

In 1974 a student from the Jamaica campus of UWI was employed by the Ministry of Planning in Trinidad to survey the caves in the Lopinot Valley with a view to developing them for tourism. His report (Aquing 1974) included brief descriptions and good maps with sketch sections of all the five known caves. This is certainly the best survey so far published of any Trinidad caves, but is not readily available.

In 1978 four members of the Bloomington, Indiana Grotto of the National Speleological Society mounted their own small expedition to Trinidad (Komisarcik 1979; Wright 1979). They visited and made rough surveys of the Oropouche Cave, Caura Cave and the Tamana Caves, and drew up a list of other reputed caves in the island, but without quoting their sources (Komisarcik 1979). This was a very worthwhile effort (although some of the information was inaccurate) but these papers have remained largely unknown in Trinidad.

At around the same time the Trinidad and Tobago Field Naturalists' Club (T&T FNC) took an active interest in caves during their monthly field trips. They surveyed the Oropouche Cave and part of the Aripo Main Cave, and estimated the numbers of oil-birds in each (Quesnel 1976, 1978b).

The emergent river in the Oropouche Cave has stimulated much discussion and some field work. Stories are often told of ping-pong balls and other buoyant objects being thrown into the underground stream in Aripo Main Cave and later recovered from the Oropouche

River, but these may be apocryphal. In 1964 two scuba divers, Adam Richards and Victor Abraham, attempted to dive through the syphon at the head of Oropouche Cave but drowned about 200 m upstream from the pool. The rescue party reported that the roof of the channel was unstable, and one of the bodies was trapped by fallen rocks. No subsequent attempt has ever been made. Members of the T&T FNC have made several unsuccessful attempts to locate a sinkhole marked on an old survey map 2 km West of the cave (Quesnel 1978a, c) which might be one source of the water. The hydrology of this whole limestone area still remains to be explored.

In 1989 a cave was explored in the Aripo Valley of which no previous written record could be found, although it is clearly well known to local inhabitants. The cave contains a small colony of oilbirds. It was named the Soho Cave (Comeau 1991a) and a rough survey was made (still in manuscript). Another large cave nearby was explored by T&T FNC members in 1991 (Comeau 1991b). It fits the description given by Carricker (1931) of cave in which he narrowly escaped a dangerous fall. There are likely to be other new caves in this area, and also in another heavily forested area of limestone in the mountains north of Matura.

STUDIES ON BATS

An outbreak of paralytic rabies occurred in 1932 in Trinidad, affecting livestock and humans. The disease was found to be transmitted by vampire bats, *Desmodus r. rotundus*. This provided a tremendous stimulus to cave exploration in the island (eg de Verteuil and Urich 1936), and also to studies on bats in general, the viruses they carry, and their associated ectoparasites and bloodsuckers.

Taxonomic work on bats resulted in the publication of a monograph reporting 58 species to occur in Trinidad (Goodwin and Greenhall 1961). A more recent update lists 64 species (Carter et al. 1981). Much work has been done on the behaviour of vampire bats, and on methods to reduce their numbers (eg Greenhall 1968, 1970). Caves containing bat roosts were sought out, and in many cases the bats were needlessly destroyed where vampires formed only a small proportion of the bat population. It is now considered more efficient to catch the bats in mist nets when they approach livestock, or to poison them with a strychnine preparation painted onto the skin of the host (Greenhall 1970). Control of vampire bats remains the responsability of the Veterinary Department of the Ministry of Agriculture.

The feeding methods of the fishing bat *Noctilio leporinus* were studied by Griffin (1963). There have been several studies on reproduction in some cave-roosting bats (James 1977; Deoraj 1987) and on social behaviour and genetics in *Phyllostomus h. hastatus* in Guanapo Cave (McCracken and Bradbury 1977, 1981).

A number of viruses have been isolated from the blood of bats, other mammals, and birds by the Trinidad Regional Virus Laboratory (TRVL), now called the Caribbean Regional Epidemiology Centre (CAREC). The same organisation has done a lot of work on arthropod vectors, including cave-dwelling species (e.g. Wirth and Blanton 1971). No disease is known to have been spread directly from cave-dwelling invertebrates to humans,

although the potential exists. An example is the reduviid bugs *Panstrongylus geniculatus* in Tamana Dry Cave that were found to be infested with *Trypanosoma cruzi*, the causative organism of Chagas disease (Omah-Maharaj 1987).

HISTOPLASMOSIS

A different health problem associated with caves came to light in the 1960s. Histoplasmosis usually occurs as a lung disease resembling tuberculosis. The causative organism is a fungus *Histoplasma capsulatum*, which is commonly found in bird guano accumulated in communal roost sites or chicken houses, and also in guano deposits in bat caves. People who inhale the spores may suffer an accute form of infection called cave sickness or cave fever, which occasionally proves fatal. The fungus was found to occur in some Trinidad caves associated either with oilbird colonies or bat roosts (Ajello, Greenhall et al. 1962; Ajello, Snow et al. 1962). Retrospective diagnoses were later made of some previously unidentified illness associated with visits to the caves (Brown 1988).

OILBIRD COLONIES

Commercial interest in oilbirds as food waned in the earlier part of this century, but scientific interest has intensified, culminating in a detailed study by Snow (1961, 1962) on the small nesting colony in a river gorge that is variously called the Arima Gorge, Spring Hill Cave, Dunstans Cave, or the Asa Wright Cave. Snow (1962) also listed all known oilbird colonies in Trinidad, eight of them active and five extinct. The Spring Hill colony is monitored regularly, once a year since 1969 (National Audubon Society Christmas bird counts) and quarterly since 1987 (Elias, pers. comm.). Numbers of birds in the Oropouche Cave and the Aripo Main Cave are estimated from time to time by members of the T&T FNC on their field trips (Quesnel 1976, 1978b, 1985). The colonies in the sea caves have not been visited for many years, and the exact locations of some of them are now uncertain.

The species composition of the seeds regurgitated by the oilbirds (adults and young) in the cave at different times of year gave detailed information about the birds' food, and their role in dispersing plant seeds (Snow 1962). The plant debris thus brought into the cave, including seedlings that sprout from the regurgitated seeds where the cave floor is moist, provide the basis for a cave-dwelling biota of decomposer organisms and their grazers and predators, which has never been studied in detail.

CAVE ECOSYSTEM STUDIES

A combined project to study the bats, macrofauna and microbiota of the Tamana bat caves was planned in the late 1960s by Professor J.S. Kenny of the Zoology Department, University of the West Indies, Trinidad. In the event only the two latter topics were carried

out at that time, and even they had to be localised in different parts of the cave because of the small size and fragility of the cave ecosystem. Only part of this work has been published.

The Tamana Main Cave was mapped by J.S. Kenny and some of his students, omitting the deepest parts of the cave which still have not been explored. A brief description of the topography of the cave and an account of the atmospheric dynamics was published by Kenny (1978-79). A connection to the Tamana Dry Cave was explored in 1989 and the map extended (Fig. 1). Several new species of invertebrates were found in the caves, including a tineid moth (Davis 1972), a lygaeid bug (Scudder et al. 1967), a ptiliid beetle (Johnson 1969), a cetaropogonid fly (Wirth and Blanton 1971) and several other arthropods still to be described.

The study of the macrofauna showed that the Upper and Deep Parts of the main cave were occupied by analogous but different species, the Upper Part (and the Dry Cave) being more diverse that the hot, wet Deep Part where most of the bat roosts were located. The fauna in the Deep Part was dominated by a blaberine cockroach *Eublaberus posticus* which is a guano eater and general scavenger. The biomass and energy dynamics of this population were studied in detail, both in the cave and the laboratory (Darlington 1970).

The microbiota was studied in great detail in the Upper Part (Hill 1969). Compared with epigean soil the population densities were high (up to 19 times the highest previously recorded density for mites) but the number of species present was low. Guano of the fruit-eating bat *Phyllostomus h. hastatus* was decomposed initially through a bacteria-nematode food chain, and later through fungus-mite food chains. Insectivorous bat guano was eaten by a cockroach *Eublaberus distanti* and also attacked by a fungus *Penicillium janthinellum*, which was then grazed by mites. A summary of the results was published by Hill 1981.

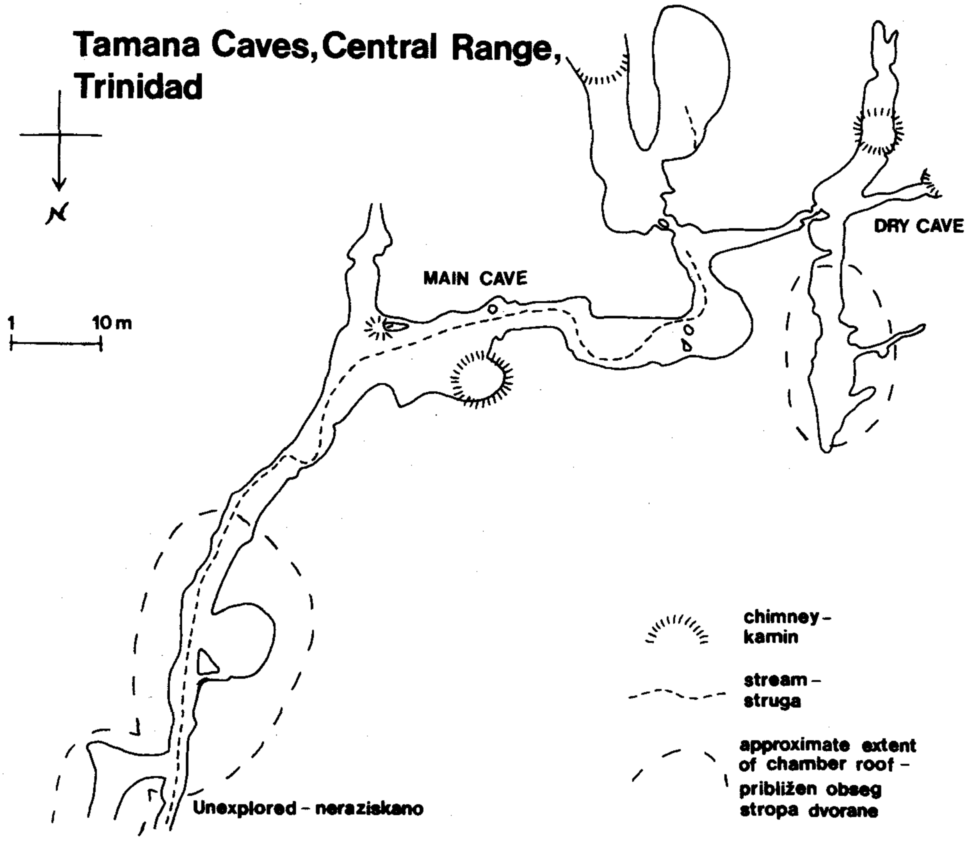
CAVES IN TOBAGO

Four small caves are known from near Crown Point in Tobago (Grady 1982). They were found to contain vertebrate fossils representing three distinct ages, and indicating changes in climate over the past 12.000 years (Eshelman et al. 1945).

WORK IN PROGRESS AND PROSPECT

Recreational visits to Trinidad caves continue, but a few people are more seriously interested in cave studies. T&T FNC members have been trying to re-locate some of the lost caves, and to improve the available information about the better known caves (Comeau 1991a, b). The Club has some basic caving equipment, but the level of caving experience among members is generally low.

A bibliography of all published information on caves in Trinidad and Tobago is available in draft (from the present author) but is not yet complete. An attempt is being made to


Tamana Caves, Central Range, Trinidad
N
1
10 m
MAIN CAVE
DRY CAVE
Unexplored - neraziskano
chimney - kamin
stream - struga
approximate extent of chamber roof - približen obseg stropa dvorane

trace all previous survey and sketch maps of the caves, although these vary greatly in quality. This will pinpoint which caves still need new or better survey work.

Specimens of cave animals have been collected over many years by overseas visitors. Some were subsequently identified or described (eg Haas 1962), while others remain unreported in collections. New material collected over the past few years is currently being studied. Results of a student project on flies in the Tamana Main Cave have been published (Jennings & Darlington 1990). A short paper on cave craneflies is in press (Darlington & Gelhaus 1993-4), and a monograph on phorid flies is in preparation (R.H.L. Disney). The gradual increase in available information makes cave studies increasingly attractive to students and research workers.

Table 1. Dimensions of some of the largest caves in Trinidad

Cave name	length	Source of information
Aripo Cave no. 1	853 m	Gunther 1940
"no. 2	152 m	"
"no. 3	305 m	"
Aripo Soho Cave	70 m	New survey, 1990
Oropouche Cave	214 m	G.M. & L.M.Miller, Jan. 1960
"	225 m	Quesnel 1976
"	215 m	Komisarcik 1979
Tamana Main Cave (incomplete survey)	130 m	+ J.S.Kenny, 1965
Tamana Dry Cave	50 m	New Survey, 1989

Tabela 1. Največje jame na Trinidadu

Ime jame	dolžina	Vir
Aripo Cave no. 1	853 m	Gunther 1940
"no. 2	152 m	"
"no. 3	305 m	"
Aripo Soho Cave	70 m	Nov načrt, 1990
Oropouche Cave	214 m	G.M. & L.M.Miller, Jan. 1960
"	225 m	Quesnel 1976
"	215 m	Komisarcik 1979
Tamana Main Cave (nepopoln načrt)	130 m	+ J.S.Kenny, 1965
Tamana Dry Cave	50 m	New Survey, 1989

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NOVEJŠE PREUČEVANJE JAM NA TRINIDADU IN TOBAGU

Povzetek

Večina danes znanih jam na Trinidadu in Tobagu je bila odkritih do 1950, vendar so slabo dokumentirane. Ta vrzel je bila v precejšnji meri zapolnjena v zadnjih treh desetletjih. Zaradi izbruha stekline je bila posebna pozornost posvečena preučevanju netopirjev, v zvezi z njimi pa tudi podzemeljskim jamam. Žal so bile uničene cele kolonije jamskih netopirjev, čeprav so vampirji - prenašalci bolezni, predstavljali le majhen delež take kolonije. V šestdesetih letih se je pojavilo vprašanje histoplasmose in izkazalo se je, da so tudi v nekaterih trinidadskih jamah, kjer so kolonije netopirjev ali ptic tolstičnikov (guacharo), glive - povzročiteljice te bolezni.

V zgodnjih letih tega stoletja so se ljudje zanimali za ptice tolstičnike predvsem kot vir prehrane, po 1960 pa so jih pričenjali preučevati iz znanstvenih in naravovarstvenih nagibov, kar je vzpodbudilo tudi raziskave jam, kjer so kolonije teh ptic.

Oddelek za biologijo Zahodnoindijske univerze v Trinidadu je izpeljal tudi deset let trajajočo ekološko študijo jamskega spleta Tamana, kar je dalo vrsto objavljenih študij o jamskih netopirjih, makro- in mikrofavni.

Avtor zaključi, da zanimanje za jame na Trinidadu in Tobagu raste, vedno več je zbranih podatkov in tudi vedno več zanimanja za nova preučevanja.

JAMAICAN CAVES AND CAVE EXPLORATION

JAME NA JAMAJKI IN NJIHOVO RAZISKOVANJE

ALAN G. FINCHAM

Izvleček UDK 551.44 (729)

Fincham, Alan G.: Jame na Jamajki in njihovo raziskovanje

Jamajka, otok v Velikih Antilih, meri več kot 11.000 km^2, dve tretjini sta zgrajeni iz zakraselega apnenca z največjo višino okoli 1.000 m n.m. Podatkov o raziskavah v 18. in 19. stoletju je malo, raziskovanje jam na otoku se razmahne po 1940, ko so začeli izkoriščati guano kot gnojilo. V zadnjem času pa se je spoznavanje jam in krasa na Jamajki poglobilo zaradi številnih "ekspedicij" iz Severne Amerike in Evrope. Jamarski klub Jamajka, osnovan 1958, je glavno središče za obiske tako jamarjev kot speleologov. Jamski kataster obsega več kot 1200 jam in verjetno so do sedaj raziskane večinoma vse večje in lažje dostopne jame. Največja do sedaj dosežena dolžina jame je 3.500 m oziroma globina 180 m. Speleološke raziskave na Jamajki so prispevale k svetovni geomorfološki, hidrološki, paleontološki, arheološki in biospeleološki literaturi. Čeprav je Jamajka gospodarsko odvisna od turizma, je do sedaj zelo malo urejenih turističnih jam. Porast prebivalstva in gospodarski pritiski na otoku bodo verjetno povečali ogroženost jam, zato priporočamo razvoj strategije za varstvo v sodelovanju zasebnih in državnih teles.

Ključne besede: regionalna speleologija, novejše raziskave, literatura, varstvo jam in krasa

Abstract UDC 551.44 (729)

Fincham, Alan G.: Jamaican Caves and Cave Exploration

The island of Jamaica in the Greater Antilles, has a land area in excess of 11,000km^2, two-thirds of which consists of cavernous limestones with a maximum elevation of about 1,000m a.s.l.. Records of explorations from the 18th and 19th centuries are few, but cave exploration in the island became more active in the 1940's when bat guano deposits were exploited as fertilizer. More recently, knowledge of Jamaican caves and karst has been enhanced by the activities of a series of "expedition" parties from both North America and Europe. The Jamaica Caving Club, formed in 1958, has acted as a focus for the work of both visiting cavers and speleologists. The present cave data-base contains records of over 1,200 sites and it is probable that most of the larger, more accessible caves have now been explored. The greatest mapped extent and depth for Jamaican caves are 3,500m and 180m, respectively. Jamaican speleological research has contributed to world geomorphological, hydrological, palaeontological, archaeological and bio-speleological literature. Although Jamaica is economically dependent on tourism, the organized development of "show-cave" sites has been minor. Existing population and economic pressures within the island are likely to increase cave-site endangerment, and the development of conservation strategies by the coordination of both private and government bodies is suggested.

Key words: regional speleology, recent explorations, literature, caves and karst protection

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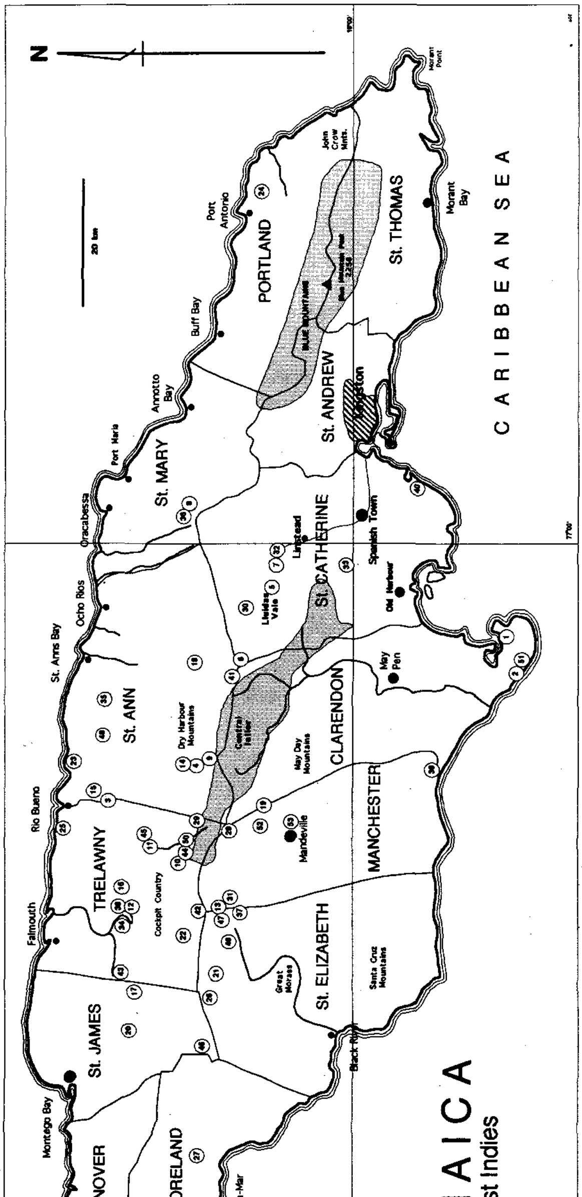
BACKGROUND

The associated article (Shaw T.R.,), provides an account of the karst literature of Jamaica covering the period from the Spanish invasion of the island (1509) to the outbreak of World War II in 1939. In this chapter, the author seeks to bring the reader an account of the more recent Jamaican karst literature and to provide an outline of the present status of Jamaican speleology.

THE TERRAIN

The island of Jamaica (Figure 1) has a land area of about 11,420km^2 of which almost exactly two-thirds of the surface rocks of are faulted limestones of Eocene to Miocene age (Robinson et al., 1977; Horsfield, 1974). Generally, the land is mountainous and much of the inland terrain is characterized by rugged areas of "Cockpit" and "Tower" karst with a local relief of over 100m, interspersed with poljes ("Glades" or "Bottoms"), making these regions difficult of access and of poor agricultural potential, apart from forestry and some subsistence farming within the glades.

The main exposure of non-carbonaceous rocks occurs in the Blue Mountain Range; a ridge of peaks of about 2,300m which comprises much of the eastern interior of the island. The principal cave-bearing formation is that of the White Limestone of Middle Eocene to Middle Miocene age within which many of the major caves of the interior are developed (Wadge & Draper, 1977c). Younger limestones comprise the coastal formations of the island (e.g. Portland Ridge and the Hellshire Hills) and also contain notable caves. Some limestones (e.g. The Newport Formation of the White Limestone) are over 1500m in thickness, but caves of a depth greater than about 250m have not been found (Wadge & Draper, 1977a). The hydrology of the island is dominated by a series of rivers which generally sink around the northern edges of the Central Inlier (Figure 1) feeding to risings associated with the E-W Duanvale fault system which is a dominant feature of the morphology of the central-northern Cockpit Country and the Dry Harbour Mountain region of the island. In many cases the underground drainage distribution has been determined through water-tracing studies and some sink-to-rising distances in excess of 20km have been established (Smart & Smith, 1976).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West Indies
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St. ANDREW
PORTLAND
St. THOMAS
Negril Point
Negril Hills
Lucea
Montego Bay
Savanna-La-Mar
Falmouth
Rio Bueno
St. Anns Bay
Ocho Rios
Oracabessa
Port Maria
Annotto Bay
Buff Bay
Port Antonio
Morant Bay
Morant Point
John Crow Mts.
Kingston
Spanish Town
Linstead
Lluidas Vale
Old Harbour
May Pen
Mandeville
Black River
Great Morass
Santa Cruz Mountains
Cockpit Country
Dry Harbour Mountains
May Day Mountains
Central Inlier
Blue Mountains

CAVE EXPLORATIONS; 1940 - 1990

(a) The Geological Survey Department: Although some early geologists and naturalists working in Jamaica (e.g. Gosse, 1851; Sawkins, 1869; de La Beche, 1827) commented on the occurrence of caves in various parts of the island, no detailed studies were made. The stimulus for a detailed investigation of the island's caves came about through the need for a local supply of fertilizer during the early years of World War II, when the Jamaican Geological Survey Department (GSD) embarked on an island-wide survey of caves for bat-guano as a possible solution to the fertilizer shortage. The initial project under this scheme included the survey of the well-known **Portland Ridge Caves** in south Clarendon where a guano mining operation was undertaken (Edwards, 1942).

In the forefront of this work was the late Mr. Brian R.G. McGrath, a "surveyor" to the GSD (Several other GSD employees also contributed to this work; most notably; B.V. Bailey and H.E. Edwards). In his field-books McGrath left notes on many caves throughout the island, recording the character and quantities of guano, together with topographic plans and sections of some of the larger, more accessible caves. While McGrath was employed to carry out this work, it is clear from his notes that he had a genuine caver's enthusiasm for

Key to Map Locations

1	Portland Ridge Caves.	2	Jackson's Bay Caves
3	Dunn's Hole	4	The Volcano
5	Worthy Park Caves	6	Pedro Cave and Pedro River sink.
7	Riverhead Cave; Black River.	8	Rock Spring Caverns, Dog Hole.
9	Cave River Sink.	10	Mouth River Sink.
11	Quashies River Sink	12	Windsor Great Cave.
13	Coffee River Cave.	14	Asuno Hole.
15	Dornock Head Rising.	16	Fontabelle Spring.
17	Peterkin and Rota Caves.	18	Hutchinson's Hole.
19	Cabbage Hall Caverns.	20	Mafoota River Caves.
21	Still Waters Cave.	22	Marta Tick Cave
23	Runaway Bay Caves.	24	Nonsuch Cave.
25	Braco Cave	26	Wondrous Cave
27	Roaring River Cave.	28	Gourie Cave.
29	Lowes River Sinks	30	Swansea Cave
31	Oxford Cave	32	St.Clair Cave
33	Mountain River Cave	34	Pantrepant Cave
35	Chesterfield Cave	36	Man Cave
37	Wallingford Cave	38	Long Mile Cave
39	God's Well	40	Two Sisters Cave
41	Blue River Sink	42	Hectors River Sinks
43	Deeside Risings	44	Printed Circuit, Mouth Maze
45	Bristol Cave	46	Me No Sen Cave
47	Golding River Cave	48	Thatchfield Great Cave
49	Falling Cave	50	Harties Caves
51	Lloyds Cave	52	Morgans Pond Hole
53	New Hall Cave		

this study and may be thought of as Jamaica's first caver. Despite this enthusiasm, McGrath was not generally equipped for vertical descents and usually terminated his exploration when low passages, deep water or vertical drops were encountered. Thus, in several cases, major cave extensions have since been made beyond points where McGrath's plans show closure. The Annual Reports of the GSD for 1954-57 include an item on; *"Topographic and Cave Surveys"*, and for 1954-55 the report notes that: *"... eleven caves were surveyed, eight in the parish of Clarendon and three in St. Catherine. One of the longest in the former parish is Long Pond Cave, situated east of Jackson's Bay, Portland Ridge. The length is nearly 400ft., with several offshoots on either side; it has an abundance of stalactites and stalagmites, with beautiful curtains. There are, however, no phosphates in this cave."* (Zans, 1957).

If McGrath was the first caver, the then Director of the GSD, Dr. V.A. Zans, may be credited as the first speleologist. Zans appears to have directed much of McGrath's earlier work and contributed some of the first detailed studies of Jamaican caves, for example, in his paper; *"The Geology of the Mosely Hall Cave"*, (Zans, 1953). (See also: Zans, 1951; 1954; 1958; 1959). McGrath also contributed to the literature with his account; *"A Descent into Dunn's Hole Sink"* (McGrath, 1958) being the most noteworthy in that this assault on the 230m deep sinkhole was made using cable ladders and in collaboration with a visiting part of cavers from the US National Speleological Society (NSS), (White and Dunn, 1962).

In addition to the cave surveys, the concerns of the GSD also centered around the hydrology of the island. In 1955, Dr. Majorie Sweeting, a karst geomorphologist from Britain, conducted a two month programme of hydrological studies in collaboration with the GSD. (Dr. Sweeting was assisted by Brian McGrath in the field work involved.) These studies culminated with the publication of a report; *"Hydrogeological Observations in Parts of the White Limestone Areas in Jamaica, B.W.I."* (Sweeting, 1956) which was to prove seminal for future work on the karst hydrology of the island, and together with additional publications (Sweeting, 1957; 1958), stimulated a wider interest in Jamaican karst and caves.

(b) The Jamaica Caving Club: The creation of the University College of the West Indies (now the *University of the West Indies*) in 1948, brought to the region, for the first time, an institution of higher education which sought to attract academics in a wide range of disciplines, including the sciences. The *Jamaica Caving Club* (JCC), formed in 1958 by a group of cavers (initially headed by Dr. Allan Cunningham, a mountaineer), was centered at the University. Under the leadership of Dr. Ronald Read, Professor of Mathematics, the club became a focus for visiting cavers and associated academics. The Caving Club's membership was drawn from the University staff and students, together with other interested individuals (principally professionals working for Jamaican Government bodies). The Club organized a programme of week-end "expeditions" during which many of the caves more accessible from the University in Kingston were explored. Curiously, at this time, little interest was shown in preparing detailed records of these explorations, or mapping the caves. Rather, "caving" was seen by most members, solely as a recreational activity. The

then existing cave records and surveys, accumulated by McGrath and his associates at the Geological Survey Department appear to have been largely unknown to the Caving Club group. Many of the original McGrath cave surveys were only discovered by the author in 1976, in the records of the Geological Survey Department , during his research for *Jamaica Underground*; (Fincham, 1977). Nevertheless, the early days of the Caving Club were embellished by several major discoveries. In 1958, entry was gained to the underground course of the Coffee River near Auchtembeddie in Manchester, and a spectacular river passage followed upstream through several boulder-falls for over 2700m. The rocks of the underground river bed were found to be eroded into contorted solutional razor-edged forms, later to be described by Aley (1964), as *echinoliths*. In 1964 the Club visited some caves reported at Jackson's Bay, on the southern side of Portland Ridge in Clarendon. This site had previously been visited by McGrath in 1955, and recorded as *Olive Park Caves*. Partial surveys of areas around Entrances #1 and #3 were subsequently found in the fieldbooks (Fincham, 1977). Initial explorations at this site extended over a period of three years, culminating in the publication of a plan of the **Jackson's Bay Cave** in 1966. In 1969 the author, a biochemist and caver from Britain, was recruited to the Faculty of the UWI and had the opportunity to work with the Caving Club until leaving the island in 1985. During this period a computerized data-base for recording of the caves of the island was developed leading to the publication of *Jamaica Underground* (Fincham,1977) which sought, for the first time, to provide a comprehensive listing and description of the known caves, then numbering some 960 sites. The initial data-base for *Jamaica Underground* was prepared using punch-cards and processed on an IBM 1620 main-frame computer. The final output for publication came from the University IBM-360 System using a line-printer, unfortunately without any lower case character capability! Since its establishment in 1956 the Jamaica Caving Club has provided both a local outlet for recreational caving activities and a nexus for Jamaican cave studies. The organization and membership of the Club has fluctuated greatly with the availability of individuals with caving experience. The current Club organizers can usually be reached through the Departments of Geology/Geography, at the University of the West Indies, Mona, Kingston 7.

(c) The Expeditions: In addition to the explorations undertaken by JCC and GSD personnel, knowledge of the island's caves has been greatly enhanced by a series of caving *expeditions*. Most of these visiting cavers originated in the United Kingdom (Leeds University Expedition, 1963; Karst Hydrology Expedition, 1965-66; Bristol University, 1967, 1969 and Liverpool University, 1977) The earliest such visit was made by a party from the U.S. National Speleological Society (NSS) in 1958 and the NSS was again the sponsor for the series of *Jamaica Cockpits Project* expeditions of 1985-1988. Frequently, these visitors have been responsible for major explorations, particularly of some of the deeper sections of caves and sinkholes where their superior experience and equipment has proved valuable. The background and achievements of each of these expeditions is briefly summarized below:-

The NSS Expedition (1958): This appears to have been the first visit to the island by

an organized party of cavers, and was made in collaboration with the GSD. The most notable contribution of this expedition was the exploration of the 230m deep pit (**Dunn's Hole**) near Stewart Town in Trelawny, being perhaps the first exploration of a deep, vertical cave ("sinkhole") in the island. In addition to this descent the party also visited **Windsor Cave** and several hitherto unrecorded sites on the south coast (White & Dunn, 1962; White, 1962).

Probably the first descent of a sinkhole in Jamaica was that made by Sir Henry Blake, (then Govenor of Jamaica) who, in July 1895, was lowered to the floor of the 80m deep **Hutchinson's Hole** in St. Ann (Ashcroft, 1976). Governor Blake's interest was to seek the remains of persons reputedly flung into the pit by a notorious local murderer; Lewis Hutchinson! (Marshall, 1963; see also; Gascoyne, 1975).

Leeds University Expedition (1963): The Leeds expedition was stimulated in part by the enthusiasm and advice given by Dr. Majorie M. Sweeting. The nine-member party spent six weeks in the island and focussed their activities on the Lluidas Vale polje in northern St. Catherine (Fig. 1). The group made explorations and surveys of 26 caves and sinkholes in and around this area (6,100m mapped), including the complex **Worthy Park Sink** caves, and the **Pedro Great Cave** (Fincham & Ashton, 1967). Hydrological studies included a tracing test (19kg of fluorescein) of the Rio Pedro sink, without result! Also, a series of discharge and water analyses were made at the **Riverhead Cave Rising**, which subsequently stimulated a theoretical treatment of the properties of karst drainage systems (Ashton, 1966). Outside of the Lluidas Vale area, the party explored and mapped the 2,600m **Rock Spring Caverns** and the associated **Dog Hole** system. On reflection, the 1963 expedition was ambitious for its time and perhaps a harbinger of the host of international caving expeditions which have today become almost commonplace.

Karst Hydrology Expedition (1965-66): Originally, this party had planned a visit to Puerto Rico, but after discussion with the members of the 1963 Leeds party, they decided instead on Jamaica. This five-man British-Canadian expedition spent a total of 8 months in the island and explored and mapped over 29,000m of cave passages, much being new exploration! (Livesey, 1966). Much of their work was focussed on new explorations of the Cave River, Mouth River and Quashies River systems, although surveys were also made of the previously explored **Winsor Great Cave** and **Coffee River Cave**. The first exploration of the waterfall shafts of the **Quashies River Cave** and the 116m free cable ladder descent of the **Asuno Hole** are both "classic" exploration accounts (Livesy, 1966; Boon, 1977). In addition to their exploration and mapping, the party conducted a major series of water traces, using both dyestuffs and lycopodium spores. The drainage of the Cave River and Quashies Rivers to the **Dornock Head Rising** (the source of the Rio Bueno) and the Mouth River to **Fontabelle Spring** drainage were established for the first time (Brown & Ford, 1968).

Bristol University Expeditions (1967, 1969): The 1967 party comprised 12 members and focussed their work on the area around Maldon and Maroon Town in St. James. An

extensive and ambitious programme of water tracing, karst hydrology and geomorphology was undertaken, together with the exploration and mapping (~6,700m) of the caves of the area (Smith et al, 1969a). In the cave exploration category, the party made a detailed study of the underground course of the **Tangle River**, from its sinks near **Peterkin Cave**, through **Rota Cave** and **Rota Sink** and at its eventual rising at Deeside some 6km distant. The intermediate course of this river, remains one of the more tantalizing problems of Jamaican cave exploration. During 1969, some cavers from the 1967 group returned to Jamaica and made significant explorations in some other areas of the island, notably of the 1,600m long complex at **Cabbage Hall**, in Clarendon and the **Mafoota River** system in St. James.

Liverpool University Expedition (1977): This five man party spent six weeks in the island based in the Troy area of Trelawny. The major cave exploration was the discovery and survey of the complex and partially flooded **Still Waters Cave** (3350m), near Accompong (McFarlane, 1980). A geomorphological study was made of karren relief in selected areas differing in average rainfall, and a survey of some bat-cave sites was also conducted.

NSS Jamaica Cockpit Project (1985-1988): In 1985 a party of nine cavers from the US initiated a project (The NSS Jamaica Cockpits Project) to explore the karst and sinkholes of the interior of the little-known Cockpit Country region. The party was based at Quick Step, in Trelawny on the southern fringe of the area and was assisted by local guides and JCC members. The 1985 party explored 22 pits and caves and completed the mapping and exploration of the 1750m long **Marta Tick Cave** (Baker et al., 1986). Further expeditions to this, and adjacent areas, were made in 1986 and 1987 (Baker, 1987). Over 20 additional sinkholes were explored, many of 70-80m in depth, but significant lateral development was generally lacking (Canter, 1987). In 1988 an NSS party again visited the island and made some explorations into the difficult terrain of the John Crow Mountains in the east of the island. This highly fissured range of limestone hills rises to about 1,000m and gives rise to numerous streams and rivers on its eastern flanks. However, no significant caves were located.

COMMERCE AND CONSERVATION

The arrival of the Spanish in Jamaica in 1509 opened a period of some 300 years of colonial rule of the island, with the Spanish control being supplanted by the British in 1655. Sugar became the basis of commerce, and the labour was provided through the importation of Africans as slaves for work on the European owned and controlled sugar plantations which expanded to occupy most of the arable level areas of the land (Williams, 1970). Frequently these cane-field areas are closely surrounded by regions of tower karst containing obvious caves in their fringing cliffs. Many such caves house substantial bat populations and probably then, as today, the bat guano provided a source of fertilizer for the small farmer. Whether such guano deposits were exploited by the plantation owners or their slaves for fertilizing vegetable plots is not recorded, but appears likely. Nevertheless, Ja-

maican folk traditions frequently associate caves with "duppies" (ghosts) and such strongly held superstitions may have inhibited the widespread exploration of caves by local people. Long (1774) in his "History of Jamaica", provides a description of the masonry dams and sluices installed within the **Riverhead Cave**, St Catherine, which were employed to provide water to an indigo washing facility operated close to the cave entrance and beside the usually dry bed of the Black River (See; Shaw, p. **39**). Although caves abound throughout the island, it is surprising that references to them in the writings of the 17th and 18th century are sparse.

In more recent times caves which contain bat guano deposits (Cousins, 1903) have been worked by local farmers for fertilizer and a few other caves have been exploited as water supplies (possibly of dubious quality) and as local tourist attractions. This latter activity has been sporadic in the past, with several caves being "shown" to passing travellers by local persons (e.g., the **Windsor Great Cave** in Trelawny). Some sites, notably the **Runaway Bay Caves** ("Green Grotto") appear to have been active, if not commercial, tourist attractions since the mid to late eighteenth century (Zans, 1960). More recently, the **Athenry Estate Caves** in Portland have been developed under the name of **Nonsuch Caves** as a show cave site. At the present time, caves in the island have not been developed as tourist attractions through government sponsored agencies, although some minor sites are now being exploited by local entrepreneurs (e.g., the **Braco Cave** in Trelawny, which attracts passers by under the title of "Arawak Cave".) These caves are certainly not amongst the more spectacular to be found in Jamaica, but many of the other suitable caves are commonly difficult of access (e.g., **Wondrous Cave**, St. Elizabeth) or are located well away from the more usual tourist areas and have not been "developed" for visitors (Frank, 1973). However the, **Roaring River Cave** in Westmoreland has apparently recently been opened as a tourist site.

Possibly, Jamaica, relying heavily on its income from tourism, needs to look more closely at the potential value of developing show caves as alternative tourist attractions and could take example from **Harrison's Cave** in central Barbados, a model show cave development pioneered by the Barbados government "Caves Authority". While the development costs may be high, once such a project is completed the site becomes a permanent national resource and, in certain cases, such "development" has proved to be an effective way of promoting cave conservation, although in the hands of the inexperienced developer, such commercialization can become a refined form of vandalism.

In the future, it is likely that conflicts between cave conservation and industrial and urban developments (water supply, waste disposal, quarrying, commercialization, mining etc.) will become increasingly important. Such problems are evident in the continuing urban development of Hellshire Bay ("Kingston's Twin City") on the honeycomb limestones of the east Hellshire Hills in St. Catherine. Industrial and urban impacts on karst water supplies in the more rural areas have been documented. Sugar industry waste has been implicated in serious water pollution problems at Black River in St. Elizabeth (Wright, 1972); Bog Walk in St. Catherine (Fincham & Ashton, 1967); Wakefield in Trelawny (Fincham, unpublished observations). Contamination of a local water supply at Maldon in St. James was noted by Tratman (1969).

While much has been accomplished in the recording and study of the caves of Jamaica together with their associated hydrology, geomorphology, archaeology and biology, much remains incomplete or unexplored. Public awareness and planning in the evaluation and control of incipient karst-related environmental problems requires strengthening. An integration of the Caving Club expertise and knowledge within existing national structures (The National Trust, the UWI and the Department of Mines and Geology), will be needed if these complex matters are to be wisely addressed.

JAMAICAN SPELEOLOGY

(a) Organization: The development of speleological studies in Jamaica is immature. There is presently no *Caves Authority* or other government-sponsored, or academic speleological organization in the island to represent caving and conservation interests, despite the very large number of caves and their actual or potential impact on the community. (However, the Jamaican National Trust has recently proposed the establishment of a number of National Park areas which would include parts of the Cockpit Country and also Portland Ridge. The Trust has also shown active interest in the conservation of cave sites). It is perhaps notable that, notwithstanding the extensive limestone areas of Jamaica, the UWI Departments of Geology and Geography have generally failed to develop karst studies as a major theme for research. While the Jamaica Caving Club, has experienced the periodic fluctuations in support and membership which are common to clubs of this type, it nevertheless has served as a focus for caving in the island and, in particular, the club has worked closely with the several groups of visiting cavers and speleologists who collectively have done much to develop the existing knowledge of the island's caves.

(b) Karst morphology studies: Accounts of Jamaican caves and their associated karst landforms are few. The pioneer hydrogeological and geomorphological studies of Jamaican karst areas (Sweeting, 1956; 1957; 1958) have served to establish the Jamaican Cockpit Country as a "type area" in tropical karst geomorphology. Versey (1959) provided a general review of the Jamaican karst and during the early 1960's, Aub (1969a,b) made detailed studies of a sinkhole karst area in northern Clarendon, although much of this latter study remains unpublished. Day (1976), and Brook & Hanson (1986) studied the morphology and hydrology of karst depressions in St. Ann, and each of the expedition groups have contributed to such studies (Drew, 1969; Smith, 1969b; Smith et al, 1972; Brown & Ford, 1973). Wadge & Draper (1977a,b) made some preliminary observations on tectonic and lithological factors in Jamaican speleogenesis and a detailed structural study of the caves of the Jacksons Bay area (Figure 2) of Clarendon was published in 1979 (Wadge et al., 1979).

(c) Hydrology: In the area of hydrology, Jamaica has provided an important proving ground for the development of water-tracing techniques suitable for tropical karst, with most of the visiting parties making their contributions (e.g., Ashton, 1966; Atkinson et al., 1973; Smart and Smith, 1976). In particular, these studies served to highlight technical

problems in the use of fluorescent dyestuffs under tropical conditions. Today, the broad picture of drainage patterns in the Jamaican karst is well established, although a few major systems (e.g., **Gourie Cave** in Manchester and **Lowes River Sinks** in St. Ann) await detailed study. The principal Jamaican karst drainage systems established by water tracing techniques are listed in Table 1.

Table 1
Jamaican Karst Drainage Tests

Sinks	Rising(s)	Distance (km)	Test Method*	Reference
Blue River	Pear Tree Bottom	27	R	Smart & Smith,(1976)
"	Laughlands Great River	20	R	Smart & Smith,(1976)
"	Roaring River	25	R	Smart & Smith,(1976)
Browns Town area	Pear Tree Bottom	3-5	F & R	Day, (1976)
Cave River	Dornock Head	21	L	Brown et al.,(1973)
Hectors River	Coffee River	4	F	Liversey, (1966)
Maroon Town area	Deeside Risings		L	Drew, (1969)
Mouth River	Fontabelle Spring	11	L	Brown et al.,(1973)
Nassau Valley area	Elim & Bogue Springs	2-6	L	Drew, (1969)
Quashies River	Dornock Head	14	L	Brown et al.,(1973)
Worthy Park	Black River	14	P	Smart & Smith,(1976)

* F: Fluorescein. L: Lycopodium spores. P: Photine CU. Conc. R: Rhodamine.

(d) Biospeleology: Studies of cave biology in Jamaica have shown the island to have several interesting endemic cave dwellers (Peck, 1975a), including crabs and crayfish (Hartnoll, 1964a,b), bats (Goodwin, 1970; McFarlane, 1986) and a species of the Onychophorian; *Peripatus* known only from a single cave site (Peck, 1975b). Other records of cave invertebrate collections include those of Bowman (1976); Darlington (1964); Holsinger (1974); Muchmore (1984); Peck (1972); Rambla (1969) and Stock (1983).

Currently, some 15 species of cave-dwelling bats have been recorded from Jamaica (McFarlane 1986), with the large colonies present in the **Swansea, Oxford, Windsor** and **St. Clair** caves being the principal focus of collections. St. Clairs' "Inferno Passage" bat population has been a frequent source of specimens for collectors from North America. While current cave bat populations do not appear threatened, McFarlane (1986) casts a note of warning in suggesting that; *"Legislation to protect some of the more important caves .... would serve to focus official attention and monitoring on these sites, ... "*. Existing records of Jamaican cave bat species and populations are limited and a wider-ranging survey, which would permit an assessment of environmental stresses, is needed.

A topic related to the exploration of guano caves is that of histoplasmosis (Frankland, 1974). Although this fungal infection is well known from caves in Puerto Rico (Zamora, 1977); prior to 1978 no clinical case of the disease had been recorded from Jamaica. In January of that year, 24 cases of pulmonary histoplasmosis were diagnosed in a single party of 27 persons exploring the **St. Clair Cave** (Fincham, 1978). Subsequent studies of histoplasmin sensitivity amongst a group of *cavers* and *non-cavers* resident in the island,

showed that *Histoplasma* exposure appeared to be restricted ***solely to the cavers*** (Fincham & DeCeulaer, 1980). These observations have lead to the proposition (Fincham, 1978), that contraction of histoplasmosis by cavers was as likely to occur through exposure in wet tropical bat caves as in the dry dusty sites typically referenced in the medical (and caving) literature (Washburn et al, 1948, Frankland, 1974).

ARCHAEOLOGY - PALAEONTOLOGY

Caves occur throughout the limestone areas of the island and some have certainly been utilized by man since the earliest settlement of the island. Explorations of the coastal caves at **Jacksons Bay** in south Clarendon have consistently revealed Amerindian (Arawak) pottery shards and bones, suggesting the use of the caves for burial rites and, possibly for domestic purposes; collection of water, shelter etc. (Miller, 1932).

The **Jacksons Bay Caves**, together with other sites, also contain Arawak Indian petroglyphs carved into stalagmites in some entrance areas. However, "cave art" other than such rock carvings, is uncommon in Jamaican caves with the **Mountain River Cave** rock shelter at Guanaboa Vale in St. Catherine (now protected and managed by the Jamaica National Trust) being the only known site of Arawak Indian rock paintings in the island. A close examination of the inner chambers and passages of caves, such as those at Jackson's Bay, has failed to provide evidence for Amerindian cave paintings (Fincham, unpublished observations) and it appears that these people used only the entrance chamber areas. The lack of paintings within the caves is somewhat remarkable, since such work is not uncommon in the inner chambers of caves in both Cuba and Hispaniola (Jimenez, 1975). While most of the Amerindian cave sites appear to be coastally located, some notable petroglyphs occur in inland caves, for example at **Pantrepant Cave** in Trelawny, **Chesterfield Cave** in St. Ann and at **Man Cave** in St. Mary.

In most cases of presumed cave use by Jamaican Amerindian people we have no reliable chronological data from which we can determine when these sites were in use. An exception to this has been some recent carbon dating of bone recovered from the **Jackson's Bay** area (McFarlane, 1989; personal communication). A human bone fragment provided a ^{14}C date of 710 BP ±60 This date is of special interest when taken together with the dating of a marine shell (795 BP ± 70) excavated from below a 2m deep deposit of fossil bat guano in an entrance chamber of the Jackson's Bay Cave, and of the presence of Arawak pottery shards associated with (now dry) cave pools. The Jackson's Bay area today receives an average annual rainfall of less than 40 cm and the existing cave-dwelling bat populations are sparse, reflecting the arid nature of this region. It appears likely that the accumulation of the guano deposits (noted above) may reflect a period of higher rainfall contemporaneous with Amerindian use of the caves for water collection and burial, if not for habitation. That some caves were used as ritual burial sites by the Arawaks appears probable from the recovery of a human radius and ulna, associated with a chared pottery shards and the presence of fragments of cassava griddles and of Amerindian skulls in some of the Jackson's Bay area caves.

The principal international motivations and interest in palaeontological research in Jamaica have come from earlier studies of the extinct rodents and the unique primate remains (*Xerothrix*). Cave-related research in Jamaica has focussed principally on the fossil finds of Anthony (1920, 1924), at the **Wallingford Cave** sites in St. Catherine (Koopman & Williams, 1951; Williams & Koopman, 1952), and McFarlane & Gledhill, (1985) have recently reviewed these data. Other recent reports include those of MacPhee et al., (1983); studies at **Long Mile Cave,** Trelawny, MacPhee (1984); Ford (1984); Goodfriend & Mittener, (1987); Ford & Morgan (1988) and MacPhee et al, (1989).

JAMAICAN CAVE EXPLORATION

(a) Current status: It is probable that most of the major river-cave systems of the island *have now been identified and at least partially explored, although there are numerous smaller* caves and sinkholes which still require detailed investigation and survey. The most extensive caves are found around the Central Inlier (Figure 1) where they are associated with the major drainage systems. The numerous vertical shafts ("Sinkholes") which occur throughout the Cockpit Country and Dry Harbour Mountain areas, commonly bottom-out in narrow joints or debris chokes with little lateral development (Canter, 1977). In the southern coastal areas, large horizontal caves such as are found in Portland Ridge, show ancient solutional features suggesting the influence of sea level changes (Wadge et al, 1979).

(b) Documentation: Documentation of the caves is a continuing activity, and while a listing of over 950 sites was originally published (Fincham; 1977), the existing data-base includes over 1200 sites. This *Jamaica Underground* data base (Macintosh, Filemaker II_) is maintained by the author and cavers making new discoveries in the island are urged to provide details for updating of the files.

A listing of the currently longest and deepest caves in the island is provided in Tables 2 & 3. It must be noted here, that in the case of "longest" the data are based on surveys which vary greatly in their detail. Thus, for example, the recent survey of **Marta Tick Cave** (Baker et al, 1986) by an NSS party is a model of thoroughness and records a length of 750m, whereas the 3,350m length recorded for the **Jacksons's Bay Cave** complex, based on the 1963-65 survey by the JCC, almost certainly excludes substantial lengths of minor passages. General accounts of Jamaican caves include those of, Peck & Kukal (1975) and Waltham & Smart (1975).

Table 2
Jamaican Caves over 1000 m in Surveyed Length.

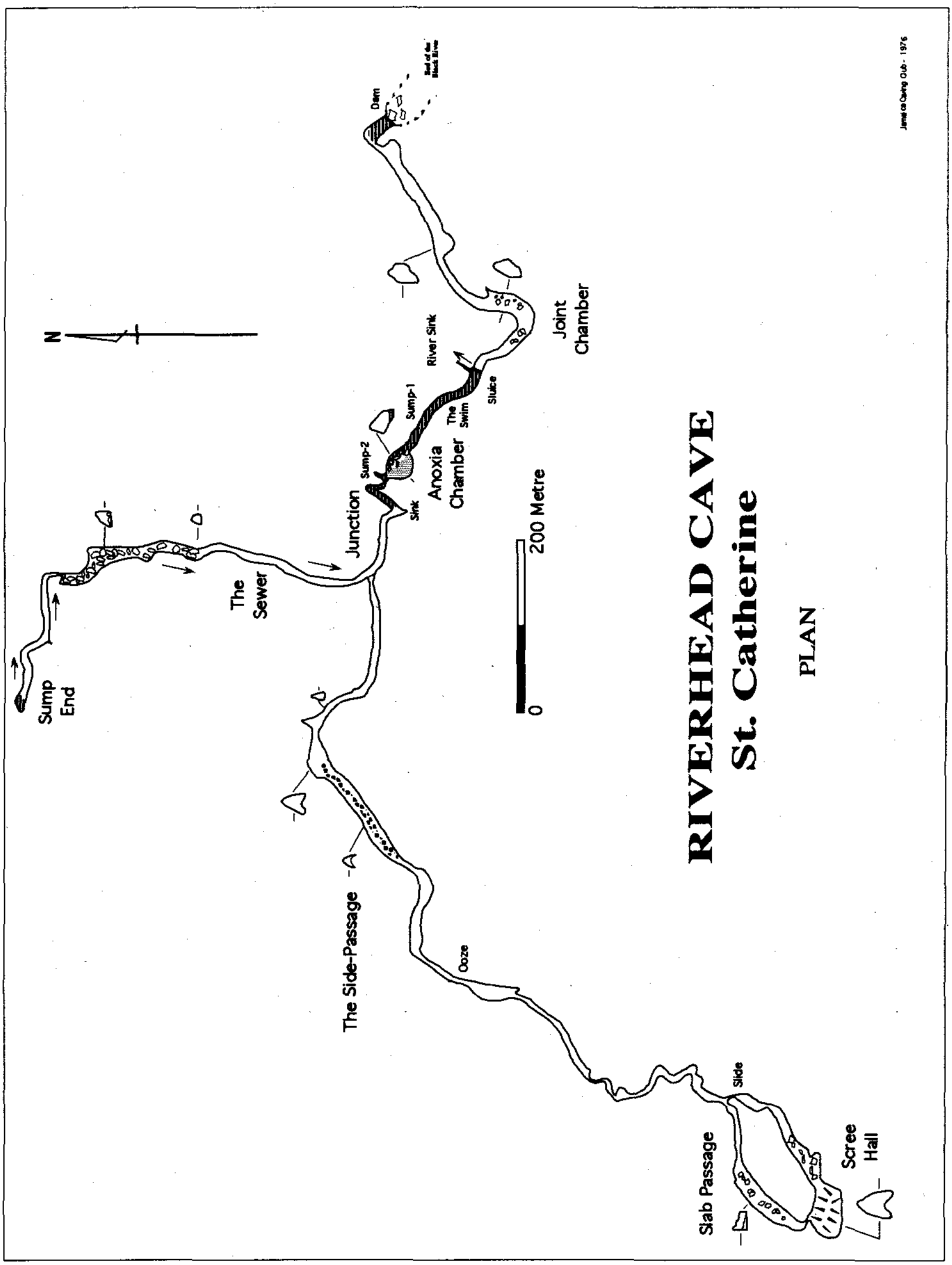
Cave	**Parish**	**Length m.**
GOURIE CAVE	Manchester	3505
JACKSON'S BAY CAVE	Clarendon	3353
STILL WATERS CAVE	St. Elizabeth	3353
PRINTED CIRCUIT CAVE	Trelawny	3219

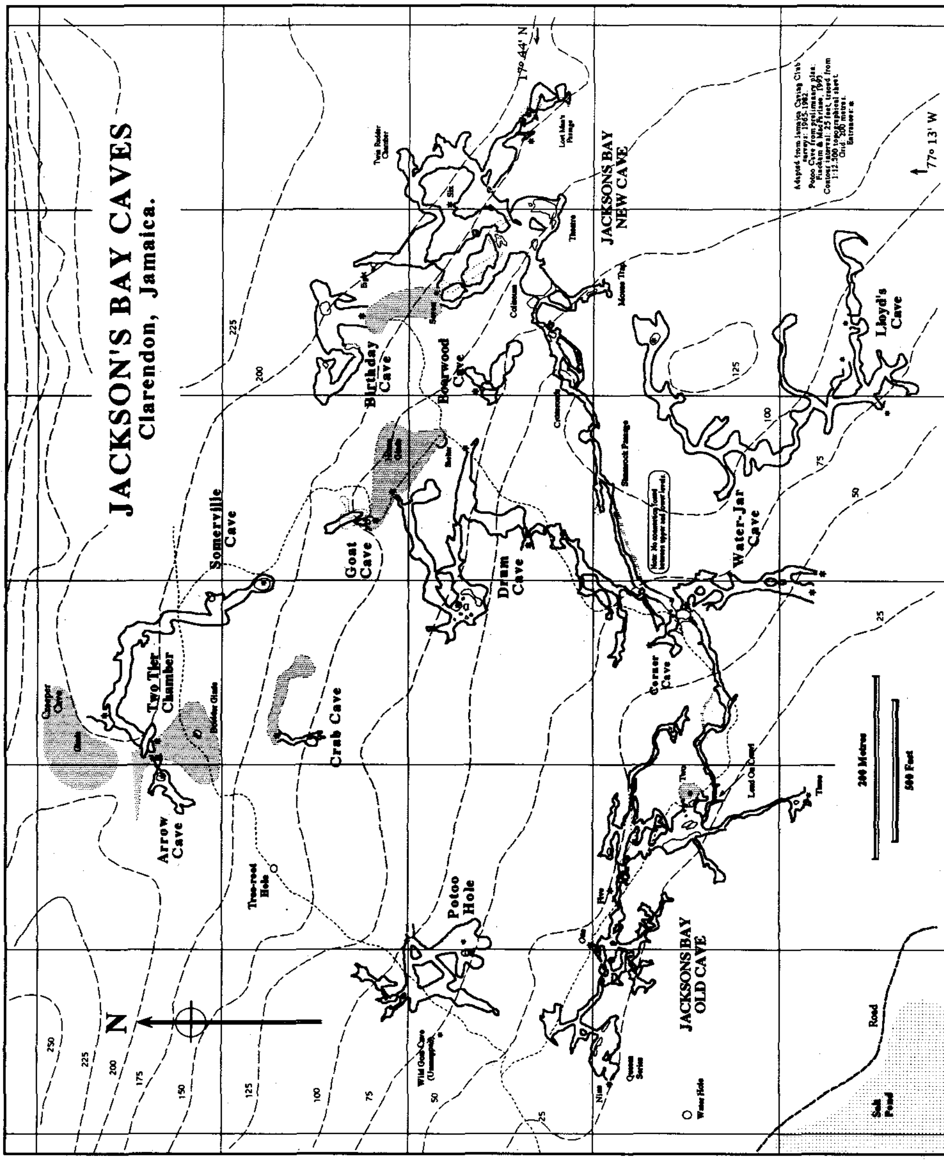
MOUTH MAZE	Trelawny	3188
WINDSOR GREAT CAVE	Trelawny	2978
St. CLAIR CAVE	St. Catherine	2896
COFFEE RIVER CAVE	Manchester	2801
ROCK SPRING CAVERNS	St. Mary	2591
CAVE RIVER: Noisy Water - 2	St. Ann	2475
RIVERHEAD CAVE	St. Catherine	2438
BRISTOL CAVE	Trelawny	2261
ME NO SEN CAVE	St. Elizabeth	1981
DOG HOLE	St. Mary	1969
CABBAGE HALL CAVERNS	Clarendon	1585
RUNAWAY BAY CAVES	St. Ann	1524
GOLDING RIVER CAVE	Manchester	1490
THATCHFIELD GREAT CAVE	St. Ann	1402
FALLING CAVE	St. Elizabeth	1294
SWANSEA CAVE	St. Catherine	1170
HARTIES CAVE - 2	Trelawny	1058
QUASHIES RIVER CAVE	Trelawny	1029
LLOYDS CAVE	Clarendon	1003

Table 3
Jamaican Caves of 80 m Depth and Above

Cave	**Parish**	**Depth m.**
DUNN'S HOLE*	St. Ann.	229
MORGANS POND HOLE	Manchester.	186
THATCHFIELD GREAT CAVE	St. Ann.	177
VOLCANO HOLE	St. Ann.	158
NEW HALL CAVE	Manchester.	151
ASUNO HOLE	St. Ann.	137
SPLOOSH POT	Trelawny.	125
WRIGHT'S HOLE	Manchester.	119
EVERLASTING HOLE	Manchester.	116
QUASHIES RIVER CAVE	Trelawny.	111
HUTCHINSON'S HOLE	St. Ann.	98
DADDY'S SINK	Clarendon.	94
GOURIE CAVE	Manchester.	91
MURROW HOLE	Trelawny.	91
HOLE-IN-THE-WALL PIT	Trelawny.	87

* The depth quoted for Dunn's Hole is somewhat artificial, since it relates to the overhanging cliff which forms the northern aspect of the sinkhole.


RIVERHEAD CAVE
St. Catherine
PLAN
N
0
200 Metre
Dam
Joint Chamber
River Sink
Sluice
The Swim
Sump-1
Sump-2
Anoxia Chamber
Sink
Junction
The Sewer
Sump End
The Side-Passage
Ooze
Slide
Slab Passage
Scree Hall


JACKSON'S BAY CAVES
Clarendon, Jamaica.
Somerville Cave
Two Tier Chamber
Arrow Cave
Crab Cave
Goat Cave
Birthday Cave
Drum Cave
Corner Cave
Water-Jar Cave
Lloyd's Cave
Potoo Hole
Tree-root Hole
JACKSONS BAY NEW CAVE
JACKSONS BAY OLD CAVE
17° 44' N
77° 13' W
N
200 Metres
500 Feet
Road
Salt Pond
250
225
200
175
150
125
100
75
50
25

WANDERING WELL	Trelawny.	87
PENITENTIARY - 3	St. Catherine.	87
JEZEBEL HOLE	Trelawny.	85
BREADNUT HILL HOLE	St. Elizabeth.	84
MENOCAL'S GLORY HOLE	Trelawny.	83
CRESCENT PIT	Trelawny.	80

(c) Exploration: It is not possible within the confines of this chapter to present any extensive descriptions of Jamaican cave explorations. However, notes on some selected explorations, having some unusual features, are given below.

Riverhead Cave, St. Catherine. While this cave had been well known (Long, 1774), the penetration of the system (Figure 3), beyond the "Sluice" water diversion was inhibited both by the deep upstream canal and sump, and by "foul air". In 1971 a JCC party lowered the sump water level and was able to swim into a farther chamber (terminated by a second sump), only to be severely affected by anoxia. (Subsequent gas analysis showed levels of oxygen: 13.9%, and carbon dioxide: 2.75%). It was thought that the foul air originated by pollution of the river with sugar washing waste from the Worthy Park factory in Lluidas Vale. Further exploration lead to the passing of the second sump and the mapping of the Side Passage, but upstream (The Sewer) exploration was halted at the foot of a boulder-fall in a lofty chamber where progress was again prevented by the foul air. An attempt to pass this point was made using scuba tanks, but the end of the cave was not reached. An extreme drought in September 1976 finally provided conditions which permitted JCC cavers to explore beyond the boulder fall to the limit (Sump End) of the upstream river passage. The acute foul air problem encountered in cave passages of such large volume makes these explorations of particular interest and has yet to be fully explained.

The Cave River System. The Cave River of St. Ann is notable for severe floods which frequently result in the inundation of the lower parts of the Cave River valley. Prior to the Karst Hydrology Expedition of 1965-66, the underground course of the Cave River was unknown. The expedition party (Livesey, 1966) made a notable contribution in their detailed exploration and mapping of this complex of caves culminating in the ladder descent of the Asuno hole (137m) and the successful water-tracing of the underground river to the Dornock Head rising. Sawkins (1869), in the Geological Survey Memoir, had wrongly interpreted the surface topology and had presumed the Cave River to be the headwaters of the Pedro River/Rio Cobre system).

Quashies River Cave. The Quashies River goes underground in an impressive and locally well known sink. The river has a steep gradient and drains a substantial area, leading to massive flooding in rains. In the underground river passage (5x20m) the walls have a "polished" appearance reflecting the power of this flow. A descent of the river passage requiring both swimming in the strong current and traversing above the waterfall

shafts, has provided a caving experience which has become accepted as a "classic" for the island (Livesey, 1967; Waltham, 1976; Boon, 1977).

Jacksons Bay Caves. The complex of caves making up the Jackson's Bay system located in the arid limestone hills of Portland Ridge in southern Jamaica has proved remarkable from several point of view. In total these caves comprise somewhat over 7,000m of fossil phreatic caverns mostly located less than 50m above present sea level (Figure 2). Speleothem dates for the Main Cave suggest a minimum age for its formation of 250,000 years BP (Wadge et al., 1979). Jamaican cavers first became aware of this system in 1964, as the result of a note in an unpublished manuscript in the Library of the Institute of Jamaica, although archaeological interest in these sites was shown as early as 1895 by Duerden. During 1964-65, the JCC carried out exploration and surveys of the main passages of the Jackson's Bay Cave (Ashcroft, 1969). The bush-covered terrain of the Portland Ridge hills makes surface navigation and entrance location extremely difficult. However, subsequent explorations revealed a second complex of caverns (**Somerville Cave, Drum Cave, Water Jar Cave**) overlying parts of the **Jackson's Bay Main Cave**, but apparently unconnected with it. These later explorations included detailed surface mapping and resulted in the location of many new sites (Wadge et al., 1979). This whole system is remarkable for its extensive phreatic caverns, complex morpholgy, unique situation and splendid speleothem displays.

(d) Cave diving: Cave diving activities in Jamaica have been few, although the 50-60m deep blue-hole (**God's Well**) in south Clarendon has often attracted attention from non-caver scuba divers, sadly with tragic results (Nicholson, 1985; Knutson, 1986). The multi-entrance flooded complex; **Two Sisters Cave** in the East Hellshire Hills has also attracted some scuba-diving interest. The most significant "cave dive" exploration to date was made in the **Worthy Park III** cave in 1981. A narrow descending, downstream passage leads into a long cavern with silt banks, ending after 75m in a deep sump which remains closed, even in drought. The sump (80m long and 10m deep) was passed by a JCC - Jamaica Sub-Aqua Club diving team to a further 140m of dry passage ending in a second sump. Exploration beyond this point has not been made, but it is thought that a linkage with the caverns lying beyond the upstream (Sump-End) pool of the Riverhead Cave (see above) is possible by this route.

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JAME NA JAMAJKI IN NJIHOVO RAZISKOVANJE

Povzetek

Jamajka, otok v Velikih Antilih, obsega 11.420 km^2. Dve tretjini otoka sestavljajo zakraseli, tektonsko prelomljeni apnenci eocenske in miocenske starosti. Za notranjost je značilen t.im. "cockpit" kraški relief (depresije nepravilnih oblik in vmesni stolpi), ki ga tu in tam prekinjajo kraška polja. Največje apnenčevo gorovje dosega višine 2.300 m.

Za hidrologijo Jamajke so značilne reke ponikalnice, ki ponikajo v srednjem delu otoka in napajajo kraške izvire vzdolž Duanvale prelomnega sistema. Več vodnih zvez je bilo dokazanih s sledenji, med njimi do razdalje 27 km.

Glavna vzpodbuda za raziskave kraških jam, ki jih je organiziral po vsem otoku Geological Survey Department, je bila potreba po guanu kot gnojilu v prvih letih II. svetovne vojne. Ta oddelek je preučeval tudi vodne razmere. 1958 je bil na univerzi ustanovljen Jamaica Caving Club, ki je že v prvih letih dela odkril velike jamske sisteme. Med 1969 in 1977 so s pomočjo računalnika uredili jamski kataster in ga tudi izdali v tiskani obliki "Jamaica Underground". K poznavanju podzemlja na Jamajki so precej pripomogle tudi tuje speleološke odprave: 5 članov britansko-kanadske odprave je bilo na otoku 8 mesecev in v tem času raziskalo, izmerilo in izrisalo načrte 29 km jamskih rovov. Danes vsebuje kataster podatke o okoli 1200 jamah. Iz tabel največjih jam na Jamajki je razvidno, da je vsega skupaj 23 jam, daljših od 1000 m, najdaljša je 3505 m dolga Gourie Cave. Več kot 80 m globokih je 21 jam z 229 metrsko Dunn's Hole kot najgloblјo.

V novejšem času so v ospredju morfološka, hidrološka in biospeleološka preučevanja. Morfologijo so preučevali tudi svetovno znani krasoslovci (Sweeting, Ford) in danes je kras na Jamajki znan kot tipični tropski kras. Na Jamajki je znanih 15 vrst jamskih netopirjev. Najpomembnejša tema biospeleoloških raziskovanj pa je bolezen histoplasmosis, pri čemer je prav na Jamajki prišlo do pomembnih odkritij. S paleontološkega in arheološkega vidika je treba omeniti raziskave izumrlih glodalcev in ostankov edinstvenega primata Xerothrix ter indijanskih kultur.

SPELEOLOGICAL HISTORY OF BERMUDA

ZGODOVINA SPELEOLOGIJE NA BERMUDIH

THOMAS M. ILIFFE

Izvleček UDK 551.44 (729.9)(091)

Iliffe, Thomas M.: Zgodovina speleologije na Bermudih

Jame na Bermudih so zabeležene in zgovorno opisane v večini knjig o tem srednje atlantskem otoku. Najmanj sedem jam so razkazovali turistom, vendar pa danes samo dve služita tem namenom. V zgodovini pa so igrale tudi pomembno vlogo v speleologiji. Globoko potopljeni kapniki v notranjosti slanih vodnih jezerc so geologom služili za različne interpretacije izvora tako otoka kot jam. Že 1864 so poskusili določiti starost masivnega bermudskega stalagmita, kar je najzgodnejša indikacija velike starosti jam. Žal pa so jame tega majhnega, a gosto poseljenega otoka precej poškodovane, voda je onesnažena, jame so uničevali kamnolomi, na kapnikih so sledovi vandalizma.

Ključne besede: speleologija, zgodovina speleologije, morska jama, "blue hole", datacija sige, degradacija krasa, Amerika, Zahodna Indija, Bermudi

Abstract UDC 551.44 (729.9)(091)

Iliffe, Thomas M.: Speleological History of Bermuda

Dating from the island's earliest history, the caves of Bermuda have been noted and eloquently described in the majority of books depicting these mid-Atlantic isles. At least seven Bermuda caves have been commercially shown as tourist attractions, although today only two still serve this purpose. In addition to their aesthetic beauty, Bermuda's caves have also played an important role in speleology. The presence of deeply submerged speleothems in interior salt water pools of Bermuda caves has provided geologists with variously interpreted data pertaining to the origin of both the island and its caves. An attempt in 1864 to determine the age of a massive Bermuda stalagmite provides one of the earliest indications of the great age of caves. Unfortunately, the caves of this small but densely populated island have suffered considerable abuse from man including water pollution, the destruction of caves by quarrying and construction activities, and the vandalism of speleothems.

Key words: speleology, history of speleology, sea-cave, "blue hole", flowstone datation, karst degradation, America, West Indies, Bermuda

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BERMUDA CAVES AND CAVE GEOLOGY

The islands of Bermuda are located 1000 km off the east coast of the United States at 32oN, 65oW in that part of the west central Atlantic Ocean known as the Sargasso Sea. Bermuda was formed as a mid-ocean volcanic sea mount about 100 million years and has never been part of a continental land mass. The emergent islands, with a land area of only 50 km2, consist of Pleistocene and Recent, eolian (wind-deposited) limestone with a thickness of less than 100 m. A broad, shallow reef tract surrounding an interior lagoon lies to the north and west of the islands. Bermuda's known caves are situated wholly within the island's eolian limestone cap-rock and primarily occur in the oldest and most highly consolidated strata.

The air-filled portions of Bermuda's caves are characterized by collapse features consisting of fissure entrances to large irregular breakdown chambers with little or no true passage development. Many of these inland caves extend down to sea level, tidal pools containing clear brackish waters. Recent diving explorations in these pools have resulted in the discovery of extensive, interconnecting networks of cave passages submerged at an average depth of 18 m below sea level. Large stalactites, stalagmites and other speleothems are present in all parts of Bermuda's caves including the submerged portions.

The presence of submerged stalagmites in Bermuda caves led to debate among geologists as to the tectonic stability of the island and to possible changes in sea level over geologic time. Lieut. R.J. Nelson (1840) mistakenly suggested that these speleothems were formed underwater, while W.F. Williams (1848)

interpreted them as indications that the land was slowly sinking. After the publication of Darwin's theory on the origin of coral atolls, geologists such as C.W. Thomson (1878) theorized that the island of Bermuda was the peak of a volcanic mountain undergoing gradually subsidence. R.W. Sayles (1931) was first to suggest that the island remained stationary, while interglacial and glacial sea levels alternately advanced and retreated.

Several theories have been proposed concerning the origin of the island's caves. A.C. Swinnerton (1929, 1932) believed that Bermuda caves had a vadose origin above the water table. He stated that these caves were formed:

> . .as zones of solution by downward migrating rain water along steeply dipping and intersecting joints. Crystal, Wonderland, Leamington, Admiral's, and Bassett's, to mention

only the largest caves, show clearly the control of jointing in the formation of large openings. Crystal, Bassett's, and Admiral's caves include tunnel-like passages also. The cave in Tucker's Town is the only large one in which the effect of joint control is not clear (Swinnerton, 1929).

W.M. Davis (1930) viewed the caves of Bermuda as being "one cycle caverns in porous limestones". These are in contrast to most other caves that, he felt, were formed two cycles - one cycle of solutional excavation occurring below the water table, and another of depositional replenishment taking place following lowering of the water table when the cave became air-filled.

J.H. Bretz (1960a & b) interpreted the horizontal elongation of the caves as evidence for their formation beneath the water table by horizontally circulating fresh ground water, supplied and maintained by rain. According to Bretz, the large fresh groundwater body necessary for cave formation could only have occurred in Bermuda during low stands of glacial sea level when the islands' total landmass would have been about 13 times as large as it is today.

Bermuda's caves also proved to be scientifically interesting due to the presence of many bird fossils (Shufeldt, 1916). Numerous bones from the caves and even feathers embedded in stalactites belong to the Cahow bird, *Petrodama cahow*. As recounted by Shufeldt (1916):

> At one time the 'Cahow' was extremely abundant on these Bermuda Islanda, and bred there in untold millions at the time of the early settlers, some three centuries ago. It was a nocturnal species, possessing discordant notes; and so fearless of man were these birds that they would alight on the head, shoulders, and arms of any person visiting their breeding-grounds. This unusual fearlessness resulted it the final extermination of the species; for the first inhabitants of the island, and those that followed them in a comparatively short period, utterly destroyed the birds for food, notwithstanding their enormous numbers.

Fortunately the story of the Cahow does not end here. Although thought to be extinct for over 300 years, a small nesting colony of cahows was discovered in 1951 (Wingate, 1960). These seabirds were breeding in shallow holes in sea cliffs located on tiny offshore islets at the entrance to Castle Harbour.

HISTORICAL SPELEOLOGY

The caves of Bermuda have been a source of mystery and fascination since the earliest colonists landed on the island. Shakespeare's play "The Tempest", inspired by the Bermuda shipwreck of Sir George Somers in 1609, takes place in and around a cave. The first published reference to Bermuda's caves was by Captain John Smith in 1623 who reported, "in some places varye strange, darke, and cumbersome Caues." In a poetic description of Bermuda from 1671 by John Hardy (quoted in Lefroy, 1877), caves were specifically portrayed:

The water flowing to them [Harrington Sound] underground,
Being most salt, and all along the shore
There are dark caves, of a miles length or more
Extending under ground, in which there be
Deep holes with water, though no one can see
A passage for it in. . . .

Lefroy (1877) footnoted this passage with a personal observation:

I believe the Island is hollow, for there is some holes that none can find the end of them some hot as a Stove upon the Northerly wind, as that near Tucker's Town; and that there is

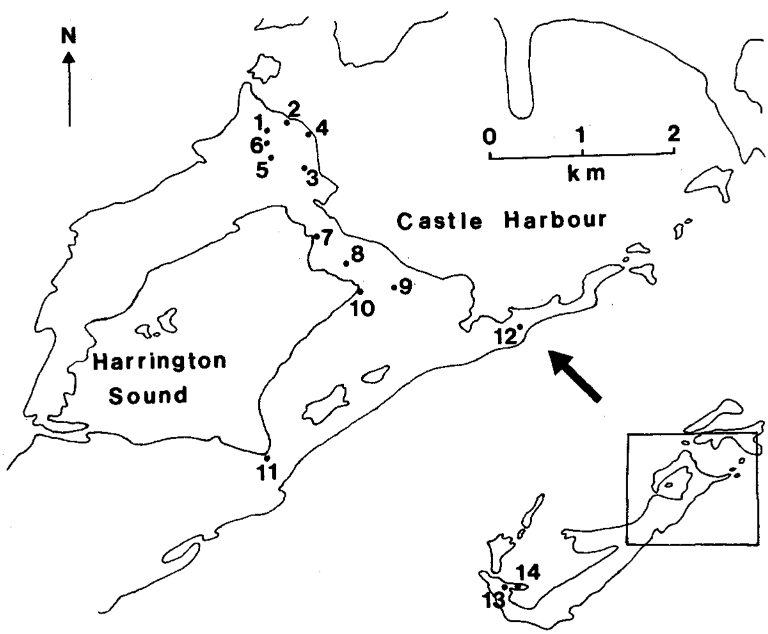

Fig. 1: Map of Bermuda showing the location of the principle caves - 1: Admiral's Cave, 2: Joyces Dock Caves, 3: Walsingham Caves, 4: Castle Grotto, 5: Crystal Cave, 6: Wonderland Cave, 7: Leamington Cave, 8: Peniston's Cave, 9: Paynter's Vale Cave, 10: Sharks Hole, 11: Devil's Hole, 12: Tucker's Town Cave, 13: Bassett's Cave, 14: Tucker's Island Cave.

Sl. 1. Karta Bermudov z vrisano lego najpomembnejih jam - 1. Admiral's Cave, 2. Joyces Dock Caves, 3. Walsingham Caves, 4. Castle Grotto, 5. Crystal Cave, 6. Wonderland Cave, 7. Leamington Cave, 8. Peniston's Cave, 9. Paynter's Vale Cave, 10. Sharks Hole, 11. Devil's Hole, 12. Tucker's Town Cave, 13. Basset's Cave, 14. Tucker's Island Cave.

water in them may be proved: by the Cooper's Hole, the Devil's Hole, and a place near Walsingham Bay which water, though a good distance from the Sea, is briny and salt as it is.

Bermuda's caves have been used and abused for many hundreds of years. At least 9 caves in Bermuda have been commercially shown to tourists at one time or another. These include Island, Cathedral, Admiral's, Castle Grotto, Wonderland, Crystal, Walsingham, Leamington, and Tucker's Island Caves (Fig.1). Stalactites and associated crystalline deposits have been literally mined from the caves. The Catalogue of the 1872 Bermuda Industrial and Loan Exhibition lists stalactites as an "article of industry" for which prizes were awarded to the best collections. Prisoners on convict hulks moored at Bermuda's Naval Dockyard in the early 1800's sculpted stalactite carvings in the form of chess pieces, rosary beads, jewelry and other items (Addams, 1990).

Numerous authors have presented descriptions of Bermuda caves. These eloquent and original narratives will be here extensively quoted from. John Matthew Jones (1859) portrayed the island's caves as follows:

> To the caverns of Bermuda, which are so remarkable for their singularity and beauty, it will be well to devote a short space; for we doubt if in interest and varied appearance, anything else on the Islands can be compared to them. It would be difficult to describe them, as any account must necessarily fall far short of the reality; but if the reader can imagine an opening of tolerably large dimensions in the limestone rock, and charmingly irregular in outline from the roof of which shining stalactites descend, reflecting their protracted forms in the light blue-green water below, which cover the floor of the cavern, and in whose pellucid depths may be seen floating the forms of fishes, garbed in coatings of the most resplendent hues, he will have some idea, albeit a faint one, of the interesting features of these subterranean recesses.

Geologist A. Heilprin (1889) contended that:

> These sea-grottoes are among the most attractive features of the Bermudas, and they would, even in regions far famed for their caves, attract attention. The principal vaults are of fairly large size, but the connecting passages are low and contracted, rendering deep penetration difficult.

Another geologist, A.C. Swinnerton (1929), wrote:

> The caves of Bermuda are caves in miniature to those who are familiar with the caverns of Kentucky and Virginia. The accessible parts are not over a few hundred yards in length, although it is undoubtedly true that a network of passages underlies much of the cave area. The presence of sea water in the caves, the variously coloured deposits stained with orange cave-earth, and fossil soils contrasted with the many brilliant white stalactites and stalagmites make the cave extremely picturesque and memorable spots for the tourist to visit and likewise for the geologist to study.

ADMIRAL'S CAVE, HAMILTON PARISH

Admiral's Cave, named after Admiral Sir David Milne, is perhaps one of the more historically significant caves in Bermuda. According to Home (1864):

> [It] is situated at Walsingham, in the Parish of Hamilton, and upon the side of a hill, about 40 or 50 feet above sea level, and a quarter of a mile distant from it. . . . The cave inside might be about 25 or 30 feet high at the greatest height of the roof, about 50 or 60 yards in length, and 20 to 30 yards in breadth. But is quite irregular in shape. It contains an immense number of both stalactites and stalagmites of all sizes. Some of the latter had grown up so high as to have reached the roof and become supports to it, and were from 30 to 40 feet in girth. At the bottom or lowest part of the cave there is a large and deep pool of salt water, rising and falling with the tides -proving a connection with the sea.

In 1819, Admiral Milne, commander of the British North American and West Indian Station in Bermuda, collected a number of speleothems from Bermuda caves that he presented to the University of Edinburgh. The largest of these was a stalagmite, 3.4 m high, 63 cm in average diameter and weighing nearly 3.5 tons, removed from Admiral's Cave (Fig. 2). Forty-four years later, Milne's son, Sir Alexander Milne, returned to Bermuda and revisited the cave where he made the following observations:

> He noticed five drops of water falling on the trunk - two at the rate, each of them, of three or four drops in the minute. The other three dropped much less frequently. On the part of the trunk where the last-mentioned drops were falling, the deposit consisted of only a thin crust. One of the knobs measured in height above the fractured surface five-eighths of an inch, and had at its base an area of about 3 3/4 inches in diameter. The other knob measured in height four-tenths of an inch, and had at its base an area of about 2 1/4 inches (Home, 1864).

David Milne Home (1864) calculated from the measurements taken by his brother that the volume of the freshly deposited knobs totalled five cubic inches. Since these knobs had formed in 44 years, Home determined, assuming a constant rate of deposit, it would have taken "the astounding and incredible period of more than 600,000 years" to form the entire original stalagmite.

Home (1864) believed however that:

> . . .in the early history of the caves, the water flowed much more copiously than afterwards . . . . On these grounds [Home] entirely repudiated the notion that this stalagmite has taken the enormous period to grow.

Sir Wyville Thomson, a professor at the University of Edinburgh, became interested in these studies. In 1873, Thomson served as chief scientist on the round the world voyage of the H.M.S. Challenger and had the opportunity to visit Bermuda where he reported on the condition of the Admiral's Cave stalagmite:

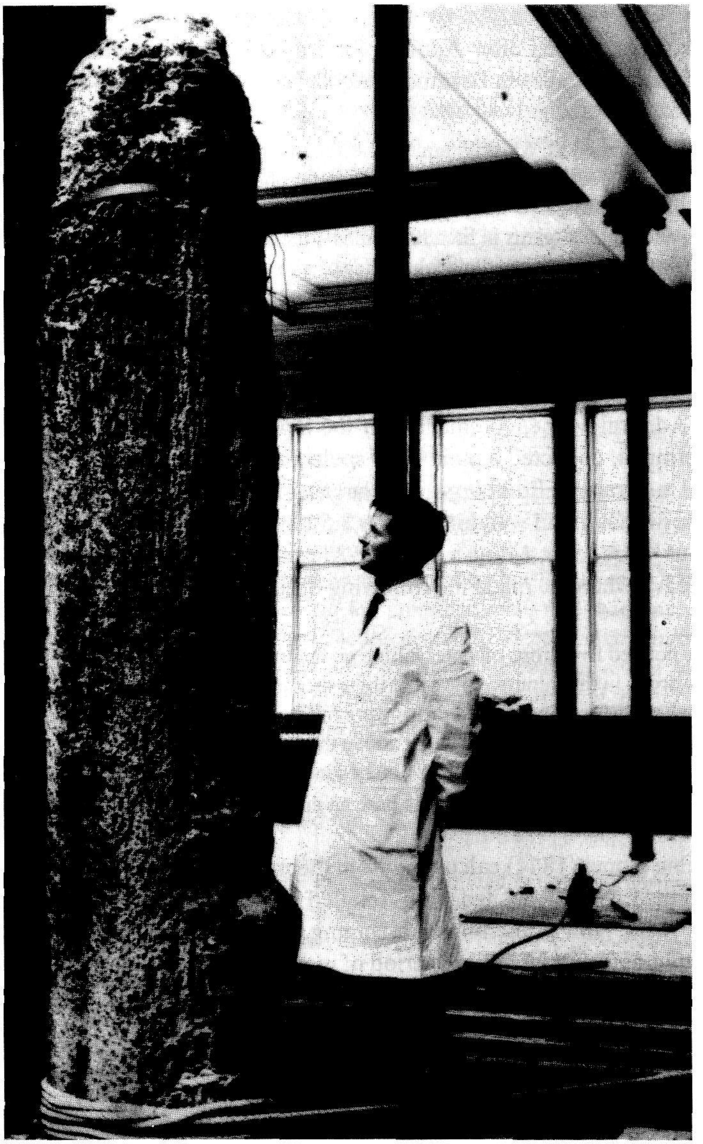

Fig. 2: Photo of the Admiral's Cave stalagmite taken in October 1969. This stalagmite was removed from the cave by Admiral Sir David Milne in 1819 for display at the University of Edinburgh.

Sl. 2. Slika stalagmita iz Admiral's Cave, posneta 1969. Ta kapnik je odnesel iz jame admiral Sir David Milne leta 1819 in ga razstavil na Univerzi v Edinburghu.

> The roof of the cave at the point whence the stalagmite was removed is at a height of about fifteen feet, and facing the stump there are two majestic columns uniting the roof and the floor, one of them upwards of 60 feet in circumference. They are beautifully fluted and fretted with stalactite, and shone out with a pure white-frosted surface in the magnesium light (Thomson, 1878).

Thomson (1878) further observed that,

> "About ten years later [than Alexander Milne's observations], the two drops were still falling, but apparently somewhat more slowly, one not quite three times in a minute, the other twice; this must depend, however, in some measure upon the previous weather." After unsuccessfully attempting to photograph the stump, Thomson ordered that a slice be taken from the stump "showing the amount of reparation during half a century, as an accessory to the Edinburgh specimen."

Admiral's Cave was briefly operated as a commercial tourist attraction in the early 1900's and was described by Hayward as follows:

> The Admiral's Cave is a long one, the first chamber being decorated by hundreds of stalactites that assume forms of the vegetal world. Farther down into the earth, the way being illuminated by gas lights, is the organ chamber where stand one large and a series of smaller columns - the organ - resulting from the union of stalactite and stalagmite. These when struck by metal send forth musical notes that echo and re-echo against the dripping roof. Another descent brings the explorer to a lake of clear water, the strange silence of this chamber being disturbed only by the occasional rumble of vehicles passing directly overhead on the St. George's highway.

Swinnerton (1929) also made observations relative to speleothem growth rates in Admiral's Cave:

> Some Bermuda caves have been open to the public for fifty years. At first burning torches and fires were used for light, later acetylene, now electricity. In the caves formerly open to the public, like Admiral's cave, clean white stalactites, presumably new, grow from the tips of old soot-coated stalactites. It seems likely that the clean ones have grown since the time when the caves were illuminated with smoky lights - not over twenty years ago.
>
> One old stalactite may have five clean ones hanging from it. One of these new ones may be half an inch in length, another may be 6 inches; one may be of large diameter, another very small.

JOYCES DOCK CAVES, HAMILTON PARISH

The Joyces Dock Caves are a group of five caves (Coffee, Bluebell, Sibley's, Cathedral and Island Caves) located at the northern end of the Walsingham Tract on the shores of

Castle Harbour. These caves have been commercially shown to the public for well over a century.

The two principal caves in the Joyces Dock group are Cathedral and Island Caves. An early tourist guide (Anonymous, 1906) presented descriptions of these caves:

> The entrance to this fine cave [Cathedral Cave] is through a gateway on each side of which stands a natural pillar apparently supporting the overhanging rock. After making an abrupt descent between walls of living rock, the visitor stands in a large grotto, known as the Pulpit Cave - so called because of an immense stalagmite standing near the centre which closely resembles an old fashioned pulpit. Scores of acetylene gas jets illuminate the grotto and reveal its beauties. On the right side the roof slopes down sharply and on that side bounds a lake in whose clear, placid water the elegant stalactites that depend from the ceiling are reflected. The water in this lake is from 15 to 18 feet deep. Great natural pillars support the roof of the cavern and the whiteness of the stalactites is dazzling. . .
>
> Magnificent as is the Cathedral Cave with its numerous chambers, and much as the visitor may be impressed by its grandeur, nevertheless he is quite unprepared for the vision of beauty that bursts upon his gaze as he enters the Island Cave, which in many respects recalls the views one has seen of the famous grotto of Antiparos.
>
> The Island Cave is a circular grotto covering an area of nearly half an acre. Groups of beautifully wrought natural pillars around the sides support the dome-shaped roof from which hang exquisite stalactites of snowy whiteness and of every conceivable length. The grotto is filled with water clear as crystal and ranging in depth from 18 to 30 feet, and the colouring of blue and brown, of green and opal, is most beautiful. From the center of the pool rises an immense stalagmite not unlike a beacon in appearance, and this resemblance is increased when the numerous gas jets that have been place upon it are lighted. A former proprietor saw in the stalagmite a strong resemblance to an island in the ocean: hence the name - Island Cave.

Although not as well visited, the other three caves of the group had their own interesting features.

> Sibley's Cave owes its name to an episode connected with the sojourn of the XXXth Regiment of Foot at St. George's (18301833). At that time St. George's was still isolated from the mainland and the Walsingham Tract had not been denuded of the original groves of cedar and the accompanying undergrowth. Five men of the Regiment, led by a corporal named Sibley, deserted, and for several weeks the military authorities could not discover any trace of the men. One morning, a man who happened to be passing though the woods in the vicinity of the cave was attracted by the odour of tobacco. Following the scent, he discovered the missing soldiers - in the Cave, since that time called Sibley's Cave after the leader of the party (Anonymous, 1906).

Bluebell or Convolvulus Cave, located next to Sibley's Cave, derives its name from vines of the blue, bell-shaped convolvulus flowers that abound nearby. Thomson (1878) visited the cave and a picture of its entrance appears in his book. The cave was described as containing:

> . . .a pool of clear water - extending beneath the rocky sides - and this pool is the principal object of attraction in the cave. Each bright day, between 1 and 1:30 p.m., this water undergoes a transformation that has excited the admiration of everyone who has witnessed it. At first dark and ugly-looking, as the first glint of the post-meridian sun strikes through a rift in the overhanging rock and falls upon the pool, a sharp line of emerald green is visible on the surface. As the sun travels onward and his rays enter more directly and fully, the line of colour gradually broadens and changes until all the tints of the rainbow are visible in the clear, sparkling water through which the light penetrates to the very bottom to the pool. Then, after a time, upon the surface farthest away a shadow falls - gradually moving across until finally it has obliterated the last line of colour and has covered the pool in gloom once more (Anonymous, 1906).

Coffee Cave is situated on the opposite side of the road and is named for an abundant growth of coffee trees at that spot.

WALSINGHAM CAVES, HAMILTON PARISH

This group of caves is located in the highly karstified area between Castle Harbour and Harrington Sound. In 1803, the Irish poet Thomas Moore (1779-1852) stayed for four months in Bermuda spending much of his time writing poetry in the shade of a calabash tree at Walsingham. His Odes and other Poems published in 1806 mentions the "sparking roofs and pearl-blue ponds" of the Walsingham Caves (Hovey, 1896).

As portrayed by Hayward (1910):

> There is no part of Bermuda where the vegetation is wilder, more luxuriant, or the colouring more intense that at Walsingham, named after its first explorer, the coxswain of the Sea Venture [Sir George Somer's ship wrecked in Bermuda in 1609]. It is almost a riotous tangle as it was in the days when Tom Moore sallied forth from Walsingham House, beside a rocky pool, and rambled through the woods to his hospitable calabash tree, now struggling against age in a cool, green glen. Here cedar brush is shrouded in jasmine, which in early summer is white with blossoms and heavy with perfume; there are coffee trees, oranges, lemons, and wild olives; stalactitic walls of fallen caverns and mouths of subterranean chambers are masked by creepers, ferns and moss, while the fiddlewood, which assumes as its regular dress soft autumn tints, lends touches of brown and red to the fresh green of the undergrowth. . . . Some of the caverns grew too large to support their roofs, and so we find throughout Walsingham 'sinks' or depressions caused by the collapse of the structure overhead. In such rocky glens there are broken boulders and irregular curtains of honeycombed limestone - damp, shadowy glades that try shoe leather but delight the eye and fire the imagination.

According to Verrill (1908), the Walsingham Caves were the most frequently visited caves in Bermuda. In the 1930's, a commercially operated nature trail led tourists along concrete pathways to the caves and karst features of this area.

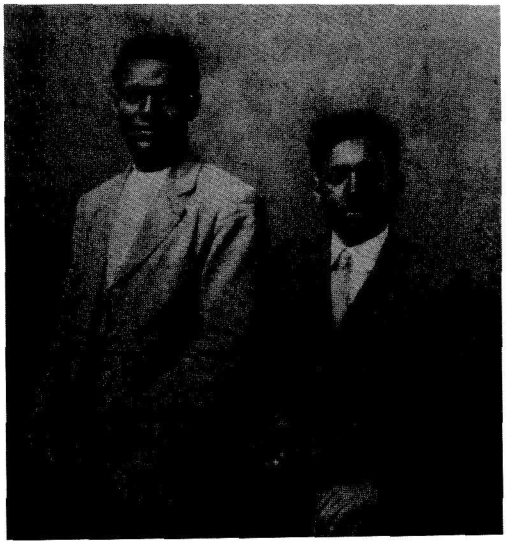

Fig. 3: Carl Gibbon (on right), discoverer of Crystal, Wonderland and Leamington Caves, and his cousin Harold Gibbon (from Paine, 1911).
Sl. 3. Carl Gibon (na desni), odkritelj jam Crystal, Wonderland in Leamington in njegov bratranec Harold Gibbon (iz Paine 1911).

Fig. 4: One of the caves discovered by Carl Gibbon (from Paine, 1911).
Sl. 4. Ena od jam, ki jih je odkril Carl Gibbon (iz Paine 1911).

CASTLE GROTTO, HAMILTON PARISH

This cave is located along the coast of Castle Harbour near the Blue Grotto pool about 100 m south of the Causeway bridge. Castle Grotto was used as the throne room of Neptune in the 1914 movie Neptune's Daughter, while other scenes were filmed in Crystal Cave and at Shark's Hole (Rider, 1928). According to Forney (1973), Neptune's Daughter was probably the first movie to use footage shot in a cave.

Bushell's (1926) tourist guide to Bermuda stated that:

> [Castle Grotto] consists of three chambers, each of which has its own entrance - all easy of access. Suspended over water of crystal clearness with an emerald or turquoise tinge, showing the white sand beneath, there are formations of wondrous beauty. . . . In order to view the northern chamber to advantage, we must embark on a large flat bottom boat, which is guided through this grotto by an experienced boatman. Twisting in and out among the low-hanging stalactites, our boat glides over the placid waters and we come into a low chamber with a beautiful arched roof. We see the large columns and pipe-like formations, fantastic shapes of putty and flint in gray, all shades of pink, snow white and sparkling crystal, with the clear water reflecting the dome and glittering lights all combining to make this scene a veritable fairyland.

CRYSTAL CAVE, HAMILTON PARISH

Paine (1911) related the discovery of Crystal Cave by Carl Gibbon (Figs. 3 & 4):

> It was a March afternoon, 1905, when Carl found his first cave. He was barely fourteen years old then, and with a playmate, Edgar Hollis, had climbed a pleasant hill overlooking the sea. . . . By and by Carl realized that a small and curiously cool current of air was fanning his cheek. He thought it strange and wondered where it came from. Then he noticed a crevice in the loose coral formation he had been using as a pillow, and, holding his hand over it, felt the cool air coming through.
>
> 'There is something down in there,' he said, 'to make that,' and the boys began pulling away the broken sections of stone.
>
> All at once quite a large piece 'fell through,' as Carl described it afterward - dropping away in front of them, leaving a hole like a well, though somewhat less perpendicular. Yet it was a steep, uncertain place, and the boys peered onto the darkness of that mysterious entrance, and spoke in whispers.
>
> So they. . .went home, quietly borrowed two lamps, and hurried back. Then they descended into that narrow, steep place again and slid down, down - holding their lamps with one hand, clinging and steadying with the other.
>
> Deeper and still deeper; fifty feet, seventy-five feet, a hundred feet - deep as a ten story building is high, the opening getting somewhat larger as they descended. Then suddenly they reached a level, the walls opened out, and by the light of their lamps the young explorers beheld an enchantment such as the lamp of Aladdin might reveal. Stretching away into the darkness before them was an arched ceiling, hung with gleaming pendants - a myriad of huge crystal icicles they might have seemed to a boy of the North, only that some were delicately

cream-tinted, others were of a pinkish hue, while from the floor beneath a myriad of inverted icicles stretched up to meet them. Crystal stalactites and stalagmites they were - the work which nature for ages had been carrying on, preparing there in total darkness a habitation suitable for kings. In the center of all this marvel the boys caught the shine of water - a clear, silent lake, catching the light on its still surface and reflecting the splendor overhead for the first time in all the ages.

Holding their lamps high, the boys looked out on this sheet of water and faintly caught the gleam of stalagmites on its farther shore. Carl set his lamp down. 'You stay here,' he said; 'I'll swim across and see what's over there.'

Half swimming, half wading, the boy made his way across. Then he saw he had reached an island; also that the crystal chambers stretched and branched away into the darkness, and that the lake, or arms of it, followed them. What a wonderful place! The most marvelous cave yet found in Bermuda - the boy realized that.

He came back to his companion, and the two made their way around among the stalagmites and broke off some pieces to show at home. Then they scrambled and tugged their way back to daylight, for it was evening. They had been down over three hours in all.

Hayward (1910) described this cave (Fig. 5) as follows:

Just off the road [Wilkinson Avenue] is Crystal Cave and Cahow Lake, a recent discovery, the most dazzling cavern in Bermuda. You enter at the top of a hill and descend ninety feet through a rift in the strata by means of a stairway fitted at intervals with rest-platforms. At the bottom you stand on the shore of Cahow Lake, across which is moored a pontoon

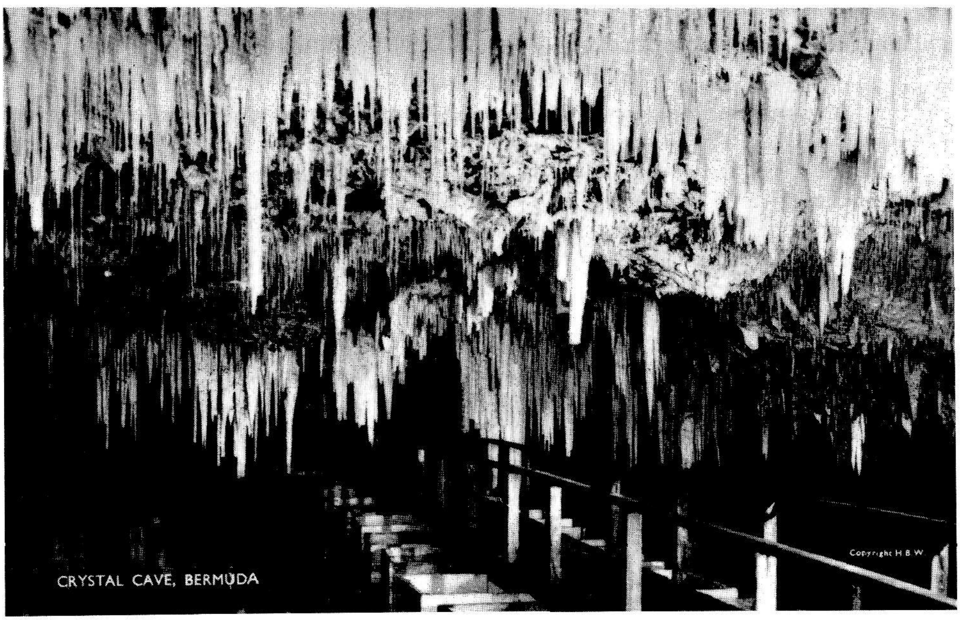

Fig. 5: The ponton bridge spanning Cahow Lake in Crystal Cave.
Sl. 5. Pontonski most, ki povezuje jezero Cahow in Crystal Cave

bridge, lighted by gas. The scene is not to be conjured. It is another world, a scintillating creation of lime and water, the drip, drip, drip signifying the slow but steady growth of pendants clinging to the salmon-tinted ceiling. . . . Cahow Lake takes its name from the fact that in one of the chambers were found deeply embedded in the calcite bones and fossilized feathers of the cahow, which became extinct about 1630. . . . The lake is subject to tidal changes, indicating connection with Castle Harbour or Harrington Sound, the whole of the hill apparently being undermined. The depth of water is thirty feet or more, but at some remote period the floor was not wholly submerged, for numerous stalagmites of large size are visible, these having been formed by the drip from the ceiling.

WONDERLAND CAVE, HAMILTON PARISH

Paine (1911) also recounted the discovery of Wonderland Cave by Carl Gibbon:

> It was about two years after the first adventure [the discovery of Crystal Cave], that a Mr. Haycock one day sent for him [Carl Gibbon] to come and examine a hole among the rocks on his land. . . . Mr. Haycock had noticed a piece of paper which seemed to be blowing away from a hole among the rocks, and when Carl arrived he agreed that the opening indicated a big cave.
>
> They enlarged the hole, and Carl went down. At first he found nothing but a small room, a few feet below the surface. The he noticed a narrow place between two stones, just wide enough for a slender boy to squeeze through. He wormed through it and thought the ground on the other side sounded hollow. He tapped it with his foot, an a piece the size of a barrel-head tumbled in, leaving a dark, steep hole like that which had led to the Crystal Cave.
>
> The boy climbed down into it a few feet, saw it was really a passage, and went back for a rope and lantern. It turned out a genuine cave - not as large as the first discovery, but very fine with a lake in it. Mr. Haycock, a man of means, decided to open the cave for private exhibition and kept Carl employed a good while at the work paying him very well.
>
> One day while crawling around among the stalagmites, near what he thought to be the end of the cave, the boy found a small opening, and, creeping through, discovered another large chamber, the largest of all.

The Haycock cave is about a quarter of a mile from the Crystal Cave and is very likely a part of the same formation.

LEAMINGTON CAVE, HAMILTON PARISH

Carl Gibbon discovered a third cave which, as with the other two, was soon open as a commercial tourist attraction. Again, Paine (1911) related this discovery:

> It was only a little while ago that Carl discovered his third and largest cave. On the 26th of November 1909. . .They [Carl and his cousin Harold Gibbon] were passing a big rocky bluff when Carl said: 'I believe there must be a cave under that bluff.'

He hardly knew why he thought so, but he had a feeling, somehow, that a cave was there.

. . .

From a rift in the coral a breath came that was decidedly cooler than the warm air of the surface. Then they went to work, pulling and prying away the loose formation, and presently had widened the opening into an entrance. There seemed to be a roomy passage below, and lighting their lantern, the boys went down.

They descended that cool, silent corridor to water-level and came to a big lake and great vaulted and columned chambers gorgeously hung with crystal pendants - a cave more grand than anything yet found. The boys wandered along the margin of the quiet lake, turning this way and that to explore diverging chambers, until they happened to notice that their lantern was getting very low. They set out for home then, but suddenly realized that they did not know the way.

Down in the black depth, with a failing lantern, they were lost. They made a turn or two, but nothing looked familiar; that is to say everything looked alike. They stopped still to consider it would not do to lose their heads. Presently Carl said:

'The opening is east of here; we must go east.'

Now that is a curious thing. The boys had wandered about and made many turns, at many angles; yet this boy had kept the points of the compass in his head.

'I can always tell the points of the compass,' he said afterward, 'wherever I am.' Which must be a sort of instinct - certainly a useful one.

At all events, the boys did 'go east,' and before the lantern had quite given out they came to some broken pieces of stalagmite which marked their trail. They followed it and soon thought they felt a current of the warn air from outside. It was, in fact, the opening and they climbed back to daylight and reported to Mr. Anderson [the landowner] their great find.

PENISTON'S CAVE HAMILTON PARISH

As described by Verrill (1908):

One of the most interesting caves, because of its peculiar situation and its elegant and profuse pure white stalactites and drapery-like sheets of stalactitic material, is Peniston's Cave, on the land of W.S.O. Peniston. It was not open to the public at the time of my visit, and partly on that account its stalactites retained their original purity of color. The entrance is near the top of a wooded hill somewhat south of Harrington House, toward Castle Harbour. There is a large, dry, cultivated sink to the north of it. The entrance is nearly perpendicular and barely large enough for a man to enter, it being only the wider part of a fissure. The fissure expands below to form the cave. The floor and roof both slope rapidly downward for about 80 feet. The height of the roof varies from 4 or 5 feet up to 10 or 15 feet. It is thickly covered in most places with multitudes of rather small stalactites, though large ones occur. These stalactites are still forming. Water was dripping from most of them. Many of the small and very slender ones were tubular and porous at the end, and had a drop of water hanging there, in which, with a lens, loose or but slightly attached crystals of calcium carbonate could be seen forming.

In the bottom of this cavern there is a pool of very clear sea water, about 8 to 10 feet deep, so that it goes below the level of Harrington Sound and Castle Harbor to that depth, but the connection with the sea is probably only by small crevices. No fishes live in it.

PAYNTER'S VALE CAVE, ST. GEORGE'S PARISH

During H.M.S. Challenger's visit to Bermuda in 1873, Wyville Thomson (1878) observed that in his opinion:

> Paynter's Vale cave is the prettiest of the whole. The opening is not very large. It is an arch over a great mass of debris forming a steep slope into the cave, as if part of the roof of the vault had suddenly fallen in. At the foot of the bank of debris, one can barely see in the dim light the deep, clear water lying perfectly still and reflecting the roof and margin like a mirror. We clambered down the slope, and as the eye became more accustomed to the obscurity, the lake stretched farther back. There was a crazy little punt moored to the shore, and, after lighting candles, Captain Nares rowed the Governor back into the darkness, the candles throwing a dim light for a time while the voices became more hollow and distant - upon the surface of the water and the vault of stalactite, and finally passing back as mere specks into the silence. After landing the Governor on the opposite side, Captain Nares returned for me, and we rowed round the weird little lake. It was certainly very curious and beautiful; evidently a huge cavity out of which the calcareous sand had been washed or dissolved, and whose walls, still to a certain extent permeable, had been hardened and petrified by the constant percolation of water charged with carbonate of lime. From the roof innumerable stalactites, perfectly white, often several yards long and coming down to the delicacy of knitting-needles, hung in clusters; and wherever there was any continuous crack in the roof or wall, a graceful, soft-looking curtain of white stalactite fell, and often ended, much to our surprise, deep in the water. Stalagmites also rose up in pinnacles and fringes through the water, which was so exquisitely still and clear that it was something difficult to tell where the solid marble tracery ended and its reflected image began. In this cave, which is a considerable distance from the sea, there is a slight change of level with the tide, sufficient to keep the water perfectly pure. The mouth of the cave is overgrown with foliage, and every tree is draped and festooned with the fragrant *Jasminum gracile*, mingled not unfrequently with the 'poison ivy' (*Rhus toxicodendron*).

Based upon Thomson's description, it is believed that Paynter's Vale is synonymous with Church Cave, located on the south side of the driveway leading in to the Castle Harbour Hotel. The cave was given this second name after a persecuted, 17th century religious group that supposedly used the cave for worship (Forney, 1973).

SHARKS HOLE, ST. GEORGE'S PARISH

An excursion to this small cave along the coast of Harrington Sound was recounted by Lloyd (1835):

> Under a rising bank, is the mouth of a curious cavern, called Sharks Hole, into which we put our little boat. It received this name from having once been a favourite retreat of these voracious fish. Being pretty certain that we were not likely to find any of its unwelcome inmates at home, we enjoyed the delicious coolness of the grotto, and the water being per-

fectly transparent, we examined with interest its variegated bottom. As our boat glided along, we beheld innumerable beautiful fish sporting in the depths beneath us, or leaping and bounding to the surface.

DEVIL'S HOLE, SMITH'S PARISH

The Devil's Hole was walled by its owner, Mr. Trott, in 1830 and was opened to the public for an admission fee as Bermuda's first commercial tourist attraction in 1843 (Zuill, 1946). According to Hayward (1910):

> The Devil's Hole or Neptune's Grotto. . .is a natural grotto, in the side of a hill, and is fed with water by underground channels that are connected with the Sound. It contains about two thousand fishes, representing thirty different species, with the wide-mouthed, voracious grouper in the majority. Standing on the bridge, you look down into the red jaws lifted out of water as the groupers listen for the rattle of the keeper's bait can. The pool is quiet, and one may study the mottled bodies until bait is thrown in; then there is great commotion, and the water is churned into a whirlpool. When the ripples smooth out, there is a surprising transformation, for the groupers have changed their dress to black - an instantaneous and unseen process. Let no one entertain the delusion that these fish are not dangerous. A British officer once ridiculed the fact and to test its truth threw his dog into the pool. In a second the animal was torn to pieces, and its master departed much chastened in spirit.

Harshberger (1914) observed that blue-green algae were contributing to the formation of stalactites present along the open sides of Devil's Hole by removing carbon dioxide from the water, thus enhancing deposition of calcium carbonate.

TUCKER'S TOWN CAVE, ST. GEORGE'S PARISH

Tucker's Town Cave is located in a hillside on the Tucker's Town Peninsula. The cave is entered by a 15 m deep shaft leading to a large salt water lake. Deteriorated remains of steps and a wooden and concrete platform in the cave indicate that it was partially developed for an unknown purpose at some time in the past.

Swinnerton (1929) noted that:

> Within the caves so slight has been the influence of sea water on the submerged deposits and limestone walls that if the water were now drawn away evidences of its previous presence would scarcely be observed. Only one cave Tucker's Town - seems to show any mark of sea-level. In that cave the influence of the tide has been to retard the mural deposits along a 2 ft. zone. The general absence of this effect suggests recent change of level.

BASSETT'S CAVE, SANDYS PARISH

Nelson (1840) depicted Bassett's Cave in his descriptions of Bermuda's caverns:

> The largest and, geologically speaking, the most instructive [cave in Bermuda], is Basset's, near Somerset bridge. It is said to extend for more than a mile; but the first few hundred yards of toilsome progress usually satisfies the curiosity of the majority of its visitors. It seems to be comparatively recent, from the fresh state of its surfaces, and the small quantity of stalactite observable; this absence of incrustation, however, renders the origin of this cavern very palpable; namely, the undermining of the substrata by the sea, the waters or which lie in pools at the bottom."

Lloyd (1835) mentions the first and only known caving fatality in Bermuda's history in this cave:

> Near the sea-shore, I visited a large cavern called Basset's Cave; the entrance is wide, and lies quite exposed: after proceeding a little way, we came upon a spring of deep water, in which an unfortunate young man lately drowned himself. He had been missing for some days when his body was discovered by a favorite dog.

A calcite-covered skull and beak of a seabird, the Strickland's shearwater, was collected from Bassett's Cave in 1907 (Shufeldt, 1916).

TUCKER'S ISLAND CAVE, SANDYS PARISH

Verrill (1907) described this cave as follows:

> In the large cavern on Tucker's Island, the bottom is covered by 6 to 10 feet of clear sea water, beneath which I saw, in 1901, many large pointed stalagmites standing upright, but not reaching the surface. Some of these were more than a foot in diameter. This cavern, which is open to visitors on payment of a fee, has to be explored in a boat. Its roof is supported by large stalactitic columns, many of which are of hardened limestone, thickly encrusted with dull-colored stalactitic material, but most of them extend beneath sea water to the bottom.

Hayward (1910) stated that:

> Tucker's Island should be visited, if only to see its cavern and underground lake, which is lighted by acetylene gas. The stalactites are of great size - much larger, indeed, that the roof pendants of caves in other localities.

Nelson (1840) described what was apparently another partially submerged cave on Tucker's Island:

> Tucker's Island cavern was a perfect bijou; with one splendid exception it has hitherto stood unrivalled amongst the caves of Bermuda. This little cavern had a length of eighty feet, a breadth of fifty, a height above the little lake within of at most fifteen, and a depth below its surface scarcely exceeding fourteen. The stalactites were remarkably clear and beautiful, varying from the massive pendant of six or seven feet in length, to the slender incipient fragile tube, which crumbled at the slightest touch. It was a scene not to be readily forgotten, when we launched a little boat into the miner's first and narrow opening, through which the sun shone strongly, and reflecting its light from the face of the water upwards and with power to the sparry fretted ceiling of the vault, illuminated it in a way which can only be appreciated by those who have been eye witnesses of such effects. This cave was shortly afterwards destroyed, as interfering with the safety of the works.

BERMUDA'S CAVES TODAY

In the intervening centuries since the above quoted cave descriptions were composed, profound alterations have modified most of the island's caves to their detriment (Iliffe, 1979). Only two caves - Crystal and Leamington - in addition to the Devil's Hole, are still commercially shown to tourists.

The staff quarters of the Grotto Bay Hotel was constructed directly over the largest chamber in Admiral's Cave. The stump of the famous stalagmite, bearing the drill holes used by Wyville Thomson to obtain a slice from the stump in 1873, is still clearly visible within the cave. However, several of the once clear sea level pools have turned murky and anoxic, possibly due to sewage pollution from the overlying hotel staff quarters. The stalagmite itself was on display for many years in front of the mathematics classroom at the University of Edinburgh, but was destroyed when the building housing it was demolished (W.J. Baird, pers. comm.).

The Joyces Dock Caves are now also part of the Grotto Bay Hotel. The saltwater pool in Cathedral Cave is now used as an indoor swimming pool by the hotel's guests. Island Cave, now called Prospero's Cave, has been converted into a subterranean bar and discotheque. A large stalagmite in undeveloped Sibley's Cave had been cut from its base and was found packed with styrofoam pieces in a oil drum in a failed attempt to transport it out of the cave. The pool in Bluebell Cave noted for its reflected sunbeams was destroyed by filling of the floor of the cave in an abortive effort at constructing an underground dance floor.

The Walsingham Caves have been preserved in a privatelyowned nature preserve, the Walsingham Trust. The concrete walkways and steps constructed through this area have disappeared into the undergrowth, though Tom Moore's ancient calabash is still to be found in an isolated woodland glen.

The Blue Grotto was recently operated as a commercial dolphin show, while dolphin food was stored in Castle Grotto. Wonderland Cave was purchased by the owners of Crystal Cave and has not been shown to tourists since before World War II (Forney, 1973). Fortunately, an entrance gate has protected many of the delicate formations within this cave.

Within the last decade, pools in Leamington and many other caves in the vicinity of the Government Quarry have become anoxic and polluted, probably due to extensive dumping of garbage and other organic wastes into a large cave pool in the quarry (Iliffe, Jickells & Brewer, 1984). Peniston's Cave, believed to have been situated at or near this quarry, has probably been buried or destroyed. Bassett's Cave, located on the grounds of the U.S. Naval Air Station Annex, is being used as a natural cesspit by the base for disposal of raw sewage and waste fuel oil. Sea level pools within the cave are covered by a half a meter or more oil, rising and falling with the tides. Nearby Tucker's Island Cave was destroyed during World War II era construction of the Naval Base.

Paynter's Vale or Church Cave, on the grounds of the Castle Harbour Hotel, is little visited. A few rotten planks on the bottom of the cave pool may be the remains of the boat Thomson used to explore the cave. Tucker's Town Cave is situated on a small tract of land between affluent private estates in Tucker's Town. The wooden steps that once led down into the cave have long since disappeared and a large platform covering a portion of the pool has collapsed into the water.

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ZGODOVINA SPELEOLOGIJE NA BERMUDIH

Povzetek

Bermudi leže v Atlantiku na 320N in 650W, 1000 km oddaljeni od ameriške obale. Nastali so kot podmorski vulkan pred okoli 100 milijoni let. Kopno, vsega skupaj okoli 50 km^2, sestavljajo pleistocenski in recentni eolski apnenci, do 100 m debeli. Vse jame so v teh apnencih, predvsem v starejših, bolj konsolidiranih. Posebno pozornost raziskovalcev in krasoslovcev so vzbujale jame, zalite z morsko vodo ("blue holes") in kapniki pod morsko gladino (Williams, Swinnerton, Davis, Bretz).

Jame so bile omenjane v literaturi od odkritja otokov dalje (Shakespearov "Vihar", Smith 1623, Jones 1859, Lefroy 1877). Tekom zgodovine je bilo devet jam urejenih za turistični obisk, od tega sta danes še dve. Kapnike in sigo so lomili po številnih jamah in jih uporabljali za surovino. Jetniki in kaznjenci so iz njih delali vse mogoče, od šahovskih figur do nakita. Admiral Milne je zbirko kapnikov podaril univerzi v Edinburghu, med njimi 3,4 m visok in 3,5 tone težak stalagmit. Zanj je D. M. Home (1864) izračunal (po sigi, odloženi na odlomljenem mestu) starost preko 600.000 let.

Danes so jame močno spremenjene in degradirane zaradi gradenj (nekaj jih je vključenih v hotelski kompleks, ena služi hotelu kot pokrit bazen), zaradi odpadnih voda, ki so napeljane v jamske lagune, jame zasipajo z odpadnim gradivom, neka jama služi za predstave delfinov, v sosednji pa je vskladiščena hrana za te delfine. Zaradi odlaganja odpadkov v jame, tudi odpadnih olj, je gladina vode v nekaterih jamah prekrita s preko pol metra debelo plastjo olja, ki se dviga in pada skupaj s plimovanjem.

PRISPEVKA O SLOVENSKEM KRASU

FASETE, POMEMBNA SLED OBLIKOVANJA IN RAZVOJA KRAŠKIH VOTLIN

FACETS - AN IMPORTANT TRACE OF SHAPING AND DEVELOPMENT OF THE KARST CAVERNS

TADEJ SLABE

Izvleček UDK 551.441 (497.12)

Slabe, Tadej: Fasete, pomembna sled oblikovanja in razvoja kraških votlin

Fasete so ena najbolj poznanih jamskih skalnih oblik. Nastajajo zaradi vrtinčenja vodnega toka ob hrapavi površini topljive kamnine. Po zbranih vzorcih s terena sem ugotavljal, da je oblika mreže faset in njihova velikost predvsem posledica hidravličnih razmer v različno oblikovanih in velikih rovih. Na nastanek in oblikovanje faset pomembno vpliva tudi sestava in pretrtost kamnine, ki jo obliva vodni tok. Pri razlagi oblikovanja faset sem si pomagal z laboratorijskimi poskusi z mavcem.

Ključne besede:

speleomorfogeneza, kraška votlina, jamska skalna oblika, faseta, Slovenija, Dinarski kras

Abstract UDC 551.441 (497.12)

Slabe, Tadej: Facets - an Important Trace of Shaping and Development of the Karst Caverns

Current markings are one of the most significant rock forms. Their origin is controlled by swirling water flow against the rough surface of the soluble rock. On collected samples I stated that the current markings net shape and their size depend on hydraulic conditions in the channels of the various shape and size. The composition and structure of the rock overflown by water are one of the important factors influencing to the origin and shape of current markings. The explanation of facets formation was backed up by the laboratory experiments in plaster.

Key words:

speleomorphogenesis karst cavern, rocky cave feature, facet, Slovenia, Dinaric Karst

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UVOD

Faseta (Slovenska kraška terminologija 1973, 6; an: scallops (Curl 1966; Allen 1972); nem: Fliesfacette; fr: vague d'érosion (De Joly 1933 - navaja Maire 1980, 31; Renault 1968)) je nekaj 10 ali 100 milimetrov dolga ovalna vdolbinica na skalnem obodu votlin, skozi katere se pretakajo ali so se pretakali vodni tokovi. Globlja in strmejša je na pritočni strani, na odtočni strani, kjer je podaljšana, pa se polagoma izklinja. Ločimo več različnih tipov manjših faset. Velike fasete so podobne plitkim kotlicam. Rebra (an.: flutes (Curl 1966)) so podolgovate zajedice pravilne oblike, ki so nanizane prečno na smer vodnega toka. Za obe obliki je značilno, da sta povezani v mrežo. Te oblike, ki so nastale zaradi vrtinčenja vodnega toka ob hrapavi površini skale, nam pomagajo pri določevanju načina in smeri pretakanja vode skozi rove.

O proučevanju in določanju povezanosti dolžine faset in hitrosti vodnega toka, ki jih vrezuje, je že poročalo več avtorjev. Sklenil sem več pozornosti posvetiti primerjavi njihovih oblikovnih značilnosti in povezanosti v mrežo ter proučevanju dejavnikov in procesov njihovega nastanka in oblikovanja. Natančneje sem opredelil tudi vpliv kamnine na vrtinčenje. Pri tem so mi koristile predvsem obsežne raziskave na terenu ter laboratorijsko oblikovanje faset na mavcu, pri katerih mi je pomagal J. Hajna.

VIRI O FASETAH

Shaw (1992, 148, 155, 165) v zgodovini speleologije omenja avtorje, ki so prvi opozorili na fasete. Maire (1980, 31) navaja, da je prvi razpoznal fasete R. de Joly leta 1933. Bretz (1942, 731), ki je skalne oblike, nastale zaradi raztapljanja kamnine, razdelil na freatične in vadozne, poudarja pri nastanku faset odločilni pomen korozije. Opisal je primere faset, iz katerih so štrleli silikatni delci. Fasete opisuje tudi v delu (Bretz 1956), kjer je prvi vrednotil skalne oblike kot speleogenetsko sled.

O proučevanju in določanju povezanosti dolžine faset in hitrosti vodnega toka, ki jih vrezuje, so poročali Rudnicki (1960, 17), Curl (1966, 1974), Goodchild in Ford (1971), Allen (1972), Lauritzen (1983) ter Lismonde in Lagmani (1987).

Rudnicki (1960) je prvi skušal razložiti nastanek faset in njihove značilnosti s poskusi na mavcu. Ugotovil je (1960, 29), da hitrejši vodni tok vrezuje manjše fasete. Pravi (1960, 30), da je oblika mreže faset zrela, če so fasete povezane v nize, ki so prečni na smer

vodnega toka. Sam sem ugotavljal, da so takšni nizi značilni za ožine v rovih, stenske zajede in odtočne strani skalnih blokov v strugi.

Curl (1966, 1974) si je nastanek faset pomagal razlagati z analizo hidravličnih značilnosti v rovih, z merjenjem toka med elektrodami na modelu in s poskusi na mavcu. Postavil je temelje za povezavo hitrosti vodnega toka in velikosti faset. Ugotavlja, da sta oblika in velikost posledica poprečne hitrosti vodnega toka v kanalu, dimenzije kanala, gostote in viskoznosti vode ter difuzivnosti ionov, če je raztapljanje enakomerno in kamnina homogena. Poudarja pa tudi pomen različnih lastnosti, zlasti razpokanosti kamnine, ki povzročajo nepravilnosti pri nastajanju faset. Nepravilnosti na površju kamnine povzročajo namreč nastanek zatišnih leg v vodnem toku in ker so fasete povezane v mrežo, se po toku navzdol poznajo tudi vplivi predhodnih oblik. Dodaja vpliv erozije. Predstavi tudi rebra.

Renault (1968, 563) je nastanek majhnih faset razlagal s pospeškom vodnega toka, ki ga usmerijo prodniki. 50 milimetrov dolg prodnik povzroči cirkulacijo vode s hitrostjo 20 milimetrov na sekundo, kar ustreza nastanku fasete, dolge 10 - 20 milimetrov. To trditev zanika že dejstvo, da fasete nastajajo tudi v rovih, kjer prodnikov ni, oziroma prodniki pogosto celo zgladijo stene rovov.

Goodchild in Ford (1971) sta s poskusi na mavcu poizkušala določiti hidravlične vzroke za različne velikosti faset. Z opazovanjem na terenu sta predpostavila velik pomen kamnine pri njihovem oblikovanju. Prevladujoč proces oblikovanja faset je tudi po njunem mnenju korozija.

Tudi Allen (1972), ki Curlu očita preveliko teoretičnost razglabljanj, si je pomagal s poskusi na mavcu. Mavec v 3 m dolgem kanalu je oblival s tokom s hitrostjo 28 do 90 cm na sekundo in debelino 1,5 do 15 cm. Allen (1972, 7) poudarja, da fasete nastanejo le, če so nehomogenosti v kamnini dovolj velike, da se oblikujejo samostojni vrtinci ob steni. Nehomogenosti v kamnini vplivajo na razporeditev faset, že posamezna nehomogenost pa povzroči nastanek faseti podobne oblike.

Lauritzen (1983) je meril hidravlične razmere v rovu, velikost faset ter hitrost njihovega nastanka.

Trudgill (1985, 75) posebej izpostavlja, da je za nastanek in razporeditev faset odločilna litološka nehomogenost: razlike v topljivosti posameznih delcev kamnine povzročajo lokalne turbulence in mešanje vode poveča lokalno korozijsko stopnjo.

Lismonde in Lagmani (1987) sta Curlove študije hidravličnih razmer v pravilno oblikovanih rovih skušala dopolniti s poudarkom na raznovrstnosti rovov.

Ford (1988, 46) meni, da fasete nastanejo z ločitvijo nasičene mejne plasti v subkritičnem režimu toka, kar omogoči agresivnemu toku raztapljanje in sublimacijo produktov neposredno, brez vmesne difuzije skozi ionski ovoj. Leto kasneje z Williamsom dodajata (1989, 305), da so prekinitve mejne plasti bolj pogoste, čim hitrejši je vodni tok.

Fasete, ki jih vodni tok vrezuje v stene Križne jame, omenjata Badiura (1909, 31) in Michler (1934, 99). Poimenovala sta jih vdolbinice podobne školjkam.

Gams je fasete omenil v študiji o Logarčku (1963, 51). Leta 1974 je v delu Kras (101, 102, 160), kjer je strnil pregled skalnih oblik, predstavil tudi fasete,

Skalne oblike so omenjene v Jamarskem priročniku.

Habe (1970, 26, 33) razlaga razvoj Predjame tudi z erozijskimi kotlicami in fasetami, Beloglavke pa (Habe 1976, 197, 200) s stopničastimi erozijskimi poličkami in erozijskimi kotlicami.

Prvi sistematični pregled skalnih oblik, tudi faset, je predstavljen v Slovenski kraški terminologiji (1973).

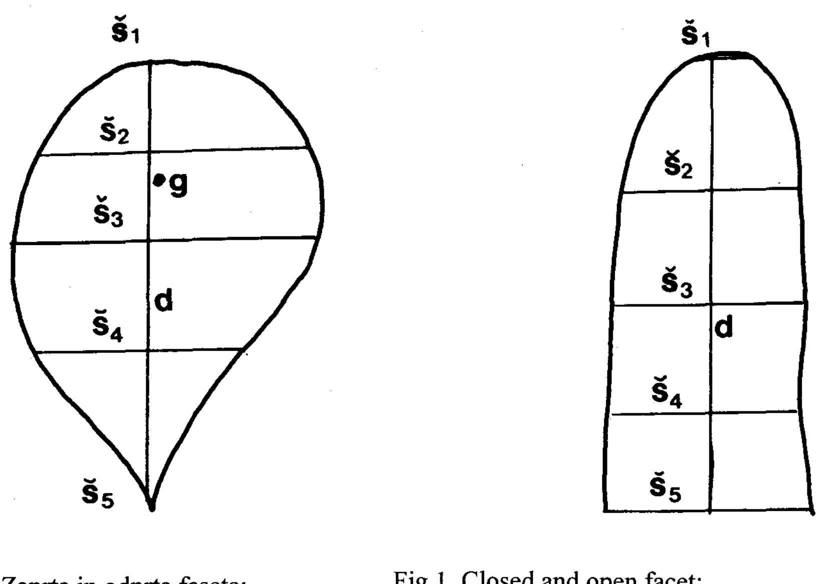
Gospodarič je pri proučevanju speleogenetskega pomena naplavin v Križni jami (1974, 332, 333, 348) skalne oblike poimenoval mikrooblike ter s fotografijo predstavil fasetirano čer. Leta 1985 je Gospodarič (1985, 22) opisal fasetirane erozijske zajede v Trhlovci.

Oblike, ki so produkt odnašanja kamnine, je Šušteršič (1985) imenoval speleogene.

Sam sem opisal majhne fasete, ki jih vrezuje občasni hitri vodni tok v Križni jami (Slabe 1989, 203).

OBLIKA IN VELIKOST FASET TER NJIHOVA POVEZANOST V MREŽO

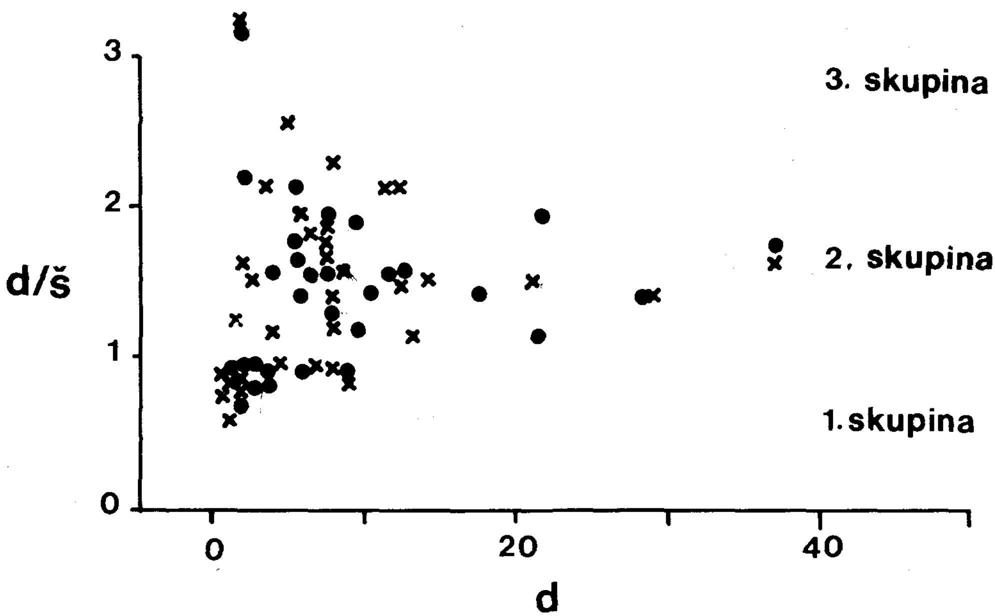
V izbranih slovenskih jamah sem dokumentiral 75 mrež faset, 53 pa jih je bilo primernih za nadaljnje proučevanje. Starejše mreže faset, ki so bile preoblikovane pod drobnozrnato naplavino ali zaradi kondenzne korozije, imajo premalo ostro ohranjene oblikovne značilnosti, zato je njihovo merjenje onemogočeno.



Sl.1. Zaprta in odprta faseta:
d= dolžina
š= širina
g= globina
k= stični kot odtočnih robov

Fig.1. Closed and open facet:
d = length
š = width
g = depth
k = contact angle of outflow edges

Obliko posamezne fasete sem razdelil v številčne skupine, kar bi skupaj z velikostjo fasete omogočilo statistično računalniško primerjavo. Izkazalo se je, da računalniška primerjava ni bila potrebna, saj je bil vzorec razmeroma majhen in podobne številčne vrednosti sem dokaj enostavno razvrstil v skupine. Faseti sem določil (sl. 1) dolžino, širino leve in desne polovice na začetku, na prvi četrtini, polovici, tretji četrtini in na koncu, ter mesto in vrednost največje globine. Izmeril sem tudi polmer pritočnega, večinoma polkrožnega roba fasete ter sklepni kot zaprtih faset. Na ta način sem dobil poprečno obliko in velikost faset v posameznih mrežah. Poprečne oblike bolj ali manj odstopajo od vsakokratne oblike na skali. To je posledica različne kamnine, na kateri so fasete in njihove povezanosti v mrežo. Izkazalo se je, da v mrežah prevladujeta dve obliki faset: fasete, ki se na odtočni strani zaprejo s širšim ali ožjim kotom (sl. 1) in fasete, ki so na odtočni strani odprte (sl. 1), posamezne se v zadnji tretjini deloma zaprejo. Ti obliki sta povezani v isti mreži ali pa v njej prevladujeta. Zaprte in odprte fasete iste mreže se praviloma uvrščajo v isto skupino. Zaradi izrazite razlike v obliki sem zaprte in odprte fasete razčlenjeval ločeno. Za primerjavo faset po obliki sem moral izločiti njihove velikosti. Zato sem izračunal za poprečne oblike faset v mreži razmerja med dolžino fasete in omenjenimi širinami. Podobne številčne podatke sem razvrstil v 3 skupine in vmesni podskupini (sl. 2).



Sl.2. Značilne skupine faset
d/š= razmerje med dolžino in širino fasete
d= dolžina fasete
Fig.2. Characteristical groups of the facets
d/š = rate between the lenghth and the width
d = facet's length

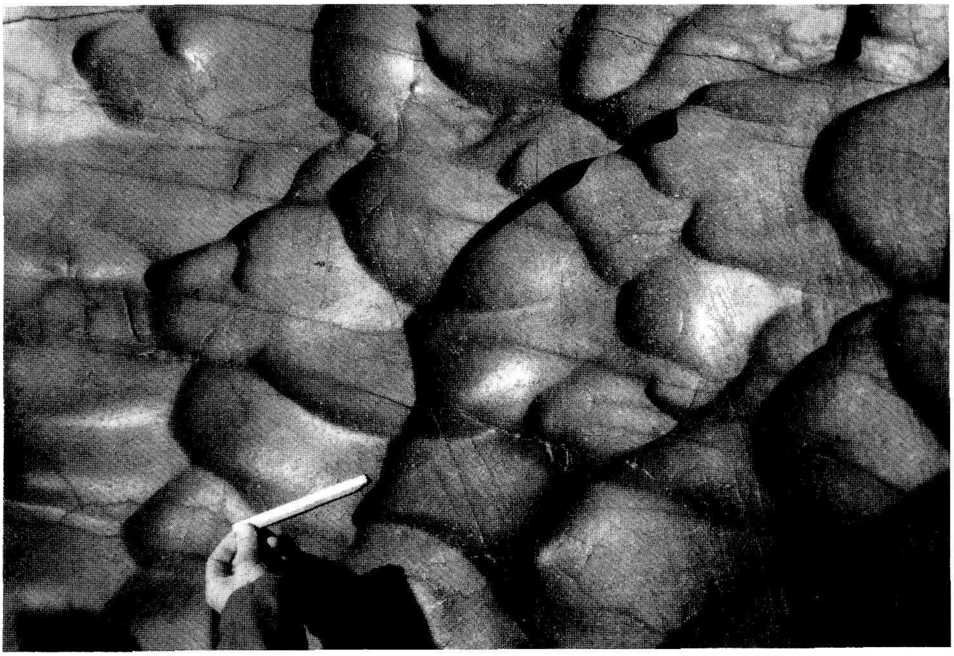
V prvo skupino sodijo fasete, katerih razmerje med dolžino in širino je manjše ali enako 1,1. Zaprte fasete lahko razdelimo na tiste, ki so enako široke na prvi četrtini in tretji četrtini ter najširše na polovici, in fasete, ki se zožujejo po polovici. V posameznih primerih (strma stena, 45o, Ponora v Odolini, strop Ponorne jame Lokve in strop v Kompoljski jami) v mreži prevladujejo odprte fasete. Fasete v 1. skupini so večinoma majhne, saj so dolge od 4,7 mm do 40 mm, globoke so od 2 do 10 mm. Izjema sta dva primera, ki sta dolga 66 in 92 mm. Fasete so povezane v nize, ki so razvrščeni prečno na smer vodnega toka (sl. 3). Odtočna robova zaprtih faset se praviloma stikata pod kotom, ki je večji od 90o (do 120o), premer pritočnega polkrožnega roba pa je glede na velikost faset velik. Bočni robovi faset so mnogokrat le slabo izraženi in mreža spominja na rebra. Prečni nizi sledijo tudi lokalnim smerem vodnega toka: v Novokrajski jami se združujejo proti odprtini sifona, v Pivki jami se usmerjajo proti robu kamnitega bloka, na katerem so nastale, v Ponoru v Odolini so nizi v žlebu polkrožno poviti. Najmanjše fasete, ki so nastale zaradi pretakanja odprtega vodnega toka, dolge so od 4,7 do 23 mm, so na strmih tleh (30o nagiba) in v strmih (75o) žlebovih. Podobne, le nekoliko večje, so v izrazitejših ožinah rovov, ki so občasno zaliti. Fasete prekrivajo cel obod ožine. Premeri ozkih delov rovov merijo od 1 do 2,5 m, pritočnih in odtočnih delov pa do 5 m. V večji stropni depresiji v Ponorni jami Lokve so na odtočni strani fasete na skorajda navpični steni. V mreži pa prevladujejo odprte fasete. Nekoliko večje fasete (33-90 mm) so v manj izrazitih ožjih delih rovov.

Sl.3. Fasete na steni ožine pri Blatnem jezeru v Beško Ocizeljski jami (merilo=15cm)
Fig.3. Facets on the wall at the narrowness at Blatno jezero in Beka Ocizla (scale = 15 cm)

Podobnih oblik, torej dokaj široke, so fasete v podskupini 1-2. Fasete imajo velike polmere pritočnih, polkrožnih robov, odtočna robova pa se stikata pod kotom 100-130o. So večje kot v prvi skupini, dolge so od 40-110 mm. V dveh primerih (stena Logaške jame, stena rova v Brlogu na Rimskem) prevladujejo zaprte fasete. Fasete so še razvrščene v prečne nize, ki pa niso tako izraziti kot v prvi skupini. Deloma je že nakazana diagonalna razporejenost faset, ki je značilna za mreže faset druge skupine. Manjše fasete (tla in spodnji del stene v Markovem spodmolu) te podskupine so nastale v odprtem vodnem toku in sicer na tleh ali na spodnjih delih sten. Druge (stena v Blatnem rovu Zelških jam, stena Logaške jame, stena Brloga na Rimskem, stena v osrednjem rovu Trhlovce) pa so nastale v občasno zalitih rovih. Pogoje njihovega nastanka je težje določiti, saj so starejšega porekla. V Zelških jamah so široke fasete na steni in kažejo lokalni tok vode navzgor, je pa v njihovih pritočnih delih odloženo nekaj ilovice, ki jih je korozijsko razširila. Na nasprotni strani rova so fasete v stenski zajedi usmerjene navzdol. Fasete na stenah Trhlovce, Logaške jame in v Brlogu na Rimskem so v podolgovatih, polkrožnih stenskih zajedah, ki so široke 0,5 m.

V drugo skupino sem uvrstil fasete z razmerjem med dolžino in širino od 1,1 do 2. Tudi te so zaprte in odprte. Zaprte fasete so večinoma najširše na polovici, nekatere so še enako široke na tretji četrtini, druge pa se ožijo že po prvi polovici. Odprte so dokaj enako široke od prve četrine naprej, nekatere pa se v zadnji četrtini nekoliko zožijo. Takšne so zlasti največje fasete. Polmer polkrožnih pritočnih robov zaprtih faset je nekoliko manjši kot pri odprtih. Zaprte fasete se zaključujejo s kotom 80-90o. V to skupino sodijo tudi največje fasete, je pa razlika med najdaljšo in najkrajšo precejšna: od 24 do 375 mm. Večinoma so dolge od 60 do 150 mm in globoke od 20 do 60 mm. V mrežah, ki jih sestavljajo manjše fasete, so še deloma poudarjeni prečni nizi. Prevladujejo mreže, za katere je značilna povezanost stranskih robov, ki omejujejo odtočne dele faset, v diagonalne nize (sl. 4). Fasete druge skupine so nastale večinoma v zalitih rovih. Fasete so lahko po vsem obodu ali le na tleh in stenah, na stropu pa so kotlice. Lahko so tudi na skalnih blokih, ki prekrivajo strugo (Osapska jama, Krožni rov v Črni jami), vendar so te nekoliko širše, v mreži pa prevladujejo odprte fasete. V to skupino sodijo tudi fasete, ki so nastale na strmih, navzdol (45o) ali navzgor (50o) nagnjenih odsekih tal, te so nekoliko podaljšane, in na strmih previsnih stenah, kot je to primer v ožini Lipiške jame. Skoznjo se je pretakal vodni tok navzgor. Premeri rovov s fasetami takšnih oblik so večji kot tistih, v katerih so fasete 1. skupine. Manjši merijo 1 meter, segajo pa do 10 m (Kozinski rov v Lipiški jami).

V tretjo skupino sodijo fasete z razmerjem med dolžino in širinami večjim od 2. Tudi te lahko razdelimo na zaprte in odprte, prevladujejo pa odprte. Radij pritočnih polkrožnih robov je ožji kot v prejšnih skupinah, stični kot odtočnih robov pri zaprtih fasetah je 75-90o. Fasete so razmeroma majhne, dolge so od 1 do 5 cm. Poseben primer so zelo ozke fasete, dolge 1-3 cm. Nastanek na skalnih blokih določa obliko in velikost mreže (sl. 5). Mreža je podobna onim v prvi ali drugi skupini, pogosto se začenja na stiku z gladko površino skale. Fasete nastajajo na skalnih blokih v večjih strugah, ki so široke 5-10 m, in po katerih se pretaka odprti vodni tok. Površina blokov je 1-2 m nad dnom struge. Nastajajo torej ob višjih vodah. V Hankejevem kanalu v Škocjanskih jamah je na zgornji, vodoravni ploskvi bloka fasetiran odtočni rob, četudi je nekoliko nižji. Zlasti izrazite so fasete, kjer se blok odsekano zaključi. Ob robu bloka so fasete povezane v prečne nize. Na dotočnih delih

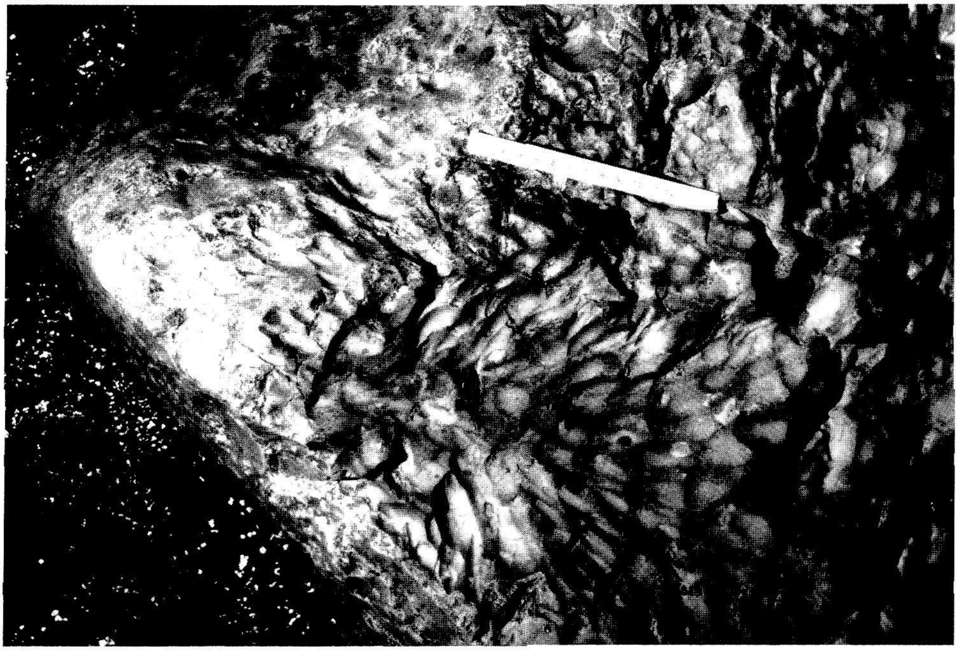


Sl.4. Fasete na stropu Markovega spodmola
Fig.4. Facets on the ceiling of Markov spodmol

blokov pa so širše fasete dokaj neizrazitih oblik, razvrščene so v delnih prečnih nizih in med njimi skorajda ni stranskih robov.

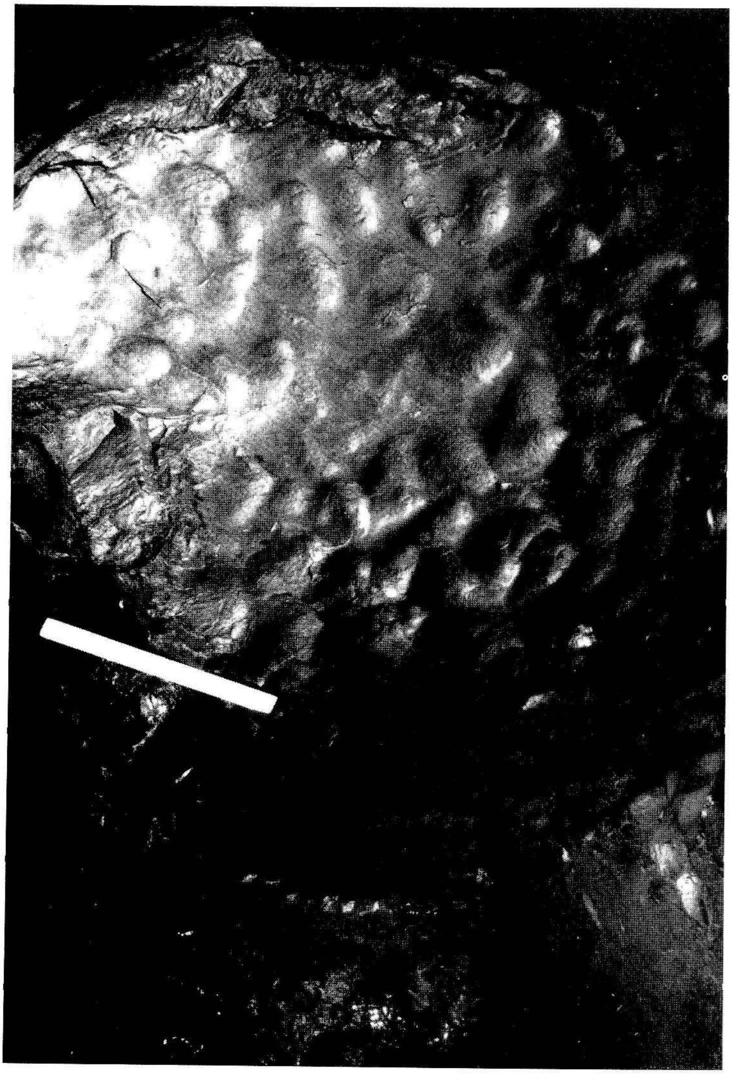
V podskupino 2-3 se uvrščajo fasete z razmerjem med dolžino in širino okoli 2, vendar so večje kot fasete v tretji skupini. Dolge so večinoma od 5 do 15 cm, a med ožjimi fasetami, ki prevladujejo, so tudi širše. Ta tip faset je značilen za rove, v katerih se pretaka odprti vodni tok, ki rove v precejšni meri zapolnjuje. Plast vode je torej dokaj debela. Fasete so na tleh ali na steni. So večinoma odprte in značilne za izpostavljena konveksna dna rovov (glavni rov v Križni jami, del izbočenih tal v Markovem spodmolu), ali za izpostavljene dele sten pred razširitvami rovov (stena 2-3 m nad tlemi v Markovem spodmolu, Vzhodni rov v Predjami: rob korita).

Posebej lahko izdvojimo še en tip manjših faset. To so majhne, le nekaj cm dolge fasete, ki so globoke do 0,5 cm. So večinoma krožnih obrisov in smer vodnega toka je iz njih le slabo razvidna. So posamične ali povezane v mrežo in so na stiku z gladko površino skale, ali pa so med njimi manjše površine gladke skale. Takšne fasete so pod večjimi padajočimi tokovi, ali pa na pritočni, pokončni strani blokov v strugi (sl. 6).



Sl.5. Fasete na skalnem bloku v strugi Škocjanskih jam (merilo=15 cm)
Fig.5. Facets on rocky boulder in the riverbed in Škocjanske jame (scale = 15 cm)

V izbranih jamah sem imel možnost videti le stare velike fasete, zato je bila večina slabše ohranjena. Premer največjih faset meri 1-1,5 m in so globoke od 0,3 do 0,5 m (sl. 7). Velike fasete imajo oblike plitkih polkrogel. Njihova mreža je težko razberljiva. Kot robovi so lahko ostali tudi večji stenski noži in roglji. Nekoliko manjše fasete imajo premer od 0,5 do 0,75 m, globoke pa so od 0,1 do 0,2 m. Tudi te so plitke polkrogle ali pa imajo elipsaste prečne prereze. Najbolj izrazite elipsaste fasete so nastale zaradi vodnega toka, ki se je pretakal od spodaj navzgor. Njihova povezanost v mrežo je bolj izrazita in iz nekaterih primerov je moč sklepati na smer vodnega toka. Velike fasete so nastale v zalitih rovih in najdemo jih lahko na stenah in na stropu.



Sl. 6. Fasete na pritočnem delu skalnega bloka v Podpeški jami (merilo je 15 cm)
Fig.6. The facets on the inflow part of rocky boulder in Podpeška jama (scale = 15 cm)

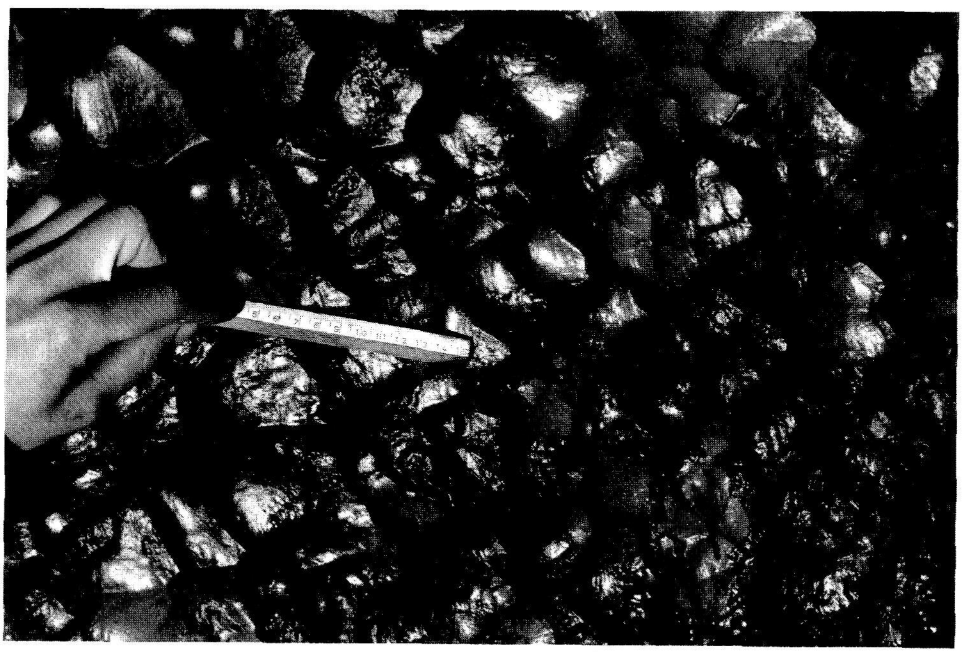
Sl.7. Velike fasete v Pivškem rokavu Planinske jame (merilo= 15 cm)
Fig.7. Big facets in Pivka branch of Planinska jama (scale = 15 cm)

VPLIV KAMNINE NA RAZVOJ FASET

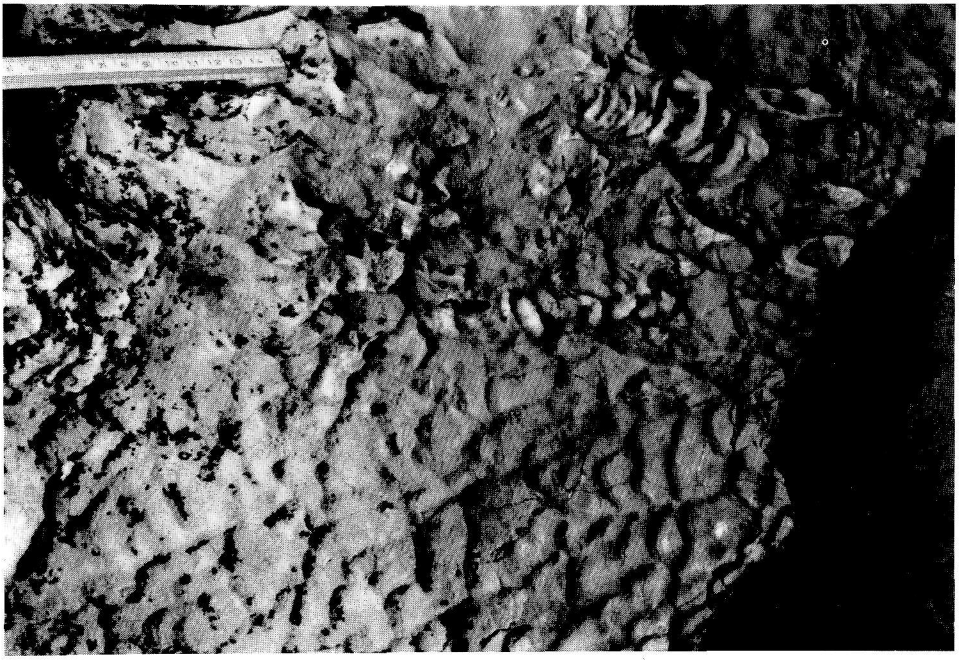
Večina faset je oblikovana na različnih apnencih, redkeje jih najdemo na dolomitu, konglomeratu, breči, sigi in peščenjaku. Na nastanek in obliko faset vpliva tudi razpokanost kamnine.

Na homogenih apnencih z enako velikimi in topnimi delci so nastale dokaj enotne mreže faset. Bolj heterogene mreže nastajajo na nehomogeni, različno sestavljeni kamnini. Takšne so tudi v Markovem spodmolu na delu stene, ki jo tvorijo večji intraklasti (sl. 8). Robovi faset so nazobčani, na posameznih odsekih pa jih ni. Na bližnji, bolj homogeni kamnini, so nastale fasete z ostrimi in ravnimi robovi. V Velikem Hublju, kjer je na posameznih odsekih apnenec prekristaliziran, površje skale pa je hrapavo, saj iz njega štrlijo 1-3 cm veliki sparitni kristali, faset ni. V površino so zajedajo le posamezne majhne vdolbinice. Na okolnem, bolj homogenem apnencu so fasete ali pa je površina erozijsko zglajena. Podobnemu primeru smo priča tudi v Biološkem rovu v Babji jami. Na občasno poplavljenem delu stene v Pivki jami so fasete dolge okoli 3 cm, kjer pa štrlijo 1,5 cm iz površine rudisti, faset ni (sl. 9). Tudi v Predjami v Ponorni jami Lokve štrlijo iz stene rudisti. Prek njih je vrezana mreža faset, ki so večje, saj so dolge 8 cm. Mreža je neenotna. Na paleogenskem apnencu pa fosili le malo vplivajo na obliko manjših faset (sl. 3).

Nehomogenost kamnine vpliva tudi na odstopanje smeri posameznih faset od lokalne



Sl.8. Fasete na intraklastnem apnencu v Markovem spodmolu
Fig.8. Facets on the intraclastic limestone in Markov spodmol

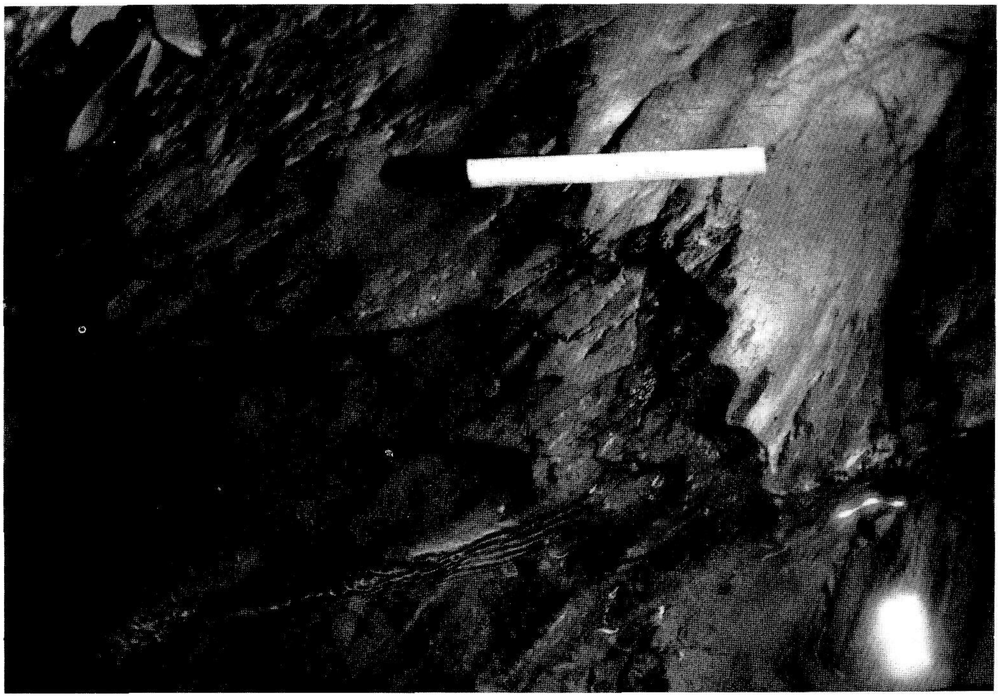


Sl.9. Fasete na apnencu z rudisti v Pivki jami (merilo= 15 cm)
Fig.9. Facets on the limestone with Rudists in Pivka jama (scale = 15 cm)

smeri vodnega toka in na njihovo različno velikost. Takšno odstopanje je značilno zlasti za mreže večjih faset, ko ob strlečih delih kamnine nastanejo "cvetovi" (sl. 4). V njih se voda razliva na različne strani in smeri posameznih faset odstopajo tudi za 60o. Fasete so usmerjene proti robovom stenskih nožev, odlomnih površin in skalnih blokov, ter temu tudi oblikovno prilagojene.

Na dolomitu so fasete redke, če pa že nastanejo, so praviloma neizrazitih oblik. Na tleh korita v Stinkotovem rovu v Turkovi jami so na dolomitu 5-7 cm dolge vdolbinice, ki so nekoliko poglobljene na pritočni strani. V Križni jami in v Velikem Hublju iz dolomita štrlijo manjši in večji skupki kristalov sparitnega veziva. Faset ni, so pa v površino dolomita, ki štrli iz sten, zajedene posamezne majhne vdolbinice. V Jami v Peklu na Kočevskem so nastale majhne mreže faset le na posameznih odsekih biosparitnega dolomita, ni pa jih na zdrobljenem mikrosparitnem dolomitu brez kalcitnih žilic.

V Smoganici so v strugi, katere obod tvori karbonatni konglomerat, fasete le na kosih apnenca, ki so večji od 20 cm. Fasete, ki so dolge 5 cm, so dokaj nepravilnih oblik. Vezivo, v katerem so manjši kosi apnenca in peščenjaka, pa je grobo hrapavo. V razčlenjenih konicah štrli iz skalne površine. Podobno je oblikovana breča v Bazinovi jami pri Podlaških topolih. Na bližnjem delu oboda, ki je apnenčast, so fasete. Faset ni na intraformacijski breči v Podstrešju Male Boke. Brečo sestavljajo manjši deli kamnine (1-3 cm premera), vmes pa je



Sl.10.Fasete na peščenjaku v Smoganici (merilo= 15 cm)
Fig.10. Facets on the sandstone in Smoganbica (scale = 15 cm)

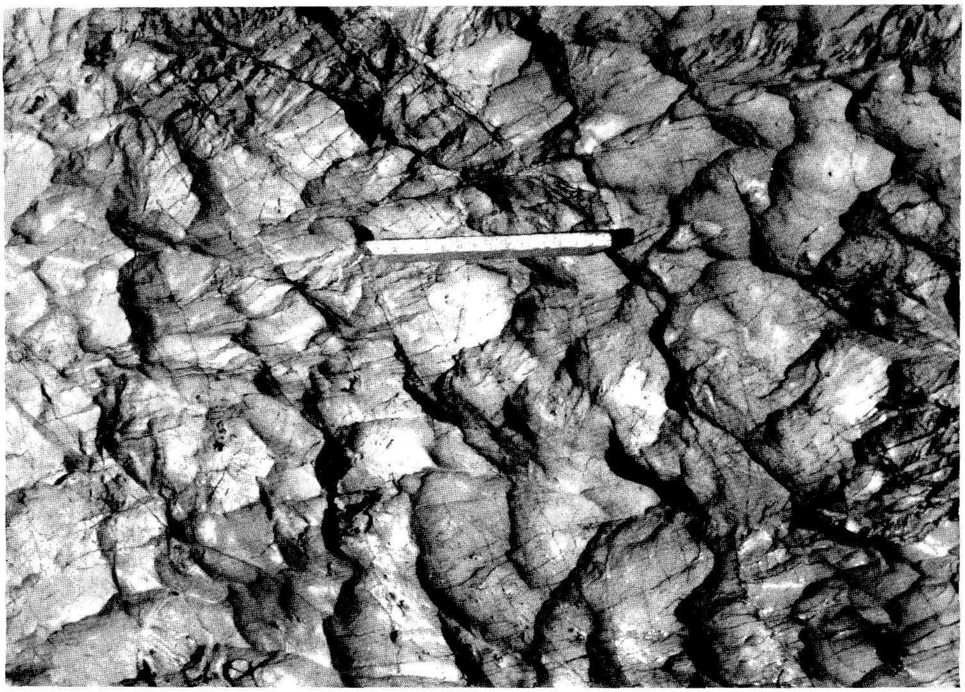
trdno sparitno vezivo, ki štrli iz sten. Med sparitnim vezivom so nastale oglate vdolbinice, podolgovate ob razpokah. V bližnjem rovu z apnenčastim obodom, kjer se ob visokih vodah ustvarijo enaki hidrološki pogoji, nastajajo fasete, ki so dolge 2-3 cm.

V Lepih jamah Postojnske jame štrlijo do 2 cm iz stene podolgovate leče roženca, katerih površina je nazobčana z ravnimi ali le malo zaobljenimi ploskvami. Okoli leč pa je lepo razvita mreža majhnih faset.

Fasete na sigi so podobne fasetam na apnencu. V Katakombah v Mali Boki so nastale fasete na prepereli sigi. Robovi faset so zaobljeni in deloma spominjajo na sipine v strugi Blatnega rova v Križni jami, ki ga prekriva pesek. Na mehkih, sipkih materialih nastanejo fasete 1. skupine.

V Smoganici so nastale fasete na kremenovem peščenjaku s kalcitnim vezivom (sl. 10). Fasete so dokaj dolge (7 cm) in ozke (3 cm). Uvrstimo jih lahko v tretjo skupino, kar odgovarja občasnemu plitkemu toku in homogeni zrnati kamnini.

Ob drobnih razpokah so fasete (sl. 11) lahko podaljšane (Slabe, 1989, 203), povezane v nize, gosta drobna razpokanost pa povzroča večje razlike v smereh faset in njihovi velikosti. Ob razpokah so robovi faset pogosto nazobčani. Razmerja med največjimi in najmanjšimi fasetami v mrežah, ki nastanejo na razpokanih kamninah, pa dosegajo tudi 3.



Sl.11.Fasete na pretrtem apnencu Podstrešja v Mali Boki (merilo=15 cm)
Fig.11. Facets on crushed limestone of Podstrešje in Mala Boka (scale = 15 cm)

Na izraziteje, gosto pretrti in zdrobljeni kamnini faset ni. So le na morebitnih vmesnih, večjih in nerazpokanih površinah. Stene rovov so zato razčlenjene v konice, ob izrazitejših razpokah pa v stenske nože. Drugače pa vplivajo na oblikovanje faset razpoke, ki so zapolnjene s kalcitnim vezivom. Vezivo je pogosto nekoliko odpornejše od okolišne kamnine in nekaj mm štrli iznad ostale površine. Vpliva na manjše fasete (Križna jama), na večjih se pogosto ne pozna (Ponikve v Jezerini). Kjer pa kalcitne žilice prepredajo kamnino vzporedno s površino stene, na kateri so fasete, je njihov vpliv neznaten. Če kalcitno vezivo premalo trdno povezuje kamnino, ta v vodnem toku ni obstojna. Od nje se krušijo manjši kosi kamnine. V Finkovi jami je močno prekristaliziran apnenec sestavljen iz večjih sparitnih kristalov. Zato na stenah ni majhnih faset, ki bi jih vrezal vodni tok, ki doseže hitrost 1 m/s. Majhne površine dolomita, ki se kroji in ga obliva hiter vodni tok v Pucovem breznu, so gladke. Površina se členi v stopničke.

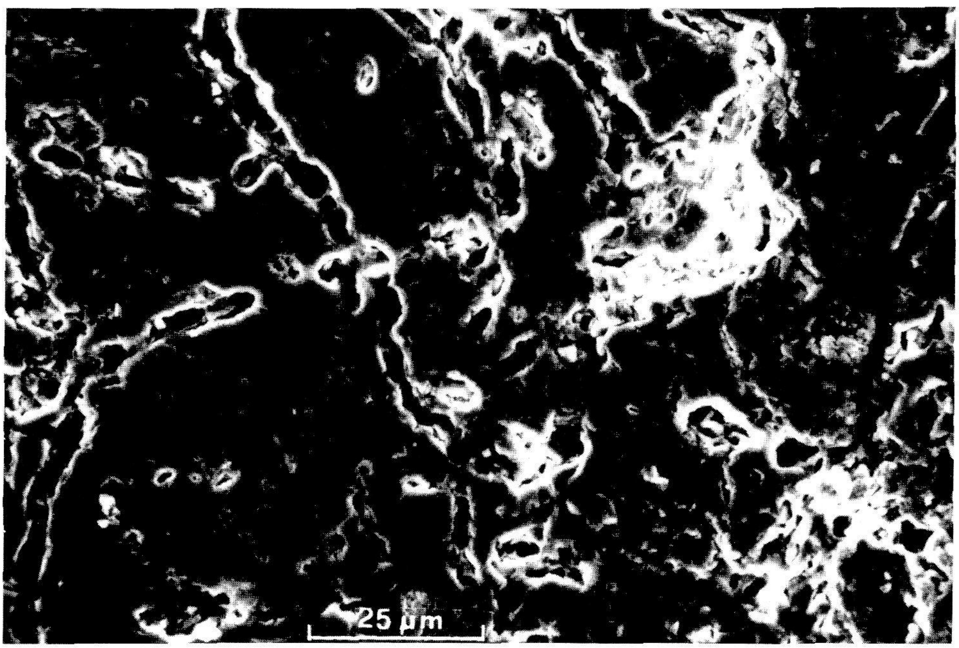
POVRŠINA FASET

Pogosto se po površini faset sklepa na proces njihovega oblikovanja. V primerjavi s površino drugih skalnih oblik je površina faset, zlasti manjših, dokaj gladka. Drobna

hrapavost je sestavljena iz štrlečih delcev ali pa vdolbinic, žlebičkov, skratka konkavno zajedenih oblik. V prvem primeru so to večji sparitni kristali, kalcitne žilice, fosili in intraklasti v mikritni osnovi. V drugem pa so vdolbinice vezane na hitreje topljive dele ali pa na drobne razpoke. Iz štrlečih delcev lahko ugotovimo tudi smeri toka v faseti. Na pritočni strani se površina kalcitnih žilic postopoma izklinja, na odtočni strani pa je strma, odsekana ob plasti kalcita.

Površine majhnih faset, tudi če so nastale na nekoliko nehomogeni kamnini, so bolj gladke od večjih. Gladke so tudi površine majhnih faset na paleogenskem apnencu. V Ocizeljski jami (sl. 3) se alveoline, numuliti in orbitoline na površini faset ne odražajo. Večjim fasetam v Ponorni jami Lokve v Predjami dajo hrapavost rudisti, ki štrlijo iz površine, majhne fasete pa na takšni kamnini v Pivki jami (sl. 9) niso mogle nastati. Fosili v kamnini so torej različno odporni proti vodnemu toku. Površina faset na peščenjaku je drobno hrapava, kar je posledica sestave kamnine.

Očitno je, da so skalne površine, ki jih gladijo hitrejši vodni tokovi, izpostavljene različnim procesom. Zato sem se odločil za njihovo razpoznavanje s pomočjo elektronskega vrstičnega mikroskopa. Za vzorce smo izdelali tudi zbruske kamnine. Tako lahko primerjamo sestavo kamnine in njeno izpostavljeno površino. Manjše fasete (sl. 12), ki so nastale na biomikritnem apnencu v Križni jami (Slabe 1989, 206) in na biomikrosparitnem apnencu v Škocjanskih jamah, so zelo gladke. Na njih se odražajo le večje nehomogenosti ali pa



Sl.12.Površina fasete v strugi Škocjanskih jam
Fig.12. The surface of the facet in the riverbed in Škocjanske jame

prepredenost s kalcitnimi žilicami. Zglajena površina manjših faset je posledica prevladujočega korozijskega delovanja vodnega toka, katerega vrtinčasto jedro se povsem približa steni in odnaša tudi počasneje topne delce kamnine, ki štrlijo iz nje. Značilno je, da so fasete v zatišnih legah, odmaknjene od vlečenega vodnega tovora, torej na odtočni strani grbin, zgornjih ploskev skalnih blokov, ali pa višje na steni. Erozijsko zglajena površina skale je pod vrstičnim mikroskopom drobno hrapava, kar je posledica trenja s trdnimi delci kamnine, ki jih prenaša vodni tok.

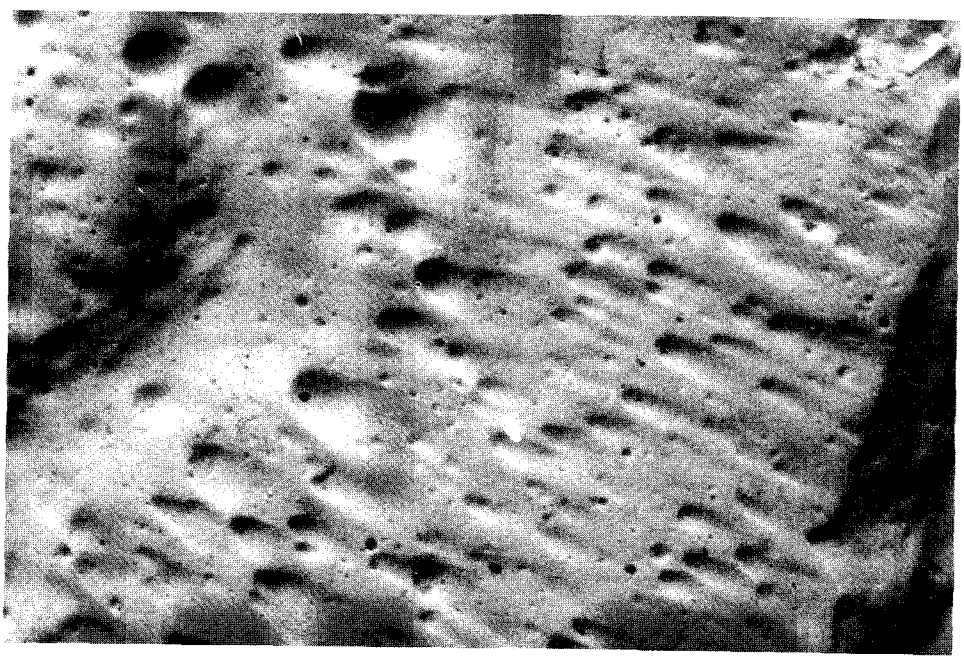
LABORATORIJSKO OBLIKOVANJE FASET NA MAVCU

Po nerazpokanem in dokaj homogenem, v polkrožen žleb odlitem mavcu, ki se ga je v vodi raztopilo 1,4 g na liter, se je pretakal vodni tok s hitrostjo 1 m /s. Debelina vodne plasti je bila le 1 cm. V nizkem toku se je voda razporedila v ozke in nekaj cm dolge, skoraj vzporedne tokovnice. Nastale so fasete (sl. 13), ki so dolge 5 mm, široke 2,5 mm in globoke 2 mm. Podobne so tistim v tretji skupini. So večinoma odprte. Ob ovirah, ob nekoliko

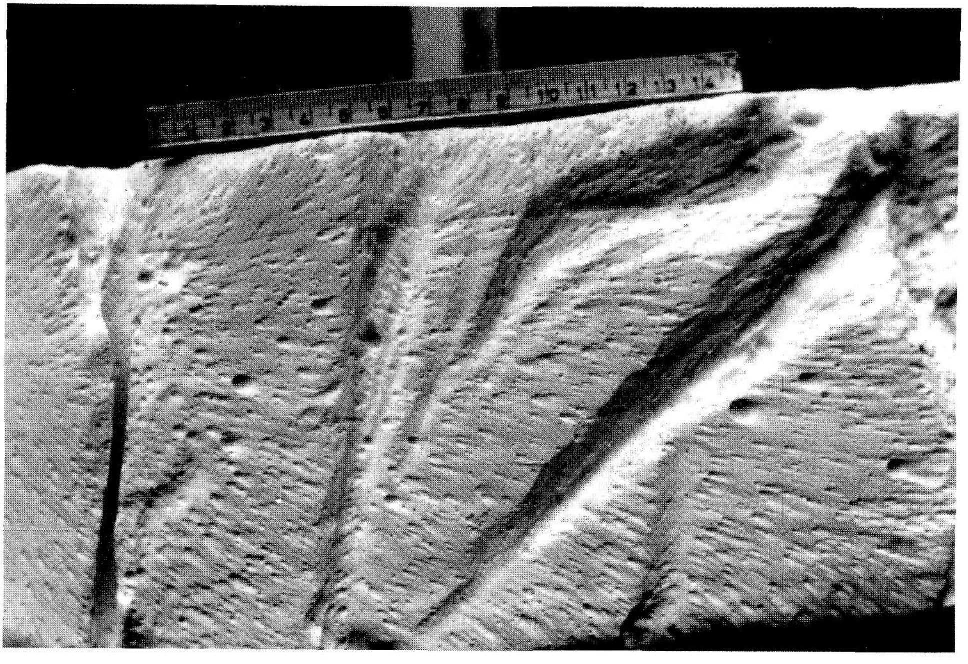
Sl.13.Fasete na mavčnem žlebu - nehomogen mavec
Fig.13. Facets on plaster groove - inhomogeneous plaster

večjih zrnih, je voda najprej izdolbla vdolbinice in zrna nato odnesla. V dveh urah so iz vdolbinic nastale fasete. Po štirih urah se njihova oblika ni več izrazito spreminjala. Podoben poskus sem ponovil z vodnim tokom, ki je imel hitrost 0,2 m/s. Tudi v tem primeru so nastale podolgovate, a nekoliko večje fasete.

Večji osmerokotni mavčni blok z ravnimi stranskimi in zgornjo ploskvijo ter s premerom 1,2 m smo potopili v umetno strugo, ki vodi do hidroelektrarne pred Planinsko jamo. Površina bloka je bila 1,5 m pod gladino vode, ki se je pretakala s hitrostjo 1,4 in 0,9 metra na sekundo. V obeh primerih so na bloku nastale fasete (sl. 14). Fasete so se izoblikovale že po dveh urah in njihova velikost ter oblika se nato nista več spreminjali. V prvem primeru so dolge do 1 cm, v drugem pa do 1,5 cm. Fasete so ozke (do 0,5 cm) in razmeroma dolge (3. skupina). Posamezne fasete so široko odprte, če pa so ena ob drugi, povezane v mrežo, so zaprte. Značilna je razporejenost in usmerjenost faset na površinah, ki so vodnemu toku izpostavljene pod različnimi koti. Na sredini pritočne stranske ploskve, ki je bila pravokotna na smer vodnega toka, so nastale vdolbinice, na obrobnih delih ploskve pa fasete, ki so usmerjene k robovom. Podobno je oblikovan tudi blok v strugi Podpeške jame. Na ploskvi (sl. 15), ki je bila vodnemu toku izpostavljena pod kotom 45o, so fasete po vsej površini. Na začetku so fasete vzporedne s tokom, na drugi polovici so usmerjene k robovom. Na



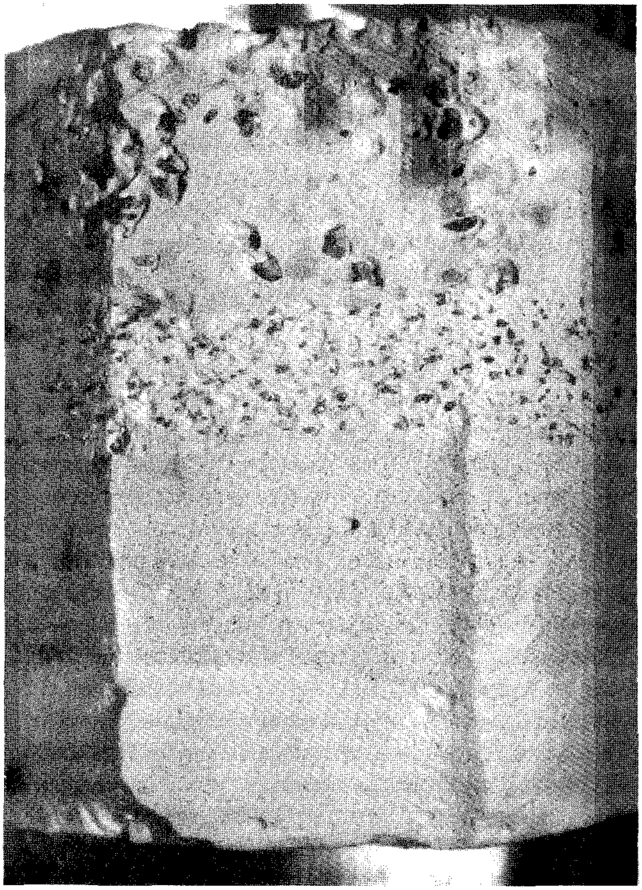
Sl.14.Fasete na mavčnem bloku - homogen mavec
Fig.14. Facets on plaster block - homogeneous plaster



Sl.15.Fasete na stranski ploskvi mavčnega bloka
Fig.15. Facets on the lateral side of the plaster block

ploskvi, ki je bila vzporedna s smerjo vodnega toka, so tudi fasete usmerjene v smeri toka. Na zadnji strani bloka, ki je bila prečno na smer toka, a v zatišju, so nastale le majhne vdolbinice. Na zgornji ploskvi mavca so na začetku fasete vzporedne z vodnim tokom, na odtočni strani pa so usmerjene k robovom bloka. Tako so razporejene tudi fasete na skalnih blokih v jamskih strugah, preko katerih se pretakajo odprti vodni tokovi in so tik pod vodno gladino (struga v Škocjanskih jamah).

Enako velik mavčni blok (sl. 16), ki je bil sestavljen iz plasti, katerim smo primešali različno velike netopne ali počasneje topne delce peska, smo izpostavili vodnemu toku, ki je imel hitrost meter na sekundo. Spodnjo plast mavca so sestavljali delci, ki so bili manjši od 0,1 mm. V drugi plasti smo delcem, velikim 0,1 do 0,25 mm, dodali 20% delcev s premerom 0,5 mm. V tretjo plast mavca, ki so ga sestavljali delci, veliki 0,1 do 0,25 mm, smo primešali 10% netopnih delcev, ki so bili veliki 1,25 do 2,5 mm. Četrti plasti mavca smo dodali 10% netopnega peska z delci s 5 do 10 mm premera. Razporejenost faset na bloku je bila podobna zgoraj opisanemu primeru, različna kamnina pa značilno oblikovana. Na najbolj homogenem mavcu so nastale lepe mreže majhnih faset. Na mavcu, ki so mu bili primešani večji netopni delci, so okoli njih nastale nekoliko večje vdolbinice. Te so bile na površinah z redkejšimi ovirami povezane v slabše razločno mrežo faset. Velikost vdolbinic je bila posledica velikosti ovire v kamnini in je dosegla 2 do 3 krat večji premer kot fasete.



Sl.16.Fasete na plastovitem mavčnem bloku
Fig.16. Facets on bedded plaster block

Torej na velikost faset vpliva tudi sestava kamnine? Na delih mavca, kjer so večje ovire najbolj gosto razporejene, o mreži faset ne moremo govoriti, čeprav je površina mavca ob ovirah luknjičasta. Ob posameznih ovirah so nastale vdolbinice, ki so imele oblike široko odprtih faset.

Velikost faset na mavcu je nekoliko manjša od tistih, ki pri enakih pogojih nastanejo na apnencu. Predvidevam, da so fasete na hitreje topni kamnini manjše. Fasete, ki so nastale na homogenem mavcu, so pravilnih oblik in njihova površina je gladka. Tiste, ki pa so na mavcu z zrni peska, so bolj raznolikih oblik in hrapave. Fasete so nastale z raztapljanjem mavca, le večje, netopne delce, je odnašala voda. Tudi ostri robovi mavca, ki se ohranijo v hitrem vodnem toku, dokazujejo, da se fasete na njem oblikuje s korozijo.

NASTANEK IN RAZVOJ FASET

Pri nastanku in oblikovanju faset so odločilni kamnina, hitrost in pritisk vodnega toka z določeno viskoznostjo in agresivnostjo vode, in velikost rova ter oblika oboda. Omenjeni dejavniki se prepletajo v različnih razmerjih, vendar so osnove oblikovanja značilnih mrež faset določene predvsem s hidravličnimi razmerami. Kamnina odloča o nastanku faset oziroma o obliki posameznih faset v mreži in vpliva na njihovo velikost.

Pri visokih Reynoldsovih številih je trenje odvisno od hrapavosti oboda cevi in skorajda neodvisno od viskoznosti tekočine, pri majhnih Re pa je odvisno od viskoznosti in le malo od hrapavosti (Reynolds 1974, 5). Ta značilnost oblivanja sten z vodnim tokom se, kot kaže, odraža tudi pri oblikovanju majhnih oziroma velikih faset. Premer vrtincev v vodnem toku je predvsem posledica njegove hitrosti. Na velikost vrtincev vpliva tudi sestava kamnine. Ob večjih ovirah so vrtinci večji (sl. 16). Če pa so ovire, ki so enako velike ali večje od faset, gosto druga ob drugi, prepletanje vrtincev lahko privede do prevelike kaotičnosti v smereh strujnic in značilna mreža faset ne nastane. Za nastanek mreže faset mora biti velikost vrtincev večja od velikosti sestavnih delcev kamnine. Tudi na razporeditev manjših faset, poleg hidravličnih razmer in geometrije prostora, vplivajo predvsem nehomogenosti v kamnini. To se je lepo pokazalo pri poskusu z mavcem. Pri oblikovanju manjših faset gre torej za prekinitve mejne laminarne plasti vode zaradi neenakomerno topljive zrnate sestave kamnine, kar ugotavljata tudi Ford in Williams (1989, 305). Na mavcu je ob oviri voda najprej izdolbla vdolbinice. Ovire, nekoliko večje drobce mavca, je nato odnesla. Hkrati so nastale vdolbinice in nato fasete tudi na bolj topnih delih mavca ter ob manjših razpokah. Fasete, ki so nastale ob redkih ovirah in niso povezane v mrežo, ali pa če so odprte, so nastale ob robu odsekanih skalnih površin. Posamezna faseta je torej odprta. Tudi Allen (1972) je ugotavljal, da lahko posamezna nehomogenost v kamnini povzroči nastanek fasete. Če je kamnina homogena, jo enakomerno prekrijejo vrtinci in razvije se mreža faset. Na homogenem pesku nastanejo "valovi" (Hsü 1989, 108), ki so podobni enakomerni mreži zaprtih
faset. Enakomerno nehomogenost omogoča zrnata sestava karbonatnih kamnin. V mreži prevladujejo zaprte fasete, ki so različnih oblik, največ pa jih ima polkrožne pritočne dele in trikotne iztočne.

Je nastanek faset mogoč le ob znatnem stanjšanju ali prekinitvi mejne plasti, ko je njen vpliv na korozijo in erozijo zanemarljiv? V agresivni vodi bi lahko že približevanje vrtincev, ki jih povzroča trenje ob mejni plasti, povzročilo hitrejše raztapljanje kamnine zaradi lokalno tanjšega difuzijskega sloja. Tako bi lahko nastale večje fasete, ki so posledica počasnega vodnega toka in pri katerih kamnina ne vpliva veliko na njihovo oblikovanje. Medtem ko večji delci kamnine lahko hitremu toku preprečijo oblikovanje faset, pa v počasnejšem vplivajo predvsem na oblikovanje mreže. Ob večjih nehomogenostih pogosto nastanejo "cvetovi". V njih se voda razliva na več strani. V Ponorni jami Lokve rudisti, ki štrlijo iz površine, ne vplivajo na obliko srednje velikih faset, medtem ko manjše fasete na podobni kamnini v Pivki jami ne morejo nastati.

Z dobrim poznavanjem hidravličnih značilnosti vrtinčastega toka in sestave kamnine lahko torej določimo razmerje, pri katerem lahko nastanejo fasete oziroma določimo vpliv

sestave kamnine na njihovo velikost. Fasete lahko nastanejo le na posameznih odsekih oboda, ki so dovolj veliki za razvoj mreže vrtincev in ki z manjšimi koti odstopajo od smeri vodnega toka.

Voda v vrtincih kroži pravokotno na površino, ki jo obliva, kar nam potrdi tudi odtočni podaljšani in plitvejši del fasete. Največja ovira tokovnicam v vrtincu je stena fasete, ki je nabolj pravokotna na vodni tok. Korozija in erozija sta na tej površini najbolj učinkoviti in fasete se zato "selijo" po toku navzdol. Seljenje pa omejuje kamnina, še zlasti razpoke, na katere se pogosto vežejo manjše fasete. Pri velikih fasetah, ki imajo premere večje od 50 cm, pa smeri vodnega toka ni več mogoče razbrati, saj vrtinci, ki so jih vrezali, nimajo več izrazitih iztočnih repov.

Z naraščanjem hitrosti vodnega toka se manjša premer vrtincev in tako dolžina faset. Najmanjše fasete, ki sem jih našel v izbranih jamah, so bile dolge 0,4 cm in najdaljše 40 cm. Izjema so velike fasete. Nastale so torej z vodnim tokom, ki se je pretakal s hitrostjo od 6 do 0,05 metra na sekundo, če računamo po formuli Lismonda in Lagmanija (1987, 38):

$UL/v = 22000$

v poenostavljeni različici, ali v popolnejši obliki:

$UL/v = 20700\,(1+0{,}266(\ln(D/2L)-1{,}5))$,

ki se uveljavi le za rove pravilnih krožnih prerezov. U je hitrost toka, L je poprečna dolžina faset. Tovrstni izračuni hitrosti vodnega toka so se dokaj ujemali s tistimi, ki smo jih dobili na podlagi velikosti prodnikov (Scheidegger 1961, 135), ki jih prenaša voda. Začetna velikost fasete je odvisna predvsem od kamnine. V Vzhodnem rovu v Predjami so fasete še majhne vdolbinice s premerom 1 cm. So na stiku z gladko površino. Za njimi, na odtočni strani, pa je razvita mreža faset, ki je nastala z vodnim tokom s hitrostjo 2,5 metra na sekundo. V Markovem spodmolu so na strmih delih struge najmanjše fasete dolge le 0,4 cm, torej nakazujejo hitrost vodnega toka 6 metrov na sekundo in drobnozrnato, homogeno kamnino, na kateri nastajajo. Za apnence je značilna zrnata sestava in glede na lokalno velike hitrosti vodnega toka ter majhne vrtince v njem, pogosto omejena homogenost.

Opazil sem več značilnih povezav faset v isti mreži. Ločimo fasete, ki imajo dokaj popolne oblike in tiste, ki so podrejene načinu povezovanja v mrežo zaradi nehomogenosti kamnine. Razporeditev vrtincev, ki na zato primerni kamnini prekrijejo vso površino, najprej določa kamnina, ko pa se vzpostavi ravnotežno stanje, za kar je potreben stacionarni tok, pa vrtinčenje pogojujejo oblike faset samih. Med začetnimi vrtinci nastanejo še vmesni, ki med seboj tekmujejo. To dokazujejo posamezne nesorazmerno majhne fasete v mreži. Po določenem času fasete v enakomernem toku dosežejo svojo mejno velikost in ravnotežno stanje. Pri poskusu na mavcu se velikost fasete po 2 urah ni več spreminjala.

Po zbranem gradivu sklepam, da po obliki podobne fasete nastajajo v enakih hidroloških pogojih.

Ko je rov dovolj velik in homogena skalna površina večja od kritičnega premera vrtincev, tako da se pri določeni hitrosti razvije samostojno vrtinčenje ob stenah, nastanejo fasete, ki smo jih po obliki uvrstili v drugo skupino. To je osnovni, zreli tip faset (sl. 4). Sorazmerno z večjo hitrostjo toka se manjša dolžina faset in sorazmerno z naraščanjem pritiska na stene se veča njihov radij, fasete pa so globlje. V cevastem rovu v Mali Boki so fasete enakih

dolžin tako na stropu kot na tleh, so pa talne fasete skorajda za tretjino širše. Hitrost toka blizu sten je manjša v širših rovih in fasete so tako večje (Serbon 1987, 16).

V prvi skupini, kjer so fasete razvrščene v prečne nize (sl. 3), na njihovo oblikovanje vpliva tudi velikost prostora. Praviloma so takšne fasete nastale v ožinah rovov ali pa na talnih in stenskih žlebovih. Vrezujeta jih je hitrejši vodni tok v zalitem rovu ali pa odprti vodni tok, ki z manjšim pritiskom delujeta na stene. Predpostavljam, da velikost rova ali njegovega dela (vzdolžna zajeda) narekuje enakomerno vtinčenje toka čez ves prerez.

V tretji skupini so najbolj podolgovate fasete. Zanje je značilno, da nastanejo, ko kamnino obliva plitev, odprt vodni tok. Njegov pritisk na steno je majhen. Zato je tudi značilna lega faset na skalnih blokih ali pa na izpostavljenih konveksnih delih jamskih strug in na stenah tik pod gladino višjega toka. Ko je tok zelo plitev, nastanejo tanke vzdolžne tokovnice, kar sem potrdil s poskusom na mavcu in se odraža tudi na podornem bloku deloma preperele sige v Mali Boki. Mreža faset je na pritočnem robu skalnega bloka (sl. 5) nastala zaradi značilnega oblivanja skale. Za oviro se tok sprošča. Mreža je ožja na pritočni strani, na odtočni strani pa se razširi. Fasete nastanejo ob enotnem vrtincu, saj so zavite.

Podskupini 1-2 in 2-3 sta kombinaciji osnovnih skupin. V skupini 2-3 so fasete značilno podolgovate zaradi izpostavljenosti na višjih delih v strugi. Vodni tok nad njimi pa je višji, torej z večjim pritiskom obliva stene kot fasete 3. skupine.

V hitrejšem vodnem toku se tanjša mejna laminarna plast ob kamnini. Vrtinčasto jedro se približuje steni. S tanjšanjem laminarne mejne plasti, ki je odvisna tudi od viskoznosti tekočine, se tanjša plast difuzije. To vodi omogoča hitrejši prenos reaktantov in pruduktov raztapljanja, kar pospeši korozijo. V izrazitem vrtinčastem toku je mejna difuzijska plast zanemarljiva (Dreybrodt 1988, 154). Zaradi tanjše mejne plasti voda s svojo maso erozijsko neposredno deluje na kamnino.

Pri nastanku faset na karbonatni kamnini sta pomembna oba procesa, tako lokalno hitrejše raztapljanje, kot neposredno erodiranje kamnine z vodno maso. Voda odnaša počasneje topne delce kamnine. S peščenjaka, ki je sestavljen iz delcev kremena, povezanih s kalcitnim vezivom, voda odnese kremenove delce, ko raztopi kalcitno vezivo. Pri oblikovanju faset na odpornejši karbonatni kamnini večji delež prispeva korozija. To potrjujejo tudi mikroskopska opazovanja površine majhnih faset, ki so tudi pod večjimi povečavami gladke. Erozijsko zglajene površine so namreč pri velikih povečavah drobno hrapave. Fasete, ki so nastale pri poskusu na mavcu, so posledica raztapljanja mavca. Le večje delce, ki so štrleli iz površine, je neraztopljene odnesel vodni tok. Fasete praviloma ne nastanejo v rovih s prevladujočim erozijskim delovanjem vodnega toka (Babja jama). Obod takih rovov je zglajen.

Iz primerjave nasičenosti voda in oblikovanosti skalnega reliefa v ponorni Finkovi jami in izvirni Podpeški jami (Ribniška Mala gora) ugotovimo, da ima pri nastanku skalnih oblik večji pomen sestava kamnine, kot pa nasičenost oziroma potencialna agresivnost vode. Ponorna voda je 21% nasičena, izvirna pa 60 % (Kranjc 1981, 52). V Finkovi jami so le stropne kotlice, skalni relief Podpeške jame pa je izrazito oblikovan z različnimi fasetami in stropnimi kotlicami. V prvi je kamnina močno prekristalizirana, v drugi obod sestavlja dokaj homogen oosparitni apnenec.

Različno visoke in korozijsko agresivne vode imajo različen pomen pri oblikovanju skalnega reliefa. V Škocjanskih jamah visoke vode vrezujejo fasete, dno struge pa je prekrito s tanko plastjo sige. To je še ena potrditev, da le del voda sooblikuje skalni relief.

Hitrost raztapljanja kamnine, kot je pokazal tudi poskus z mavcem, vpliva na obliko in velikost faset. Predvidevam, da so fasete manjše in značilno razpotegnjene (skupina 3), če se kamnina topi hitro.

Fasete lahko sooblikuje ali preoblikuje tudi material, ki ga prenaša voda. Pesek, ki je pretežak, da bi ga vodni tok vključil v pravokotno vrtinčenje, ki vrezuje fasete, se vrti vzporedno s skalno površino. Fasete so zato na dnu krožno, erozijsko poglobljene. V občasno zalitih rovih (Osapska jama), kjer počasne vode odlagajo ilovico, korozija pod naplavino poglablja in širi fasete. Gre torej za kombinacijo faset in podnaplavinskih vdolbinic.

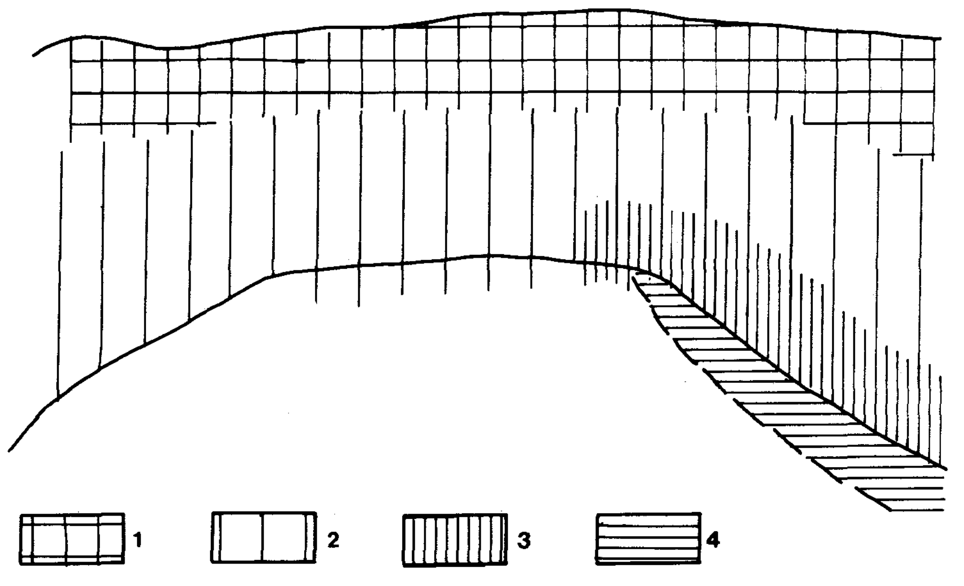
NEKAJ PRIMEROV ZNAČILNEGA OBLIKOVANJA FASET

Fasete lahko nastanejo v singenetskih in paragenetskih rovih. V prvih so lahko v zalitem rovu, v rovu, skozi katerega se pretaka odprti vodni tok, v meandrih, v paragenetskih rovih pa večje fasete nastanejo zaradi toka vode nad drobnozrnato naplavino. Fasete so torej lahko na celem obodu ali le na delu oboda. Na obodu prevladujejo ali pa se pojavljajo v z drugimi oblikami, na primer s podnaplavinskimi žlebiči in vdolbinicami. Zaradi učinkovitosti vodnega toka tudi v drugem primeru prevladujejo.

Prepletu različnih oblik faset lahko sledimo na majhnem odseku izbočenega, podkvasto zavitega rova v Markovem spodmolu (sl. 17). Tla pritočnega dela rova, ki se dviguje pod kotom 25o, so do začetka zavoja, torej v najbolj strmem delu, gladka. Na zunanjem robu polkrožno zaključene gladke površine se na še malo navzgor nagnjeni površini začenjajo fasete skupine 2-3. Ta oblika je značilna za fasete, ki so na izbočenih delih tal ali pa na skalnih blokih, za katerimi se tok skokovito poglobi. Takšne fasete so tudi na spodnjih delih sten. Na tleh, ki se v nadaljevanju spuščajo navzdol z manjšim strmcem (10o), sledijo manjše fasete skupine 2-3, ki so značilne za hitrejše, plitkejše vodne tokove. Dolge so 2-5 cm in globoke 1,5 cm. Na tleh, ki se na odtočnem delu strmo spuščajo, so najmanjše fasete. Sprva so dolge 2 cm, na najbolj strmem delu, kjer se struga zoži v polkrožen žleb, ki ima naklon 45o in več, pa so fasete 1. skupine dolge le 0,42 cm. Povezane so v prečne nize. Prehodi med različnimi fasetami so seveda postopni. Na zgornjih delih sten in na stropu so večje fasete 2. skupine (sl. 4), ki so značilne za zalite rove. Te fasete so starejšega porekla in kaže, da so prekrivale cel obod rova. Nato so jih na spodnjih delih sten in na tleh prekrile manjše fasete, ki jih je vrezal hiter, odprt vodni tok. Oblika in razporeditev faset sta torej pogojeni s spremenjenimi hidravličnimi razmerami v značilno oblikovanem rovu.

V ponorni jami Tenteri pod Ribniško Malo goro sem v vhodnem delu in v labirintnem spletu rovov izmeril dolžino faset.

Fasete na stropu, 8 m nad tlemi, so dolge 7 cm, na stenah proti tlem pa se manjšajo. Na robu struge, 1-2 m nad tlemi, so fasete dolge 5 cm. V strugi so pritočni, nekoliko dvignjeni



Sl.17.Razporeditev faset v delu rova v Markovem spodmolu
1. večje fasete 2. skupine, stare
2. večje fasete skupine 2-3
3. manjše fasete skupine 2-3
4. manjše fasete v žlebu, 1. skupina

Fig.17. Distribution of the facets in one part of the channel in Markov spodmol
1. bigger facets of 2nd group, old
2. bigger facets of group 2-3
3. smaller facets of group 2-3
4. smaller facets in groove, 1st group

deli, ki so vodnemu toku najbolj izpostavljeni, gladki, na njihovi odtočni strani pa se je oblikovala mreža majhnih faset, ki so dolge do 1 cm. V anastomoznem spletu rovov, v katerih tla in zlasti zgornje rove prekriva tanka plast ilovice, so fasete dolge 5-10 cm.

Če sklepamo iz velikosti faset po formuli Lismonda in Lagmanija (1987, 38), dobimo naslednjo razporeditev hitrosti vodnega toka v jami:

strop rova Tržiščice	0,35 m/s
korito Tržiščice 1-2 m nad tlemi	0,50 m/s
tla korita Tržiščice	2,5 m/s
ožine anastomoznega spleta rovov	0,25-0,50 m/s

Po meritvah proda v jami Kranjc (1981, 52) sklepa, da ga prenaša tok vode, katere hitrost preseže tudi 2 metra na sekundo, torej je enaka tisti, ki vrezuje najmanjše fasete. Pritočne izpostavljene dele kamnine gladi tudi erozija. Rov je najbolj prevoden ob nižjih ali srednje visokih vodah, saj ožina za rovom povzroča zastajanje visokih voda. V anastomoznem spletu rovov, razen v ožinah, je tok počasnejši.

Podobno razporeditev različnih velikosti faset lahko opazujemo tudi v glavnem vodnem rovu Križne jame. Na razčlenjenem obodu struge so na izpostavljenih, spodnjih delih sten in na tleh fasete dolge do 3 cm, 1-2 m nad tlemi pa 5 cm. Na istih višinah, a v zatišnih legah stenskih niš, so fasete dolge do 8 cm. V ožini, v katero se prelivajo visoke vode in jo zapolnijo v celoti, so po vsem obodu majhne fasete, ki so dolge do 3 cm. Različna velikost faset je posledica različne hitrosti toka, ki obliva skalo. Ta je določena z vzdolžno prepustnostjo rovov in oblikovanostjo sten. V večjih rovih je pritisk na stene večji, v vmesnih manjših rovih pa se poveča hitrost toka.

V občasno ponornem Beško-Ocizeljskem jamskem sistemu so na stenah Novega rova velike fasete, ki imajo premer 1 m in več. Na njih so le nekaj cm dolge fasete (sl. 18). To je posledica spremenjenega načina pretakanja vode skozi rov. Rov je bil najprej globoko zalit. Nato ga je le deloma preoblikoval hitrejši vodni tok, ki ni trajal dolgo, oziroma se le redko pojavi ob visokih vodah.

Zanimiva je tudi razporeditev faset na velikem skalnem bloku, ki štrli iz korita Vzhodnega rova v Predjami. Blok je nagnjen v smeri vodnega toka. Na njem se menjavajo prečni pasovi gladke površine, ki so široki do 10 cm in fasete, ki so dolge 2-10 cm. Odseki kamnine, ki je bolj strma, skorajda pravokotno izpostavljena vodnemu toku, so gladki. Takšne gladke površine so značilne za vse pritočne dele strmih ovir v strugah. Gladita jih material, ki ga prenaša voda in samo erozijsko delovanje hitre vodne mase. Fasete nastajajo le na površinah, ki z manjšimi koti odstopajo od smeri vodnega toka.

Ugotovimo lahko, da je nastanek faset razmeroma kratkotrajen proces. Razumljivo je, da mlajše, zlasti manjše, fasete hitro prekrijejo morebitne starejše. Vodni tok, ki zadnji obliva kamnino, je praviloma odločilen za oblikovanje jamskih sten. Le del spreminjajočega toka vrezuje fasete, in to verjetno tudi ne najbolj dolgotrajni, temveč tisti, ki na strugo deluje najbolj učinkovito, kar smo ugotovili tudi na primeru vhodnega rova v Tenteri. Lauritzen in sodelavci (1985, 143) so izračunali, da v proučevanem zalitem rovu nastajajo fasete le ob največjem pretoku, ta pa traja le 5% leta. Merjenje z mikrometrom jim je omogočilo sklepanje, da so se fasete v tem rovu oblikovale približno 800 let.

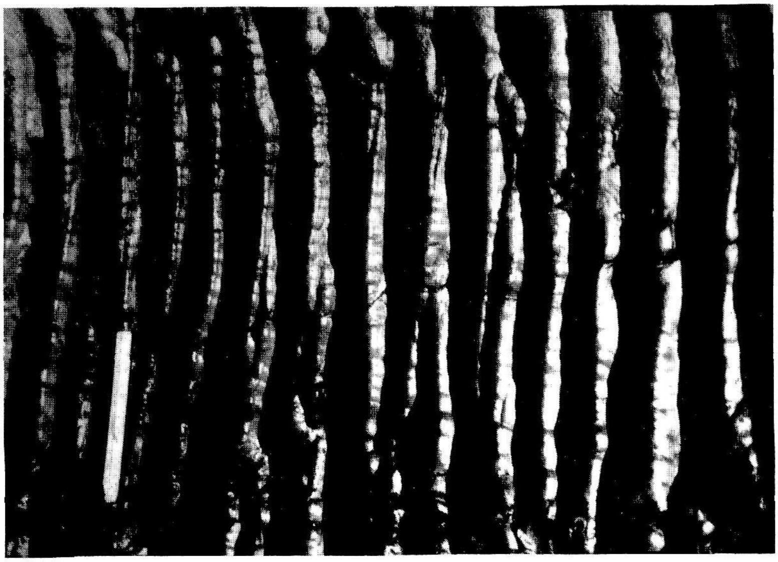
REBRA IN NJIHOV NASTANEK

V izbranih jamah sem zasledil le en izrazit primer reber. V Markovem spodmolu so v vzdolžni zajedi na konkavni strani zavoja, 1,5 m nad tlemi, nastala pokončna rebra, torej

Sl.18.Majhne fasete na velikih v Novem rovu v Beško Ocizeljski jami
Fig.18. Smaller facets above the big ones in Novi rov in Beka Ocizla

prečna na smer vodnega toka (sl. 19). Rebra so dolga 60 cm, to pa je tudi širina stenske zajede, široka pa so poprečno 5 cm in globoka 1,5 cm. Na nekaterih robovih med rebri je manjše rebro, ki se navzdol širi. Rebra so polkrožnih prečnih prerezov, njihovo dno pa je neizrazito valovito.

Nastanek reber je razlagal Curl (1966). Nastala naj bi zaradi dolgotrajnega oblivanja stene s tokom enake hitrosti. Ugotovimo pa lahko, da so rebra značilna za vzdolžne, polkrožne stenske zajede. Te se oblikujejo zlasti ob tanjših skladih apnenca, ki so različno odporni v vodnem toku. Neizraziti prečni robovi v rebrih, ki se vrstijo na razdalji enaki njihovi širini kažejo, da so rebra skrajni primer faset 1. skupine. Predvidevam, da je za njihov nastanek odločilno določeno razmerje med hitrostjo in lokalno dimenzijo vodnega toka, ki jo določa premer rova ali pa zajede v steni. V njih se vodni tok značilno vrtinči prek celega premera.



Sl.19.Rebra na vzdolžni stenski zajedi Markovega spodmola
Fig.19. Flutes on the longitudinal rocky notch of Markov spodmol

SKLEP

Do večine predpostavk o oblikovanju različnih tipov faset sem se dokopal v številnih slovenskih kraških jamah, ki so se oblikovale v različnih hidroloških pogojih in kamninah. Bogato terensko gradivo je pripomoglo k nadgradnji dosedanjega znanja. Domneve o nastanku faset so mi pomagali razjasniti laboratorijski poskusi z mavcem.

Na nastanek manjših faset odločilno vpliva predvsem sestava in razpokanost kamnine, ki jo oblivajo različno hitri vodni tokovi. Manjše fasete nastanejo s prekinitvijo laminarne mejne plasti. Z vrtinci ob posameznih ovirah, večjih delcih kamnine ali vdolbinicah v njej, lahko nastanejo samostojne odprte fasete. Lastnost karbonatne kamnine je drobnozrnata, pogosto dokaj homogena sestava. Kamnino zato enakomerno prekrijejo vrtinci in razvije se mreža faset. Na nehomogeni kamnini, sestavljeni iz delcev, ki so skorajda enaki teoretični dolžini faset ali pa na pretrti ali hitro razpadajoči kamnini, fasete ne nastanejo. Velikost počasneje topnih delcev v kamnini vpliva tudi na velikost vrtincev ob njih in tako na velikost faset. Vrtinci, ki oblikujejo velike fasete, so, kot lahko sklepam iz primerov s terena, predvsem

posledica trenja med laminarno in vrtinčasto plastjo vodnega toka. Vrtinčenje se lahko razvije tudi ob večji oviri, manjše ovire se odražajo le na obliko posameznih večjih faset.

Pod velikimi povečavami elektronskega vrstičnega mikroskopa so površine manjših faset gladke. To priča o pretežnem korozijskem delovanju vrtincev. Erozijsko zglajene površine so namreč drobno hrapave.

Poprečna oblika in velikost faset, posamezne so v večji meri pogojene s kamnino, odraža predvsem hidrološke pogoje njihovega oblikovanja. Osnovi tip (2. skupina) mreže je sestavljen iz zaprtih faset, ki imajo odtočne robove povezane v diagonalne nize. Nastane, ko se ob razmeroma homogeni kamnini razvije popolno vrtinčenje, ki ni omejeno s prostorom. Smer vodnega toka je iz takšnih faset jasno razvidna. So večinoma sled srednje hitrih in hitrejših epifreatičnih vodnih tokov. Ko na vrtinčenje vpliva tudi prostor, njegova oblika in velikost, nastanejo fasete, ki so povezane v prečne nize. Nastajajo praviloma v ožinah med večjimi rovi ali pa v stenskih zajedah. Podolgovate, manjše fasete odražajo odprte, tanjše vodne tokove. Velike fasete so sledi počasnejših freatičnih tokov, ki z večjim pritiskom oblikujejo stene.

Poznane različice, velikosti in položaj faset nam s pridom služijo kot speleogenetske sledi bodisi da v rovu prevladuje ena vrsta faset ali pa da stene prekriva več tipov mrež. Slednje so lahko posledica spreminjajočih sedanjih vodnih tokov, oblike in velikosti rova ali pa spremenjenih hidroloških pogojev v vodonosniku, ko so mlajše fasete le deloma prekrile starejše.

S poskusi na mavcu kaže vsekakor nadaljevati, saj bi pri oblikovanju faset lahko natančneje določili razmerja med sestavo kamnine in hitrostjo vodnega toka ter vrtinci v njem.

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FACETS - AN IMPORTANT TRACE OF SHAPING AND DEVELOPMENT OF THE KARST CAVERNS

Summary

During my study of the rocky relief in the slovene karst caves my attention was dedicated to facets which originate due to the turbulent water flow on the rough rocky surface. They are helpful at defining the way and direction of water flow through the channels.

Facet, called current marking too, is some 10 to 100 millimeters long oval solution niche. It is deeper and steeper on the inflow side, on the outflow side it is elongated and gently disappears. Various types of smaller facets are distinguished. Big facets ressemble to shallow solution cups. The flutes are oblong indentations of regular form arranged in the series transverse to the direction of the water flow. Typical of both features is their tendency to join in nets.

About study and definition of the relation of the facets length and the water flow velocity, incising them, several authors have already reported. I decided to dedicate more attention to the comparison of their form properties and their ability to join into nets and to determine the factors and processes of their origin and formation. Extensive researches on the field and the laboratory tests (facets in plaster) were extremely useful. Here I summarize some results of the study.

For the origin and for the facets development the rock, velocity and pressure of water flow with given viscosity and the aggressivity of water, as well as the size of the conduit and the shape of the rim are the most decisive. I suppose that the basic forms of the characteristical scallop network is mostly determined by the hydraulic conditions. The rock decides upon the origin, upon the shape of the particular facet within a network and partly influences on their size.

Most of current markings appear on all types of the limestones, seldom they are found on dolomite, conglomerate, breccia, flowstone and sandstone.

On homogeneous limestones where the particles are of regular shape and the same solubility, rather uniform scallop network occurs. More heterogeneous networks appear on inhomogeneous rock composed by intraclasts. On temporary flooded part of the wall in Pivka jama the facets are about 3 cm long, but where the rudists are protruded for 1.5 cm out of the surface there are no facets. On paleogene limestone the fossils have little influence on the shape of small facets.

Facets are found on carbonate conglomerate and breccia too if the pieces of limestone are several times bigger than the facets length.

In Smoganica the facets developed on chert sandstone with calcitic cement.

Along thin fissures the facets may be elongated, threaded into series, the differences in the orientation and the size of facets are bigger. Along the fissures the edges of facets are frequently toothed.

At great Reynold's numbers the friction depends on roughness of the tube's edge and is almost independent on viscosity of the fluids, while at small Re it depends on viscosity and just a little on roughness (Reynolds 1974, 5). This property of rock walls overflown by the water stream is reflected, as it seems, in the formation of small or big current markings. The diameter of the whirlpools in the water flow depends mostly on water's velocity. But the lithology of the rock influences as well upon the size of the whirlpools. Near bigger obstacles the whirlpools of the water are bigger (Fig. 16). If the obstacles of the same size or bigger than the current markings are dense one to the another the interlacing of the whirlpools may conduct to chaos within the counters and the characteristic net of the curent markings does not appear. To get the net of current markings the size of the whirlpools must be bigger than the size of the constituent particles of the rock. The distribution of the smaller current markings is controlled apart from the hydraulic conditions and space geometry by the inhomogeneities of the rock. It was clearly shown at the experiments with plaster. While forming smaller current markings the interruption of the boundary laminar water layer is decisive due to unequal solubility of the grained rock composition. The same was stated by Ford & Williams (1989, 305) as well. In plaster the water incised at the obstacle a solution niche firstly. The obstacles, bigger particles of plaster, were later washed off. Singular facets developed along rare obstacles and not connected into network, remained open. The particular facet thus remained open. Allen (1972) too stated that a particular inhomogeneity in the rock causes the facet's origin. If the rock is homogeneous it is evenly washed by the turbulent flow and a net of current markings develops. An equal inhomogeneity is enabled by the grained structure of the carbonate rocks. The closed facet of various forms predomine in the net, most of them have half-circular inflow parts and triangular outflow parts.

Is the origin of the facets possible only at a considerable thinning or interruption of the boundary water layer when its impact on corrosion and erosion is negligible? In the aggressive water the approach of the turbulent flow caused by friction along the boundary water layer may cause more abundant solution of the rock due to locally thinner diffusion layer. In such a way bigger facets can occur being the result of a laminar water flow there, where the influence of the rock has no essential impact on their formation. Bigger particles of the rock may prevent the high velocity flow to form the facets, but in slower flow they influence on the formation of the net mostly. At bigger inhomogeneities the "clusters" occur frequently. In them the water flows to several directions. In the ponor cave of Lokva the rudists jutting out of the surface do not influence upon the form of medium sized facets while smaller facets on similar rock in Pivka jama did not develop.

Having good knowledge of hydraulic properties of the turbulent flow and of rock lithology one can consequently define the rate when the facets may develop, or determine the influence of the rock lithology to their size. The facets may develop on a particular sections of the rim which are sufficiently large for the formation of the whirlpools' net and which deviate from the water flow direction by smaller angles.

The water in the whirlpools circulates perpendicularly to the surface which it overflows; that is confirmed by the outflow lenghthened and more shallow part of the facets. The biggest obstacle to the flow lines in the whirlpool is the facet's wall which is the most perpendicular to the water flow. The corrosion and erosion are the most efficient on this

surface and thus the facets "move" downwards the flow. The moving is limited by the rock, by the fissures in particular to which smaller facets are frequently linked. Along the big facets, having the diameter of more than 50 cm the water flow direction is no more legible as the whirlpools which incised them have no more distinctive outflow tails.

By increase of the water flow velocity the diameter of whirlpools and the length of the facets decrease. The smallest facets I have found in chosen caves were 0,4 cm long and the longest 40 cm long. The exception are big facets. They originated by the water flow which had the velocity from 6 to 0,5 m/s if we consider the equation by Lismonde and Lagmani (1987, 38): UL/v = 22000 in simplified version or in more complete form: UL/v = 20700 (1+0,266(ln(D/2L)-1,5)) which may be adopted for the conduits of regular circular cross-sections only. U means the water flow velocity, L is average facet's length. These calculations of the water flow velocity correspond rather well with those attained by the pebbles size (Scheidegger 1961, 135) transported by water. The initial size of the facet depends on the rock mostly. In Vzhodni rov of Predjama the facets are small solution niches with diameter of 1 cm on the contact with smooth surface. Behind them, on the outflow side, the current markings net developed, formed by water flow of 2,5 m/s of velocity. In Markov spodmol there are on the steep side of the river bed the smallest facets only 0,4 cm long, thus indicating the water flow velocity of 6 m/s and fine-grained homogeneous rock on which they occur. The granular composition is characteristic for the limestones and according to locally high velocities of the water flow and small whirlpools it them, the limited homogeneity is frequent.

I've noticed several characteristical connections of the facets within the same net. We distinguish the facets with rather accomplished shapes and those subdued to the manner of connection in a net due to inhomogeneous rock. The distribution of the whirlpools which cover the adquate rock entirely is firstly controlled by the rock and when the equilibrium is achieved, for which a laminar flow is needed, the turbulent flow controls the shape of the facets themselves. Among the initial whirlpools the interjacent ones occur, competing among themselves. This is indicated by some extraordinary small facets within a net. After some time the facets in regular flow achieve their maximal size and the state of equilibrium. During the experiments in plaster the facets size did not change after 2 hours.

I infer that the facets similar by shape develop in characteristical hydrological conditions.

I have presented the shape of singular facets within 60 networks into numerical data. To each facet the lenght, the width of the left and right half and the point and the biggest depth were defined. I have also measured the radius of inflow, mostly half-circular edge of the facet and the final angle of the closed facets. Thus the average shape and size of facets in the particular networks were obtained. It turned out that in the networks the facets which are closed on the outflow side by wider or narrower angle and the facets which remain open on the outflow side predominate. These two shapes are either connected within the same network or predominate in it. For comparison of the facets referring to their shape I had to eliminate their size. For the average shapes of the facets I have calculated the proportion between the facet's length and the above mentioned width. The results are classified into three groups and into the intermediate groups.

We speak about the second group when the conduit is big enough and the homogeneous rocky surface bigger than the diameter of the whirlpool of water thus that at the walls perfect whirls develop and "mature" facets occur. The difference between the longest and the shortest current marking is considerable, being from 24 to 375 mm. Proportionally with the flow velocity increase the length of the facets decreases and by increase of the pressure against the walls their radius augments and the current markings are deeper. The nets characteristically associated to lateral edges limiting the outflow parts of the facets into diagonal series predominate.

To the first group belong the facets where the rate between the length and the width is smaller or equal to 1. They are mostly small, from 4,7 to 40 mm long and from 2 to 10 mm deep. The facets are associated into series which are distributed transverselly to the direction of the water flow. As a rule such facets developed in the narrows of the channels or on floor and wall solution flutes. They are incised by water flow increased in the flooded channel or the open water flow acting to the walls by smaller pressure. I presume that the size and the shape of the channel or its part (longitudinal notches) controls the constant turbulence across the entire section.

To the third group belong the facets with the rate between the length and the width bigger than 2. The facets are relatively small, from 1 to 5 cm long. They occur when the rock is bathed by the shallow open water flow. Its pressure against the walls is slight. It is evidenced by the position of such facets also on rocky blocks or on exposed convex parts of the river beds and on the walls close below the level of higher water flow.

In the chosen caves I had the opportunity to see only old big facets mostly badly preserved. The diameter of the biggest facets measures from 0,5 to 1,5 m and is from 0,3 to 0,5 mm deep. Big facets have the shape of shallow half bowls. Their net is hardly legible.

By increase of the water flow velocity the boundary laminar layer along the rock becomes thinner. The turbulent nucleus approaches the wall. By thinning the boundary laminar layer which depends upon the fluid viscosity too, the diffusion layer is made thinner as well. It enables the water to transport the reagents and the product of dissolution quicker and thus the corrosion is increased. In a very expressed turbulent flow the existence of a diffusion boundary layer is neglected (Dreybrodt 1988, 154). Due to thinner boundary layer the water acts by erosion directly to the rock by its mass.

At the facets developing on the carbonate rock both processes are important: the locally faster dissolution and direct erosion of the rock by the water mass. The water transports less soluble particles of the rock. From the sandstone composed by quartz particles cemented by calcite the water transports the quartz particles after dissolving the calcitic cement. During the formation of the current markings on more resistant carbonate rock more important role is played by the corrosion. The microscopic observations of the small facets surfaces confirm it as they remain smooth under greater magnifications too. The erosionally polished surfaces are namely under greater magnifications thinnly rough. The facets formed at the experiments in plaster are due to plaster dissolution and only bigger particles, jutted out of the surface were undissolved washed off by the water flow. As a rule the facets do not occur

in the conduits with prevailing erosional activity of the water flow (Babja jama). The rim of such passages is polished.

Comparing the saturation of water to shape of the rocky relief in the swallow hole Finkova jama and in spring cave Podpeška jama (Ribniška Mala gora) one can establish that the lithology is much more important at the origin of rocky forms than the saturation, potential water aggressivity respectively. Allogenic water is up to 21% saturated and spring water up to 60% (Kranjc 1981, 52). In Finkova jama there are ceiling pockets only while the rocky relief of Podpeška jama abounds with various current markings and ceiling pockets. In the first cave the rock is strongly recrystallizwed, while in the second one the rim is built of rather homogeneous oosparitic limestone.

Differently high and corrosionally aggressive waters play different role at the rocky relief formation. In Škocjanske jame the high waters incise the current markings and the riverbed bottom is covered by a thin film of flowstone. It is another confirmation that a part of water only takes part at the formation of the rocky relief.

The velocity of the rock dissolution, shown also by the experiment in plaster, influences to shape and size of the facets. I suppose that the facets are smaller and characteristically lengthened (group 3) if the rock is easily dissolved.

The facets can be formed or transformed by the material transported by the water. The sand being too heavy to be included into perpendicular turbulence incising the facets, whirls parallel to the rocky surface. This is why the facets are at the bottom circular and erosionally deepened. In vadose zone of the channels (Osapska jama) where slowly flowing waters deposit loam, the corrosion below the sediment deepens and widens the facets. Thus the combination of facets and below sediment solution niches are involved.

Current markings develop in singenetic and paragenetic passages. In the first ones these are water flooded channels, the channels through which the open water flow passes, in the oxbows; in paragenetic channels bigger facets develop due to water flow above the fine grained sediment. Thus the facets may occur on the entire rim or on one part of it only. On the rim they predominate or else they occur in combination with other forms, f.e. below sediment half tubes or solution niches. In short, the current markings are an important speleogenetical sign.

In seasonal ponor Beka Ocizla cave system there are on the walls of Novi rov big facets and on other places some cm long new facets. The channel was phreatic at first and was later partly transformed by more rapid water stream.

On the upper parts of the walls and on the ceiling of one part of the passage in Markov spodmol there are bigger facets distinctive for phreatic channels. They are older and it seems that they covered the entire rim of the conduit. Later they were on the lower parts of the walls and on the floor covered by smaller facets incised by rapid, open water stream. The shape and distribution of the facets are controlled by changed hydraulic conditions in characteristically shaped conduits.

Flutes are significant for longitudinal, half-bowl wall notches. They mostly develop along thinner limestone beds which are variously resistant against the water flow. Undistinctive transverse edges in the flutes which are found on the distance equal to their length show that flutes are the extreme case of facets of the first group. I presume that for

their development the defined rate between the velocity and local dimension of the water flow is decisive which is controlled by the conduit's diameter or notches in the wall. The water flow whirls across the entire diameter in a characteristic manner.

Translated by Maja Kranjc

HIDRODINAMIČNI REŽIM KRAŠKEGA VODONOSNIKA MED SOLKANSKO AKUMULACIJO IN BRUHALNIKOM LIJAKOM

HYDRODINAMIC REGIME OF THE KARST AQUIFER BETWEEN THE ACCUMULATION OF THE HYDRO - POWER STATION SOLKAN AND THE LIJAK EFFLUENT

METKA PETRIČ

Izvleček UDK 556.33 (497.12)

Petrič, Metka: Hidrodinamični režim kraškega vodonosnika med solkansko akumulacijo in bruhalnikom Lijakom

Primerjava nihanja podzemne vode v bruhalniku Lijaku pri Novi Gorici s spreminjanjem višine akumulacije HE Solkan je pokazala na hidravlično povezavo med obema objektoma. S kvantitativno analizo ugotovljenih vplivov so bile določene hidrodinamične lastnosti vodonosnika v zaledju izvira. *Izračuni temeljijo na predpostavki, da so piezometrski valovi v Lijaku realizacija osnovnih valov, ki* jih povzroči spreminjanje višine vode v akumulacijskem jezeru. Difuzivnost je faktor, ki pogojuje njihovo razširjanje v prostoru in času. Na podlagi zapisov obeh nihanj je bila tako najprej izračunana difuzivnost vodonosnika, nato pa še teoretične krivulje nihanja podzemne vode v Lijaku. Te se dobro ujemajo s krivuljami, dobljenimi na osnovi rezultatov opazovanj.

Ključne besede: krasoslovje, hidrologija krasa, hidrodinamični režim, kraški bruhalnik Lijak, Trnovska planota, Slovenija.

Abstract UDC 556.33 (497.12)

Petrič, Metka: Hydrodinamic regime of the karst aquifer between the accumulation of the hydro - power station Solkan and the Lijak effluent

Close hydraulic connection between the periodical effluent Lijak near Nova Gorica and the Solkan accumulation was shown by the comparison of water level oscillations in both objects. Hydrodinamic properties of the aquifer in the background of the spring were determined by the quantitative analysis of the established relations. Calculations are based on the presumption that the piezometric waves in Lijak are the realization of the basic waves, which are caused by the water level oscillations in Solkan accumulation. The propagation of those waves through space and time is conditioned by the difusibility. So first the difusibility of the aquifer and then also the theoretical curves of the water level oscillations in the effluent Lijak were calculated from the known data. The correlation between the calculated and the observed curves is very good.

Key words: karstology, karst hydrology, hydrodinamic regime, karst effluent Lijak, Trnovo plateau, Slovenia.

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VSEBINA

UVOD

Kraški izvir Lijak deluje kot občasni bruhalnik, ki le v obdobju visokih vod preliva čez neprepustno flišno bariero. S kontinuiranim merjenjem višine podzemne vode so bile določene hidrodinamične lastnosti vodonosnika v zaledju izvira. Ugotovljen je bil kraški režim s kratkotrajnimi visokimi valovi in daljšimi obdobji nizkih vod ter veliko amplitudo (Janež 1992). Visoki valovi nastopijo kot posledica močnejših padavin, doseženemu maksimumu pa sledi zniževanje piezometrskega nivoja po negativni eksponencialni krivulji. Posebnost zapisa nihanja podzemne vode v Lijaku so odstopanja od te značilne krivulje upadanja. Pojavljajo se kratkotrajna znižanja, ki niso v nobeni zvezi s padavinami. Izvor dodatnega nihanja je bil pojasnjen s primerjavo med izmerjenimi piezometrskimi nivoji v Lijaku in zapisom spreminjanja višine vode v akumulaciji HE Solkan. Hitra znižanja gladine akumulacijskega jezera imajo namreč jasen odziv v limnigramu Lijaka. Ugotovljena odvisnost dokazuje obstoj kraškega vodonosnika med obema objektoma (Čar & Gospodarič 1988), nadaljnja kvantitativna analiza hidrodinamičnega režima pa omogoča tudi opredelitev njegovih značilnih lastnosti.

Članek je povzetek mojega diplomskega dela, pri katerem sta mi s strokovnimi nasveti pomagala mentor prof.dr. Miran Veselič in dipl.inž.geol. Jože Janež iz RŽS Idrija. Ob tej priliki se jima za pomoč še enkrat zahvaljujem.

GEOGRAFSKI PREGLED

Vodonosnik med umetno akumulacijo HE Solkan in izvirom Lijakom obsega območje zahodnega dela Trnovskega gozda med Grgarjem in Trnovim. Teren s 300 - 900 m nadmorske višine je izrazito kraški. Razvite so številne globoke vrtače, brezna in tudi dve ledeni jami. Na južni strani je omejen z neprepustno pregrado, ki jo gradijo flišne plasti spodnje Vipavske doline in okolice Nove Gorice.

Približno 6 km vzhodno od Nove Gorice je občasni kraški bruhalnik Lijak. Nahaja se na koti 102 m v dnu visoke skalne zajede pod robom Trnovskega gozda severozahodno od Ozeljana v spodnji Vipavski dolini. Ob visokem vodostaju se vode iz izvira združijo v potok Lijak, ki se severno od Renč izliva v reko Vipavo.

Soča priteče na Goriško iz severozahodne smeri po dolini med Sabotinom in Skalnico. Približno 1.2 km severno od Solkana se obrne proti jugozahodu in teče naprej na italijansko ozemlje. Na tem mestu so leta 1984 zgradili jez za hidroelektrarno Solkan, ki sodi v sklop Soških elektrarn. Nivo akumulacije je običajno na 77 m nadmorske višine.

KLIMATSKE IN HIDROLOŠKE RAZMERE

Klimatske razmere

Strm prehod iz Vipavske doline na visoko kraško planoto Trnovskega gozda ima jasen odraz tudi v klimatskih razmerah. Za Vipavsko dolino so značilni mediteranski vplivi in srednja letna temperatura okrog 12° C. V osrednjih delih Trnovskega gozda z občutno hladnejšim podnebjem se ta temperatura giblje le še med 7° C in 9° C, v najvišjih predelih pa doseže komaj 5° C.

Podobne razlike so opazne tudi pri razporedu padavin, ki naraščajo z nadmorsko višino in z oddaljevanjem od Vipavske doline proti severovzhodu (Janež 1992). Pregled padavin za padavinsko postajo Trnovo v obdobju 1960 - 1990 je pokazal, da znašajo letne padavine na tem območju med 1500 in 2700 mm s povprečno vrednostjo 2025 mm.

Hidrološke razmere

V okviru raziskav kraškega bruhalnika Lijaka je bila v neposrednem zaledju izvira leta 1988 izvrtana in nato leta 1989 poglobljena do globine 147 m vrtina Li - 0188 (Čar & Janež 1990). Z namestitvijo limnigrafa v vrtino je bilo zagotovljeno neprekinjeno beleženje vodostaja. Pri analizi so bili uporabljeni podatki za obdobje od 19.7.1989 do 2.6.1990. Zapisi nihanja podzemne vode kažejo na značilni kraški režim s kratkotrajnimi visokimi valovi in daljšimi obdobji nizkih vod ter veliko amplitudo. Najnižje se je nivo podtalnice spustil do 76.55 m nadmorske višine 29.10.1989, najvišjo vrednost 115.76 m pa je dosegel 7.4.1990. Amplitida torej znaša kar 39.21 m. Porasti vodostaja so hitri s povprečno hitrostjo dviga 1.5 m/h, maksimalne hitrosti pa znašajo celo 5 m/h (Čar & Janež 1990). Vsake zaznavne padavine rezultirajo s porastom piezometrske gladine. Reakcija je zelo hitra, s časovnim zaostankom manjšim od 24 ur. Bolj točne korelacije zaradi grobega merila - dnevni podatek za padavine - ni možno izvesti. V ekstremnih primerih se dvigne nivo podzemne vode nad prelivni flišni rob pri 102 m nadmorske višine in izvir bruha. Po prenehanju padavin sledi doseženemu maksimimu upadanje po negativni eksponencialni krivulji. Pri tem se vrednosti asimptotično približujejo nivoju akumulacije HE Solkan, ki se večji del zadržuje okrog kote 77 m.

Tudi v HE Solkan imajo avtomatsko registrirno napravo za beleženje gladine akumulacijskega jezera. Nivo regulirajo umetno glede na trenutne razmere in potrebe elektrarne. V obdobju od 19.7.1989 do 2.6.1990 je bila maksimalna amplituda nihanja 1.62 m. Najvišja gladina je bila zabeležena 21.12.1989 in sicer 77.20 m nadmorske višine, najnižja 75.58 m pa 1.2.1990.

S primerjavo zapisov obeh nihanj se je pokazalo, da imajo hitra, kratkotrajna znižanja akumulacije HE Solkan v obdobju srednjih in nizkih vod jasen odziv v limnigramu Lijaka. Pri višjih vodostajih pa je ta povezava zabrisana zaradi prevladujočega vpliva padavin na nihanje gladine vode v vrtini.

GEOLOŠKE IN HIDROGEOLOŠKE RAZMERE

Podatke o geološki zgradbi obravnavanega ozemlja sem povzela po Osnovni geološki karti 1:100 000 list Gorica (Buser 1968) s tolmačem (Buser 1973) ter po člankih Geološka zgradba in nekatere značilnosti bruhalnika Lijaka (Čar & Gospodarič 1988) in Geološka zgradba jugozahodne Slovenije (Placer 1981). Dopolnila sem jih še z rezultati podrobne geološke preučitve okolice Lijaka (Čar & Gospodarič 1986), območja Ravnice in Škabrijela (Čar 1987) in območja Grgarske kotline (Čar 1988).

Stratigrafsko-litološka razčlenitev plasti

Najstarejši na obravnavanem območju so barremijski in aptijski temno rjavkasti do sivo rjavkasti mikritni organogeni apnenci z vložki apnenčevih peščenjakov zahodno od Trnovega. V normalnem geološkem zaporedju prehajajo proti zahodu v svetlo sive do rjavo sive plastnate apnence albijske in cenomanijske starosti, ki gradijo tudi območje Škabrijela, Skalnice in Sabotina ter dve krpi v okolici Solkana. Enake starosti je pas temno sivega bituminoznega dolomita severozahodno od Voglarjev. Vzhodno od Grgarja, na Sabotinu in na ozemlju med Lijakom in Ravnico najdemo turonijske in senonijske bele do svetlo sive neplastnate ali neizrazito plastnate apnence z rudisti.

V posameznih krpah v okolici Lijaka izdanjajo zgornjesenonijski in paleocenski rdeči in zelenkasto sivi laporovci in laporasti apnenci. Severno od Ravnice pa ležijo diskordantno na zgornjekrednih plasteh apnenčevi konglomerati in peščenjaki ter peščenjaki in konglomerati, ki so značilni za začetni flišni razvoj. Velik del ozemlja prekrivajo inverzne eocenske flišne plasti Vipavske doline. Kamnine enake starosti najdemo v normalni legi tudi v okolici Ravnice.

Najmlajši so kvartarni terasni sedimenti pri Novi Gorici, aluvialni nanosi v Grgarski kotlini, ob potoku Lijaku in v okolici Solkana ter delno sprijet pobočni grušč, ki prekriva zgornji del flišnega pobočja Vipavske doline in njegov prehod v apnenčeve stene Trnovskega gozda.

Tektonske razmere

V tektonski rajonizaciji jugozahodne Slovenije sta bila na obravnavanem ozemlju opredeljena dva pokrova. Tako pripada Trnovski gozd Trnovskemu pokrovu, območje na severozahodu Vipavske doline pa predstavlja del Hrušiškega pokrova (Placer 1981). Močan narivni stik med obema, ki je nakazan z inverzno lego flišnih plasti, se pred Ozeljanom spusti iz pobočja v dno Vipavske doline in se vleče po flišnih kamninah proti severozahodu

v Furlansko nižino. Plasti Trnovskega gozda prehajajo zahodno od Ozeljana v neprekinjenem zaporedju v poleglo antiklinalo, ki tone proti severozahodu (Čar & Gospodarič 1986).

Ozemlje je razsekano s številnimi različno močnimi prelomi s prevladujočo dinarsko smerjo. Glavna prelomna cona Raškega preloma se na obravnavanem območju vleče od Šmihela do Grgarske kotline. V eni izmed vzporednih prelomnih con pa se nahaja izvir Lijak (Čar & Gospodarič 1986).

Geološka zgradba neposredne okolice Lijaka

V obdobju 1988/89 so 15 m za izvirom izvrtali vrtino Li - 0188. Analiza njenega jedra je dala pomembne podatke o geološki zgradbi tega območja. Do globine 8 m je bil navrtan grobozrnat pobočni grušč, nato pa do globine 126 m svetlo siv zgornjekredni apnenec. Vrtina je potekala skozi enake litološke člene, kar potrjuje s površinskim kartiranjem ugotovljeno subvertikalno lego plasti in s tem na antiklinalni del polegle gube. Od globine 126 m do konca vrtine pri 147 m so bile določene neprepustne flišne plasti. Ob dinarsko usmerjenemu prelomu, ki seka neposredno okolico bruhalnika, je v zgornjekrednih apnencih 20 m široka porušena cona, v kateri leži izvirno območje Lijaka (Čar & Gospodarič 1986).

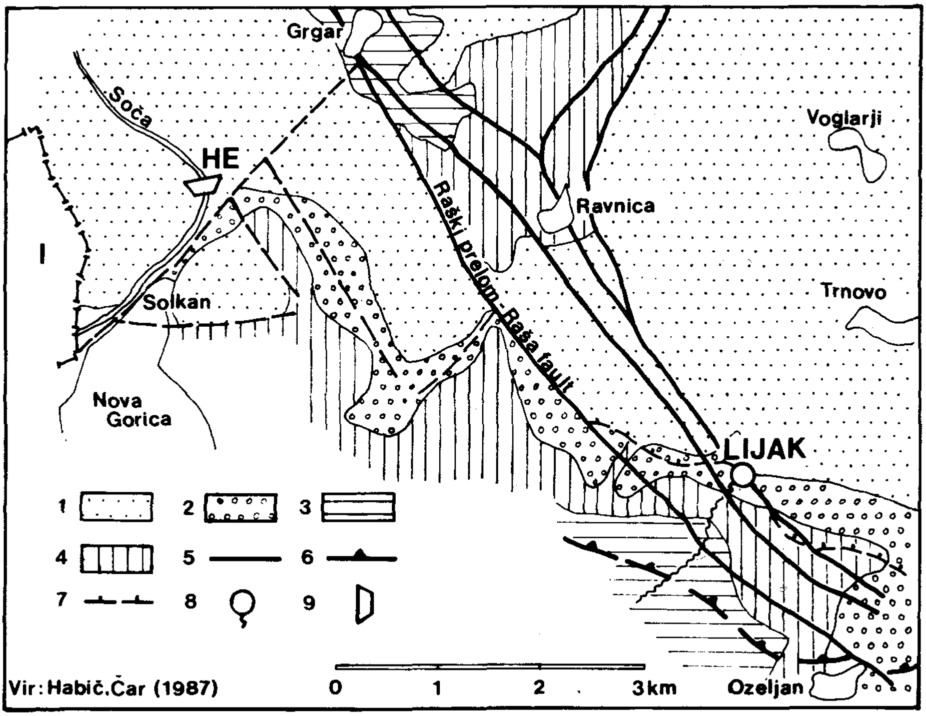
Hidrogeološka funkcija plasti

Po njihovi hidrogeološki funkciji uvrščamo kamnine obravnavanega ozemlja v štiri razrede (Čar & Habič 1987), ki so shematsko prikazani na sliki 1. Močno zakraseli in pretrti spodnjekredni in zgornjekredni apnenci osrednjega dela Trnovskega gozda spadajo med dobro prepustna območja s kraško in razpoklinsko poroznostjo. Kvartarne pobočne grušče in breče, ki prekrivajo prehod iz flišnega pobočja Vipavske doline v apnenčeve stene Trnovskega gozda, uvrščamo med dobro prepustna območja z medzrnsko poroznostjo. Enako poroznost imajo aluvialni nanosi v Grgarski kotlini, okolici Nove Gorice in v širokem pasu med Šempasom in Kromberkom, vendar so slabše prepustni. Fliš Vipavske doline in okolice Ravnice ter paleocenski laporji pa predstavljajo neprepustna območja z omejenimi prepustnimi vložki.

ANALIZA HIDRODINAMIČNEGA REŽIMA KRAŠKEGA VODONOSNIKA

Predstavitev problema

Na sliki 2 so prikazani zapis nihanja podzemne vode v Lijaku, zapis umetnega spreminjanja višine solkanske akumulacije in podatki o dnevnih višinah padavin na padavinski postaji Trnovo. Že na prvi pogled je dobro vidna zveza med njimi. Vsake zaznavne padavine povzročijo hiter dvig nivoja podzemne vode v Lijaku, doseženemu maksimumu pa sledi upadanje po značilni negativni eksponencialni krivulji. Vplivi spreminjanja višine akumulacije HE Solkan se kažejo kot odstopanja od te idealne krivulje. Če dejanski krivulji upadanja priredimo teoretično negativno eksponencialno krivuljo, lahko z razlikami med



Sl. 1: Hidrogeološka skica ozemlja med Lijakom in solkansko akumulacijo. 1 - dobro prepustna območja s kraško in razpoklinsko poroznostjo, 2 - dobro prepustna območja z medzrnsko poroznostjo, 3 - slabo prepustna območja z medzrnsko poroznostjo, 4 - neprepustna območja z omejenimi prepustnimi vložki, 5 - prelom, 6 - domnevna meja pokrova, 7 - domnevna narivnica, 8 - kraški bruhalnik Lijak, 9 - jez HE Solkan

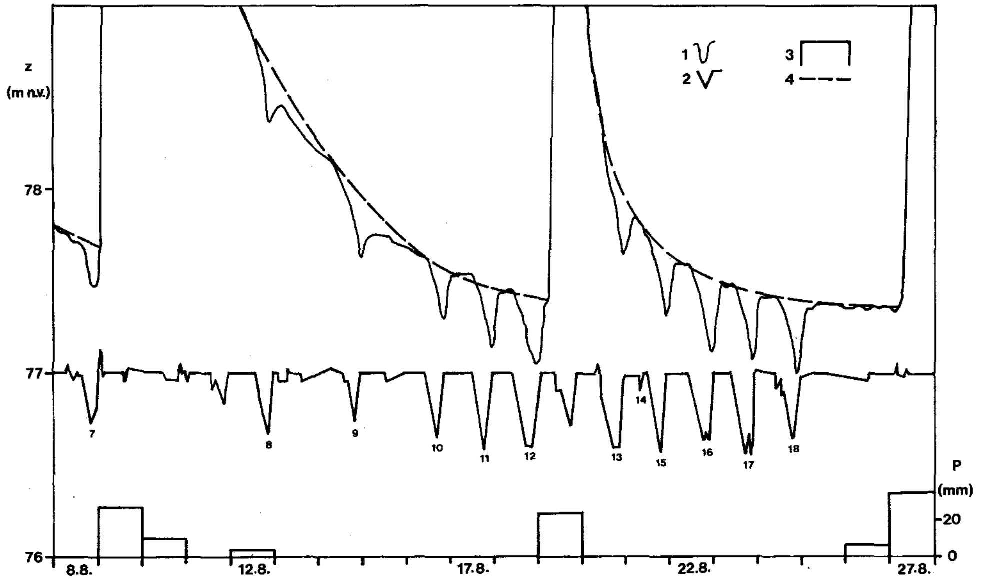
Fig. 1: Hydrogeological sketch of the area between the Lijak effluent and the accumulation Solkan. 1 - well permeable zones with karst and fissure porosity, 2 - well permeable zones with intergranular porosity, 3 - badly permeable zones with intergranular porosity, 4 - impermeable zones with permeable inliers, 5 - fault, 6 - supposed nappe border, 7 - supposed overthrust line, 8 - karst effluent Lijak, 9 - dam of the hydropower station Solkan

obema krivuljama določimo reakcije piezometrskega nivoja v Lijaku na hitra znižanja solkanskega akumulacijskega jezera. S tem je omogočena direktna primerjava obeh nihanj.

Nadaljnja analiza temelji na predpostavki, da je nihanje piezometrskega vala v Lijaku realizacija osnovnega vala, ki ga povzroči spreminjanje višine solkanske akumulacije. Faktor, ki pogojuje to razširjanje v prostoru in času, je difuzivnost. Izračunamo jo lahko na osnovi splošne enačbe piezometrske površine z upoštevanjem podatkov za osnovni in realizirani

val. Difuzivnost opisuje razširjanje tlačne motnje skozi porozno kamnino, zasičeno z vodo. Definirana je kot kvocient med transmisivnostjo T, ki v vodonosniku opisuje funkcijo prevodnika in koeficientom elastičnega vskladiščenja S, ki določa funkcijo akumulatorja. Če v enačbi širjenja piezometrskih valov upoštevamo rezultate kontinuiranega merjenja nihanja nivoja vode v Lijaku in v akumulaciji, lahko ocenimo vrednost difuzivnosti kraškega vodonosnika med njima.

Na osnovi izračunane difuzivnosti in podatkov o spreminjanju gladine akumulacije HE Solkan je mogoče določiti teoretične krivulje nihanja piezometrskega nivoja v Lijaku. V splošnem lahko ob znani vrednosti difuzivnosti vodonosnika v okviru ugotovljene natančnosti določimo vpliv spreminjanja višine akumulacije na nivo podzemne vode na poljubni oddaljenosti od izhodišča.



Sl. 2: Vpliv padavin (3) in umetnega spreminjanja višine akumulacije HE Solkan (2) na piezometrski nivo v Lijaku (1). 4 - teoretična krivulja upadanja

Fig. 2: The influence of precipitations (3) and artificial oscillations in the accumulation Solkan (2) on the piezometric level in the Lijak observation well (1). 4 - theoretical regression curve

Analiza krivulje piezometrskega nivoja vode v Lijaku

Direktna primerjava med spreminjanjem višine solkanske akumulacije in nihanjem nivoja podzemne vode v Lijaku ni možna zaradi prevladujočega vpliva padavin. Dejanski krivulji nihanja zato priredimo teoretično negativno eksponencialno krivuljo, po kateri bi se zniževal piezometrski nivo, če nanj ne bi vplivalo gibanje gladine akumulacijskega jezera. Iz razlike med obema krivuljama nato določimo reakcije podzemne vode v izviru na hitre spremembe višine akumulacije. Tako dobljene vrednosti predstavljajo osnovo za nadaljnjo analizo hidrodinamičnega režima v vodonosniku.

V matematičnem smislu je zgoraj opisano obliko krivulje definiral E. Maillet (1905, po Mijatoviću 1968). Opredelil je t.i. "krivuljo praznjenja", ki podaja zmanjševanje dotoka iz rezervoarja pri pogojih brez napajanja:

$$Q_t = Q_o \cdot e^{-\alpha \cdot (t - t_o)} \qquad (1)$$

Q_o dotok ob času t_o, ko se je praznjenje začelo
Q_t dotok ob času t
α Mailletov koeficient praznjenja

Analogno je definirana krivulja upadanja nivoja podzemne vode, ki se prav tako obnaša kot negativna eksponencialna funkcija:

$$H_t = H_o \cdot e^{-\alpha' \cdot (t - t_o)} \qquad (2)$$

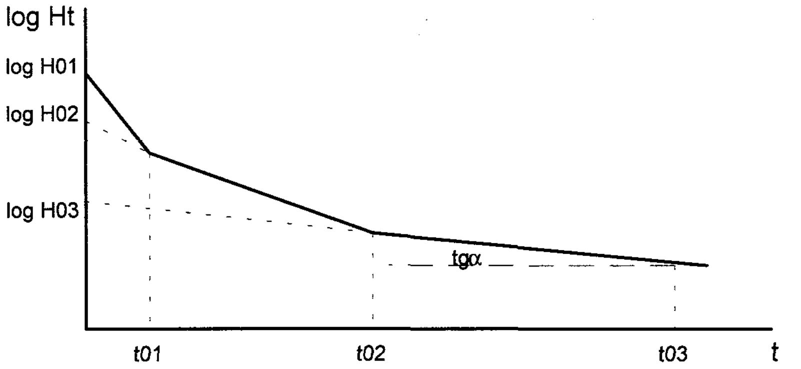
H_o nivo podzemne vode v času t_o, ko se je upadanje začelo
H_t nivo podzemne vode
α' koeficient upadanja

Za različne hidravlične tipe kraških vodonosnikov veljajo nekoliko spremenjene oblike te enačbe. V primeru Lijaka pa lahko za obdobje srednjih in nizkih vod privzamemo laminarni režim toka, ki ga opisuje kar osnovna enačba.

Ker praznjenje vodonosnika poteka istočasno iz različnih kolektorjev od kanalov največjega preseka preko manjših kanalov in razpok do mikrorazpok, ima vsak kolektorski nivo poseben podrežim upadanja nivoja podzemne vode, ki ga opredeljuje določen koeficient a'. Enačba upadanja dobi kompleksno obliko (Mijatović 1968):

$$H_t = H_{01} \cdot e^{-\alpha'_1 \cdot (t - t_{01})} + H_{02} \cdot e^{-\alpha'_2 \cdot (t - t_{02})} + \ldots + H_{on} \cdot e^{-\alpha'_n \cdot (t - t_{on})} \qquad (3)$$

Krivulja upadanja je tako sestavljena iz posameznih odsekov, ki jih v semilogaritemskem merilu predstavljajo premice z različnim naklonom. Vsak tak odsek predstavlja poseben podrežim z značilnim koeficientom α' (sl. 3).



Sl. 3: Teoretična krivulja upadanja v semilogaritemskem merilu
Fig. 3: Theoretical regression curve in the semilogarithmic scale

Koeficient α predstavlja tangens kota, ki ga oklepa premica z absciso. Dobimo ga z logaritmiranjem iz osnovne enačbe:

$$\alpha' = \frac{\log H_o - \log H_t}{0.4343 \cdot (t - t_o)} \qquad (4)$$

Neznanki v tej enačbi, H_o in a', določata posamezne odseke in omogočata izračun krivulje upadanja. Določimo ju tako, da v izbranih točkah dejanske krivulje upadanja nivoja vode v Lijaku izmerimo vrednosti $H_t = f(t)$ glede na referenčni nivo 77 m. S prikazom v semilogaritemskem merilu lahko opredelimo posamezne podrežime upadanja in izračunamo koeficiente a'. Z upoštevanjem teh vrednosti v modificirani osnovni Mailletovi enačbi (2) priredimo vsaki krivulji upadanja piezometrskega nivoja v izviru ustrezno teoretično negativno eksponencialno krivuljo. Za primere na sliki 2 so dobljeni koeficienti prikazani v tabeli 1, prirejene teoretične krivulje pa na sliki 2.

Tabela 1: Vrednosti H_o in α' za primere na sliki 2

Krivulja	t_o (ura)	H_o (m)	α'
3	0	0.910	0.011184
	0	10.568	0.031238
4	48	3.981	0.011790
	154	1.738	0.006348
	0	3.802	0.054468
5	25	1.274	0.010446
	104	0.589	0.002987

Izračunane krivulje se ujemajo z dejanskimi. Odstopanja, ki se pojavljajo, pa so reakcija nivoja podzemne vode v Lijaku na spreminjanje višine solkanske akumulacije in predstavljajo osnovni podatek za nadaljnjo analizo hidrodinamičnih razmer v kraškem vodonosniku.

Analiza razširjanja umetnih piezometrskih valov

Z analizo razširjanja piezometrskih valov lahko v danih okoliščinah opredelimo hidrodinamične lastnosti vodonosnika in ocenimo vrednost difuzivnosti Pri tem izhajamo iz splošne enačbe toka (Boussinesq 1877; Ferris 1951; po Krivicu 1982):

$$\frac{\delta^2 H(x,t)}{\delta x^2} = \frac{S}{T} \cdot \frac{\delta H(x,t)}{\delta t} \qquad (5)$$

H(x,t)	piezometrska površina, ki se spreminja v prostoru in času
x	oddaljenost od izhodiščne točke
t	čas, od začetka pri t = 0
S	koeficient elastičnega vskladiščenja
T	transmisivnost

To je enačba nestacionarnega toka, ki opisuje pretakanje podzemne vode skozi sisteme linijskih, paralelnih prevodnikov. Rešitev diferencialne enačbe je odvisna od oblike spreminjanja proste gladine s časom. V naravi je značilno sinusno nihanje nivoja vode v vodonosnikih, ki ga zaradi periodičnosti opisujejo enostavne enačbe. S tem problemom so se ukvarjali številni avtorji, ki so postavili teoretične osnove za različne hidrodinamične modele (Krivic 1982).

V obravnavanem primeru kraškega vodonosnika med solkansko akumulacijo in izvirom Lijakom pa nihanje nima oblike sinusoide. V HE Solkan namreč umetno spreminjajo nivo akumulacije glede na trenutne razmere in potrebe elektrarne, zato ima tudi spreminjanje proste gladine s časom poljubno obliko. Ker ga je nemogoče opredeliti z enačbami za periodično nihanje, je za ta posebni primer potrebno izpeljati splošno enačbo. Izpeljava predpostavlja idealizirane razmere v vodonosniku. Rešitev enačbe je funkcija H = H(x,t), ki definira piezometrsko površino.

Glede na robne pogoje H(x,t) = 0 za t< 0 in H(x,t) = h_0 za tł0 da dvojna transformacija Carson - Laplacea rešitev temeljne enačbe, ki se po aplikaciji teorema superpozicije prehodnih stanj razširi še na bolj kompleksne primere (Bonnet & Schneider 1969 po Krivicu 1982):

$$H(x,t) = h_0 \cdot \left(1 - \frac{2}{\sqrt{\Pi}} \cdot {}_0\!\int^{p} e^{-y^2} dy\right) + \Sigma\left((h_i - h_{i-1}) \cdot \left(1 - \frac{2}{\sqrt{\Pi}} \cdot {}_0\!\int^{r} e^{-y^2} dy\right)\right) \qquad (6)$$

kjer je $p = \sqrt{\frac{x^2}{4 \cdot D \cdot t}}$ in $r = \sqrt{\frac{x^2}{4 \cdot D \cdot (t - t_i)}}$

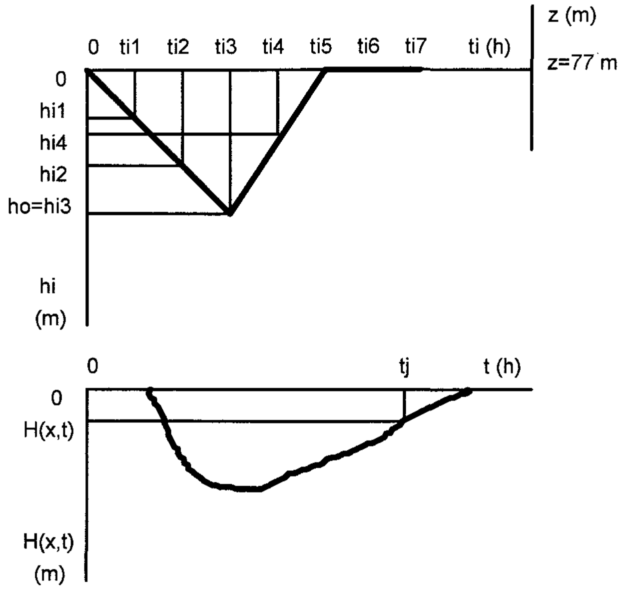
$H(x,t)$	piezometrska površina, ki se spreminja v prostoru in času
h_o	amplituda nihanja
x	oddaljenost od izhodiščne točke
t	čas, od začetka pri $t = 0$
D	difuzivnost
h_i	piezometrska površina izhodiščnega nihanja v času t_i

Izpeljano splošno enačbo piezometrske površine (6) sem uporabila pri analizi razširjanja umetnih piezometrskih valov med akumulacijo HE Solkan in izvirom Lijakom. Osnovne pogoje tega širjenja opisujeta dve skupini podatkov (sl. 4). Prva obsega digitaliziran zapis spreminjanja gladine akumulacije HE Solkan in predstavlja vrednost osnovnega vala v izhodiščni točki $x = 0$. Običajno se ta gladina zadržuje na koti 77 m, kratkotrajna znižanja ali zvišanja so posledica umetnega spreminjanja nivoja jezera. Natančno obliko nihanja sem dobila z ločeno analizo za posamezne časovne intervale, ki obsegajo čas od začetka spremembe, preko intervalnega maksimuma do vrnitve v začetno stanje. V celotnem opazovalnem obdobju od 19.7.1989 do 2.6.1990 sem določila 45 različno dolgih intervalov. Drugo skupino podatkov predstavljajo nivoji podzemne vode v Lijaku. Značilne piezometrske višine sem dobila z digitaliziranjem zapisa nihanja podzemne vode, v katerem je bil na osnovi modificirane Mailletove enačbe (2) že odstranjen prevladujoč vpliv padavin. Tudi v tem primeru je referenčni nivo kota 77 m. Izražene vrednosti predstavljajo realizacijo osnovnega vala na oddaljenosti $x = 6000$ m od izhodiščne točke; torej po opravljeni poti od solkanske akumulacije do Lijaka.

Tabela podatkov obsega tako naslednje parametre (sl. 4):

h_i	za vsak interval obsega skupino podatkov o višini vode v akumulaciji glede na referenčni nivo 77 m od začetka ($t_i = 0$) do konca intervala (t_{imax}) v časovnih razmikih $Dt_i = 2$ uri
t_i	čas, ki je potekel od začetka intervala do izbranega trenutka in se spreminja v vsakem intervalu od $t_i = 0$ do t_{imax}.
$H(x,t)$	predstavlja podatek o piezometrski višini vode v vrtini Li - 0188 v izbranem trenutku na oddaljenosti $x = 6000$ m od izhodiščne točke po odstranitvi prevladujočega vpliva padavin; vrednosti so določene glede na referenčni nivo 77 m.
t	v vsakem intervalu trenutni čas t
x	razdalja med akumulacijo HE Solkan in izvirom Lijak; torej pot, ki jo opravi opazovani val
h_o	amplituda vsakega posameznega intervala

Vsak interval s podatki o višini vode v akumulaciji h_i predstavlja en val, ki ga opisuje splošna enačba piezometrske površine (6). V tej enačbi je ob znanih vrednostih za osnovni in realizirani val iskana neznanka difuzivnost D, ki opisuje širjenje teh valov v prostoru in času.



Sl. 4: Osnovni val akumulacije HE Solkan (zgoraj) in realizirani val v Lijaku na oddaljenosti x = 6000 m od izhodišča (spodaj)
Fig. 4: Basic wave of the accumulation Solkan (above) and influenced wave in the Lijak observation well at the distance x=6000 m from the starting - point (below)

Rešitev integrala $\int e^{-y^2} dy$ je neskončna vrsta, ki konvergira proti $0.5 \cdot \sqrt{\Pi}$ (Vidav 1976). Število členov te vrste, ki pridejo v poštev pri izračunu, pa je odvisno od izbranih mej integrala. V obravnavanem primeru je pomembna zgornja meja, ki ima obliko

$\sqrt{\frac{x^2}{4 \cdot D \cdot t}}$. Ob upoštevanju dejanskih in predpostavljenih vrednosti parametrov je zadostna natančnost dosežena že z izračunom prvih šestih členov neskončne vrste. Splošna enačba piezometrske površine dobi tako naslednjo obliko:

$$(7)\ H(x,t) = h_o \cdot \left(1 - \frac{2}{\sqrt{\Pi}}\right) \cdot \left(y - \frac{y^3}{3} + \frac{y^5}{10} - \frac{y^7}{42} + \frac{y^9}{216} - \frac{y^{11}}{1320}\right) \Big|_0^{\sqrt{\frac{x^2}{4 \cdot D \cdot t_j}}} +$$

$$+ \Sigma\left((h_i - h_{i-1}) \cdot \left(1 - \frac{2}{\sqrt{\Pi}}\right) \cdot \left(y - \frac{y^3}{3} + \frac{y^5}{10} - \frac{y^7}{42} + \frac{y^9}{216} - \frac{y^{11}}{1320}\right) \Big|_0^{\sqrt{\frac{x^2}{4 \cdot D \cdot (t_j - t_i)}}}\right)$$

kjer nastopajo isti parametri kot v enačbi (6).

Vpeljala sem nove spremenljivke:

$$m=\sqrt{\frac{x^2}{4\cdot t_j}} \qquad n_{in}=\sqrt{\frac{x^2}{4\cdot(t_j-t_{in})}} \qquad k=-\frac{2}{\sqrt{\Pi}} \quad \mu=j-1 \quad \varepsilon=\sqrt{D}$$

in prikazala enačbo (7) v spremenjeni obliki:

$$\begin{aligned}
&-H(x,t_j)+h_0+(h_{i1}-h_{i0})+(h_{i2}-h_{i1})+\ldots+(h_{ij}-h_{i\mu})+\\
&+\frac{k}{\varepsilon}\cdot(h_0\cdot m+(h_{i1}-h_{i0})\cdot n_{i1}+(h_{i2}-h_{i1})\cdot n_{i2}+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij})\\
&-\frac{k}{3\cdot\varepsilon^3}\cdot(h_o\cdot m^3+(h_{i1}-h_{i0})\cdot n_{i1}^3+(h_{i2}-h_{i1})\cdot n_{i2}^3+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^3)\\
&+\frac{k}{10\cdot\varepsilon^5}\cdot(h_0\cdot m^5+(h_{i1}-h_{i0})\cdot n_{i1}^5+(h_{i2}-h_{i1})\cdot n_{i2}^5+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^5)\\
&-\frac{k}{42\cdot\varepsilon^7}\cdot(h_0\cdot m^7+(h_{i1}-h_{i0})\cdot n_{i1}^7+(h_{i2}-h_{i1})\cdot n_{i2}^7+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^7)\\
&+\frac{k}{216\cdot\varepsilon^9}\cdot(h_0\cdot m^9+(h_{i1}-h_{i0})\cdot n_{i1}^9+(h_{i2}-h_{i1})\cdot n_{i2}^9+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^9)\\
&-\frac{k}{1320\cdot\varepsilon^{11}}\cdot(h_0\cdot m^{11}+(h_{i1}-h_{i0})\cdot n_{i1}^{11}+(h_{i2}-h_{i1})\cdot n_{i2}^{11}+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^{11})=0
\end{aligned} \tag{8}$$

Vrednosti v oklepaju sem izrazila kot:

$$\begin{aligned}
a&=-H(x,t_j)+h_0+(h_{i1}-h_{i0})+(h_{i2}-h_{i1})+\ldots+(h_{ij}-h_{i\mu})\\
b&=k\cdot(h_0\cdot m+(h_{i1}-h_{i0})\cdot n_{i1}+(h_{i2}-h_{i1})\cdot n_{i2}+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij})\\
c&=-\frac{k}{3}\cdot(h_0\cdot m^3+(h_{i1}-h_{i0})\cdot n_{i1}^3+(h_{i2}-h_{i1})\cdot n_{i2}^3+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^3)\\
d&=\frac{k}{10}\cdot(h_0\cdot m^5+(h_{i1}-h_{i0})\cdot n_{i1}^5+(h_{i2}-h_{i1})\cdot n_{i2}^5+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^5)\\
e&=-\frac{k}{42}\cdot(h_0\cdot m^7+(h_{i1}-h_{i0})\cdot n_{i1}^7+(h_{i2}-h_{i1})\cdot n_{i2}^7+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^7)\\
f&=\frac{k}{216}\cdot(h_0\cdot m^9+(h_{i1}-h_{i0})\cdot n_{i1}^9+(h_{i2}-h_{i1})\cdot n_{i2}^9+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^9)\\
g&=-\frac{k}{1320}\cdot(h_0\cdot m^{11}+(h_{i1}-h_{i0})\cdot n_{i1}^{11}+(h_{i2}-h_{i1})\cdot n_{i2}^{11}+\ldots+(h_{ij}-h_{i\mu})\cdot n_{ij}^{11})
\end{aligned} \tag{9}$$

Ob upoštevanju teh vrednosti in množenju z e[11] dobi enačba naslednjo obliko:

$$a \cdot \varepsilon^{11} + b \cdot \varepsilon^{10} + c \cdot \varepsilon^{8} + d \cdot \varepsilon^{6} + e \cdot \varepsilon^{4} + f \cdot \varepsilon^{2} + g = 0 \quad (10)$$

Z uporabo računalniškega programa EUREKA sem določila ničle tega polinoma. Zaradi visoke stopnje polinoma in velikih vrednosti koeficientov je določitev ničel v nekaterih intervalih nezanesljiva. Vendar je primerjava rezultatov pokazala, da se v večini primerov vrednosti za e gibljejo okoli istega števila. Zato sem na osnovi teh rezultatov določila povprečno vrednost za e in po enačbi $D = \varepsilon^2$ še difuzivnost kraškega vodonosnika:

$e_{sr} = 734.85$
$D = 540\,000$ m²/h
$D = 150$ m²/s

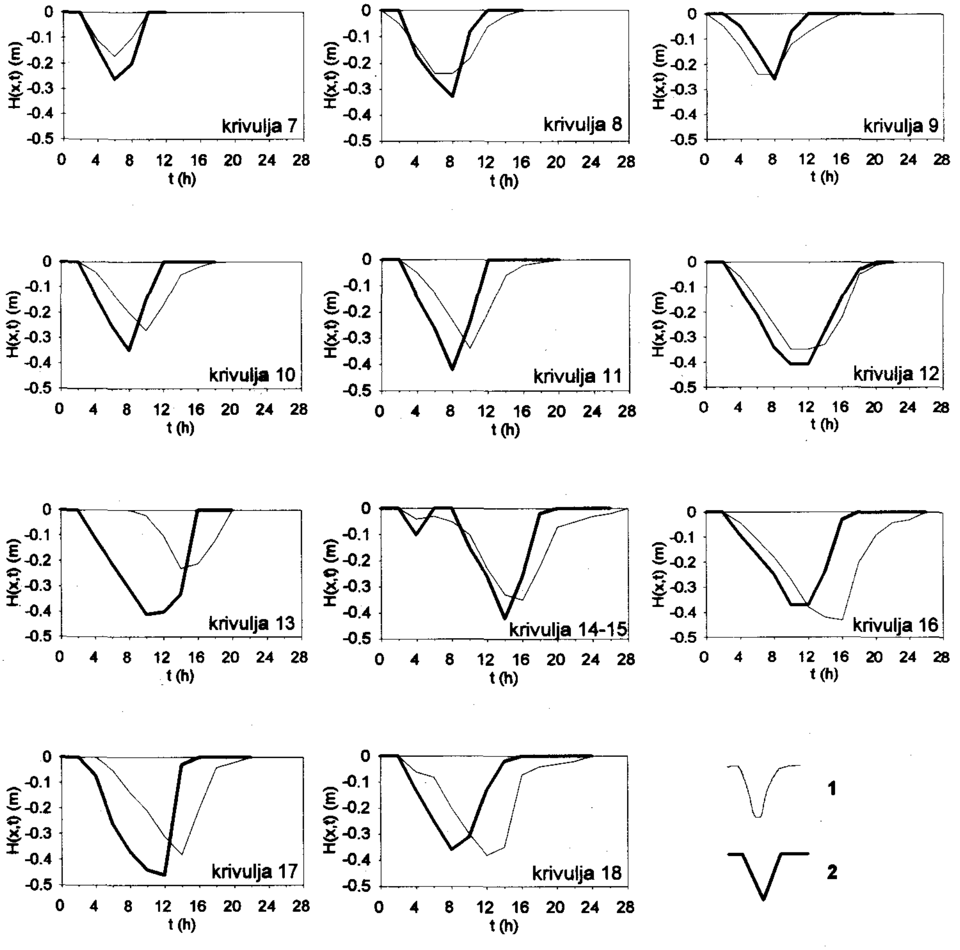
Računi, dobljeni na podlagi zapisa nihanja gladine podzemne vode v Lijaku v odvisnosti od spreminjanja nivoja vode v solkanski akumulaciji na razdalji 6000 m od izhodišča, so torej dali vrednost difuzivnosti 150 m^2/s. Kontrola in vrednotenje tega rezultata bi bila možna z analizo rezultatov črpalnega poizkusa. Primerjava iz literature pa je obalni kraški vodonosnik, na katerega vpliva plimovanje v Tržaškem zalivu. S podobno metodo je bila zanj izračunana difuzivnost okrog 200 m^2/s (Krivic 1982).

Izračun teoretične krivulje piezometrske površine

Na osnovi izračunane difuzivnosti in podatkov o spreminjanju gladine akumulacije HE Solkan je mogoče določiti teoretično krivuljo nihanja piezometrskega nivoja v vrtini Li - 0188. Vse naštete parametre namreč povezuje splošna enačba piezometrske površine. Vrednosti H(x,t) predstavljajo realizacijo osnovnega vala, ki potuje skozi kraški vodonosnik z difuzivnostjo D na oddaljenosti x od izhodiščne točke. S pomočjo računalniškega programa sem za konstantno vrednost difuzivnosti D=150 m^2/s za vseh 45 intervalov izračunala višine H(x,t). Zadostna natančnost pri izračunu integrala $\int e^{-y^2} dy$ je glede na velikost zgornje meje dosežena z upoštevanjem prvih dvaindvajsetih členov neskončne vrste. Rezultati so prikazani na sliki 5. Vsak interval je predstavljen z izračunano teoretično krivuljo in z dejansko krivuljo nihanja piezometrskega nivoja podzemne vode v Lijaku po odstranjenem prevladujočem vplivu padavin. Iz slik je jasno vidno, da se teoretične in dejanske krivulje dokaj dobro ujemajo.

Odstopanja se razlikujejo od intervala do intervala in so posledica različnih faktorjev:

(a) Splošna enačba piezometrske površine temelji na hipotezah, ki opredeljujejo preprost model in ne upoštevajo nekaterih stranskih vplivov.
(b) Spremembe akumulacije manjše od 0.07 m ne povzročijo reakcije piezometra.
(c) Pri zelo počasnem upadanju nivoja vode v akumulaciji piezometer reagira šele takrat, ko sprememba preseže 0.05 m.
(d) Razlike nastopajo v drugem delu krivulje, ki opisuje vračanje nivoja podzemne vode v začetni položaj. Pri teoretičnih krivuljah, ki sledijo umetnemu nihanju akumulacije, je



Sl. 5: Dejanske (1) in izračunane teoretične (2) krivulje nihanja podzemne vode
Fig. 5: Real (1) and calculated theoretical (2) curves of the groundwater level oscillations

ta del strm in vrnitev v osnovno lego je hitra. Dejanska krivulja pa reagira bolj počasi in kaže postopno prilagajanje nivoja podzemne vode, ki je značilno za naravna nihanja. V nekaterih primerih je ta pojav prikrit zaradi vpliva padavin, ki povzročijo hiter dvig gladine podzemne vode.

(e) Nekatera odstopanja so tudi posledica napak pri analizi krivulje upadanja. Te so še

posebej izrazite v začetnem strmem delu, kjer je vpliv padavin največji.

(f) 21.8.1989 sta dva ločena intervala nihanja akumulacije v razponu le dveh ur. Gladina podzemne vode počasi reagira na to spremembo, zato se piezometrski krivulji zlijeta v eno samo.

(g) Na ostre spremembe nivoja akumulacije piezometer ne reagira takoj in posledica je zglajena oblika dejanske krivulje.

Pri primerjavi teoretičnih in dejanskih krivulj se je tudi pokazalo, da se gladina podzemne vode odzove na spremembo z določenim časovnim zaostankom, ki je odvisen od hitrosti širjenja valov skozi vodonosnik in se od krivulje do krivulje razlikuje. V nekaterih primerih je reakcija praktično takojšnja, v drugih pa zamuja tudi do 6 ur. Skušala sem določiti odvisnost hitrosti odziva od višine vodostaja, vendar je primerjava pokazala, da zaostanki niso pogojeni z nivojem vode v vodonosniku. Pri tem moramo upoštevati, da je bila ugotovljena občasna neusklajenost urnih mehanizmov v Lijaku in Solkanu in si lahko različne zaostanke razlagamo tudi kot posledico teh napak. Poleg tega tudi digitalizacija krivulje nihanja podzemne vode v Lijaku ni dovolj natančna, da bi omogočala točno določitev časovnih zaostankov.

SKLEP

Kraški bruhalnik Lijak leži približno 6 km vzhodno od Nove Gorice v dnu visoke skalne zajede pod robom Trnovskega gozda. Deluje kot občasni izvir, ki le v kratkem obdobju visokih vod preliva čez neprepustno podlago. Voda izvira na kontaktu vodonosnih krednih apnencev Trnovskega gozda in neprepustnih eocenskih flišnih kamnin spodnje Vipavske doline, ki imajo vlogo bočne pregrade.

S preučevanjem in analizo piezometrskega nivoja v vrtini za izvirom je bil ugotovljen značilen kraški režim nihanja podzemne vode s kratkotrajnimi visokimi valovi in daljšimi obdobji nizkih vod ter veliko amplitudo. Porasti vodostaja so hitri, doseženemu maksimumu pa sledi upadanje po negativni eksponencialni krivulji. Posebnost Lijaka so nenadne spremembe nivoja vode, ki odstopajo od te idealne krivulje in niso v nikakršni zvezi s padavinami. Ta zanimiv pojav je bil pojasnjen s primerjavo rezultatov opazovanja nihanja podzemne vode v izviru z zapisom spreminjanja gladine akumulacije HE Solkan. Že na prvi pogled je vidna zveza med obema objektoma, saj imajo hitra, kratkotrajna znižanja akumulacijskega jezera jasen odziv v limnigramu Lijaka. Izdelana kvantitativna analiza pa je to zvezo le še potrdila.

Značilnosti vodonosnika sem opredelila na osnovi analize širjenja piezometrskih valov od izhodišča v solkanski akumulaciji do opazovane realizacije v Lijaku. Razširjanje teh valov v prostoru in času je pogojeno z difuzivnostjo. Ta je definirana kot kvocient med transmisivnostjo, ki v vodonosniku opredeljuje funkcijo prevodnika in koeficientom elastičnega vskladiščenja, ki opisuje funkcijo akumulatorja. Na osnovi splošne enačbe piezometrske površine sem s primerjavo osnovnega in realiziranega vala izračunala, da ima difuzivnost obravnavanega kraškega vodonosnika vrednost 150 m^2/s.

Na osnovi podatkov o spreminjanju višine akumulacijskega jezera in izračunane difuzivnosti sem določila še teoretično krivuljo nihanja gladine podzemne vode v Lijaku.

Zaradi privzetih poenostavitev teoretične in dejanske krivulje niso povsem enake, očitno pa je, da se ujemajo v generalnem trendu in s tem dokazujejo ugotovljeno hidravlično zvezo med akumulacijo in izvirom. Dobljeni rezultati so potrdili uporabnost prikazane metode za analizo širjenja umetnih piezometrskih valov v prostoru in času. Ob znani vrednosti difuzivnosti lahko v okviru ugotovljene natančnosti določimo vpliv spreminjanja višine akumulacije na nivo podzemne vode v določenem času na poljubni oddaljenost od izhodišča.

Rezultate prikazane kvantitativne metode bi bilo potrebno preveriti še z nekaterimi dodatnimi analizami. V HE Solkan in Lijaku so nadaljevali z začetimi meritvami tudi po 2.6.1990 in primerjava dobljenih zapisov bi lahko dala nove podatke o hidrodinamičnih lastnostih vodonosnika in povedala več o mejah uporabnosti prikazane metode. Podobno vlogo bi imela tudi analiza rezultatov črpalnega poizkusa na Lijaku, ki bi omogočila primerjavo izračunanih difuzivnosti. Z namestitvijo dodatnih piezometrov na različnih mestih v kraškem vodonosniku pa bi dobili še širši pregled nad pretakanjem podzemne vode in nihanjem njene gladine v kraškem vodonosniku zahodnega dela Trnovskega gozda.

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HYDRODINAMIC REGIME OF THE KARST AQUIFER BETWEEN THE ACCUMULATION OF THE HYDRO - POWER STATION SOLKAN AND THE LIJAK EFFLUENT

SUMMARY

The karst effluent Lijak is located about 6 km to the east of Nova Gorica in the bottom of the high rocky indentation under the edge of the Trnovo plateau. It works like a temporary spring and flows over the impermeable basis only during short periods of high waters. The spring is situated on the contact between waterbearing Cretaceous limestones of the Trnovo Plateau and the impermeable barrier of Eocene flysch beds of the lower Vipava valley (Fig. 1).

The tipical karst regime of the underground water level oscillations with short periods of high altitudes, longer periods of low waters and high amplitude was established by the measurements and analyses of the piezometric level in the borehole behind the spring. The raise of the water table, that follows the precipitations, is very fast. In the phase of regression the decrease of the piezometric level is described with the negative exponential curve. The peculiarity of the Lijak spring are unexpected changes in the water level, that decline from the ideal curve, and are in no connection with the precipitations. This interesting phenomena was explained with the comparison between the water level oscillations in the accumulation of the hydro-power station Solkan and the effluent Lijak. The connection between both objects is visible at first sight. Fast changes of the water height in the accumulation have an evident response in the water table of the Lijak observation well (Fig. 2). This relationship was confirmed by quantitative analyses.

For the direct comparison between both oscillations the predominated influence of the precipitations on the water level in the spring had to be removed. So first the theoretical negative regression curve was adjusted to the real curve (Fig. 2). From the differences between both curves the reactions of the piezometric level in Lijak on the fast changes of the water level in the accumulation were defined. These data were then used in further analyses.

The calculations were based on a presumption, that the reactions in the Lijak effluent are the realization of the basic waves, which are caused by water level oscillations in the accumulation. The propagation of those waves through space and time is conditioned by

the difusibility. The described parameters are defined in the general equation of the piezometric surface, which for the discussed case can be derived into equations (7), (8), (9) and (10). By the comparison betwen the basic and the influenced wave and on the bases of those equations the difusibility of the discussed karst aquifer D = 150 m^2/s was estimated .

From the known changes of the water level in the accumulation and calculated difusibility the theoretical curve of the water level oscillations in the effluent Lijak can be established. For the discussed case those curves are shown in Figure 5. Because of the assumed simplifications theoretical and real curves are not completely the same, but it is obvious, that they have the same general trend. Hence this method can be used for the analyses of the propagation of the artificial piezometric waves through space and time. Also the established hydrodinamic connection between the accumulation and the spring has been proved.

The results of the shown quantitative method should be checked with some additional analyses. The comparison with further measurements in the Solkan accumulation and the effluent Lijak would give some new data about the hydrodinamic properties of the karst aquifer and tell us more about the usefulness of the shown method. Through the comparison with the analyses of the pumping test data the calculated difusibility could be confirmed. With the installation of the additional piezometric boreholes on various locations in the karst aquifer also a wider overlook on the groundwater flow and the water level oscillations in the karst aquifer of the Trnovo plateau would be given.

POROČILA

AN ACCOUNT ON STUDY EXCHANGE WITH FRANCE 1993

Due to the tradition since 1979 this year too the researchers of the Karst Research Institute ZRC SAZU have taken part at the scientific technical cooperation with France, more precisely URA 903 CNRS (Aix-en-Provence), Laboratoire souterrain du CNRS (Moulis).

The visit lasted from October 11 to 19, 1993 and was realized by two geologists mag. Martin Knez and mag. Stanka Šebela. In the first part we visited, guided by prof. J. Nicod and under the authority of prof. J.J.Blanc the caves Grottes de Baudinard in the Verdon canyon. In the Baudinard canyon's profile four levels of the cave systems may be observed. In these caves J.J.Blanc (1992) studied the speleogenesis in respect to tectonic laws.

In one of these caves, in the Grotte de l'Eglise namely, the prehistoric symbols in the roof solution cups were discovered presenting the sun, stars respectively. The age of these signs is postglacial.

Our voyage continued to Montpellier where we were hosted by the Ambert family. We discussed the possibilities for common french-slovene cooperation in future.

Near Montpellier and at St. Guilhem le Désert dr. P. Ambert presented us his studies on travertines which is the study topic of several researchers in France.

The second part of study voyage was spent in Pyrénées. In small village named Moulis lies world famous Laboratoire souterrain du CNRS where they breed the famous slovene proteus. Within the area of karst hydrogeology and chemistry we got a lot of new knowledge from dr. A. Mangin and dr. M. Bakalowicz who accepted us kindly and presented us their work. D. d'Hulst presented the computer aided program for big data bases (t, CO_2, humidity, pressure) from the Grotte de Gargas where they monitor the impact of tourist visits on the prehistoric paintings.

The biologist R. Rouch presented us interesting assessment of hydrogeology and biology in the karst aquifers confirming the same bases of the karst system.

In Moulis the director M. dr. C. Juberthie presented the cave-laboratory where they daily observe the cave animals from all over the world. A special attention is paid to proteus. We visited the cave Mas d'Azil through which the road goes. We also visited the entrance to the cave Niaux where are the most famous prehistoric paintings.

Our kind hosts enabled our visit to a part of the Système de la Cuomo d'Hyouernedo which is the longest french cave, 130 km and and among the deepest (- 1004 m). The labyrinth of the passages and potholes remains one of the speleologically the most promising systems. The caver and the guide, P. Durand who is in charge of the caving hut Maison du Gouffre dans le Labaderque village, a little northwards from Arbas, guided us for one hour by foot to one of the 40 entrances, called Grotte de pène Blanque (930 m a.s.l.). This cave is a system of horizontal passages and potholes. In three hours we only got a general impression about the cave labyrinth where is quite easy to be lost. The horizontal passages are former phreatic channels actually filled up by the old cave sediments but also the areas with the moon-milk.

The Arbas-Paloumère massif, where the cave developed, was uplifted and it still does today (6-8 mm/10 years). It is built by the limestones and dolomites from Liassic to Jurassic

and by the limestones of the Urgonian age (K). An important fault is "north-Pyrennean" having the direction E-W. Along the parallel satellite fault, probably in Triassic, the characteristic pyrennean rocks outcroped from the earth crust - called "lersolite".

In future scientific-technical cooperation with France we expect more comon work within the problematics of the travertines namely the comparison and complement of the Slovene cases with these from France.

Stanka Šebela

THE FIRST INTERNATIONAL KARSTOLOGICAL SCHOOL "CLASSICAL KARST"

The Karst Research Institute ZRC SAZU has organized within the Speleological Association of Slovenia, supported by the Slovenian Commission at UNESCO and sponsored by the Ministry for Science and Technology and the Ministry for School and Sport, the first international karstological school at us. The topic of school was Classical Karst, it was held in Lipica in the time from September 20 to 23, 1993.

The decision for the organisation of such school is due to facts that the Slovene classical karst presents a reference karst abroad, scientists from all over the world revisit it wishing to know it better. The topic of the first school was classical karst and its superficial geomorphological phenomena and its underground and the processes dealing with the problematics of the karst pollution.

The school was well visited. There were 36 participants altogether, among them professors, researchers and students. Thirteen participants came from abroad, namely: Czech Republic, France, Italy, Germany, Poland, Russia and United States of America. In the morning the lectures were held and in the afternoon the field work took place; Škocjanske jame were presented in all its richness and diversity, contact karst of Brkini Hills and the examples of classical dolines.

The first complex of lectures presented Škocjanske jame. A. Kranjc - Classical Karst, about the name and its history, D. Rojšek - Inventory of natural heritage, M. Knez - Phreatic Channels in Velika dolina (Škocjanske jame), J. Kogovšek - Impact of human activity on Škocjanske jame and M. Puc - The Project Škocjanske jame.

The second complex included the lectures of B. Berce-Bratko, L. Mahne and M. Mlinar treating the problematics of Park of Notranjska, primarily the relationship between man and karst, the tourism, the recreation in Park, management and financial structure.

M. Piškula reported on diving explorations in the Timavo springs, F. Cucchi about dissolution and lowering of the karst surface, P. Bosak about paleokarst in Czech Republic, E.P. Lhnert about specific karst properties in Westphalia (Germany), D. Crouch about geological bases of Greek colonization, U. Sauro presented the karst in the world by slides. The student of geology M. Vrabec has taken an active part by presenting the poster entitled Some thoughts on pull-apart origin of karst poljes along Idrija strike slip fault in Slovenia.

J. Kunaver presented the role and the importance of karst and its phenomena in ecological education; F. Šušteršič lecture was entitled Classical Dolines of Classical Site and he presented the examples in field in detail.

Karstological school ended by the whole day excursion over the classical karst of Notranjska. For this excursion as well as for field work at other days a written material, a guide-book was prepared.

Referring to great interest for the first school we plan to organize it each year and treat a chosen topic with the karst problematics in detail.

Janja Kogovšek

AN ACCOUNT OF THE INTERNATIONAL SYMPOSIUM MAN ON KARST

At the time from September 23 to 25, 1993 at Postojna the International Symposium Man on Karst was held, organized within the International Geographical Union, Commission on Environmental Changes and Conservation in Karst Areas by the Karst Research Institute ZRC SAZU. The meeting was dedicated to the 70th anniversary of the Academician Prof. Dr. Ivan Gams who was at that occasion honoured by the honorary membership of the Czech's Speleological Union.

The participants were greeted by the minister for Science and Technology, Dr. R. Bohinc, by the secretary general of the Slovene Academy of Sciences and Arts Acad. Prof. Dr. M. Drovenik, by the maire of Postojna, Mr. I. Bratina, by the representative of the Association of the Geographic Societies of Slovenia, Prof. Dr. A. Černe, and by the representatives of the international organizations, Prof. Dr. P. Forti, the UIS president and Dr. P. Bosak, secretary of the UIS, by Prof. Dr. Ugo Sauro, the president of the Commission on the Environmental Changes and Conservation in Karst Areas at the International Geographical Union.

The Symposium was attended by 69 participants who delivered 50 papers. The introductory lecture of P. Habič presented the important part played by the man celebrating his jubilee for the progress of the karstology in this century and M. Panoš presented the karstology as a joint system of sciences on karst.

After the opening part and the plenary lectures the work was organized within two sections. In the section Karst as a Natural Process 24 communications were delivered.

The lectures dealt with the conditions of the sedimentation of some carbonate rocks, tectonics and its influence on formation of the karst aquifers. Several papers treated hydrogeological topics, development of particular hydrogeological areas and chemical and isotopic composition of the karst waters.

Some papers dealt with geomorphological formation of the surface on karst and development of the soil on karst. Several lecturers spoke about the development of the karst underground, distribution of caves and speleomorphology, about the cave minerals and speleoclimatology.

In the section Man and Karst 26 lectures were delivered. According to the subjects they may be divided into some groups.

The contributions about the agrarian use of the karst surface mostly presented the types of the land use from the lithological differences point of view and soil origin or hydrotechnical works on karst. The intensive and unsuitable land use in past provoked the degradation of the karst surface.

Similar themes were treated by the papers involved in the use of mountainous regions for touristic purposes, ski ressorts in particular. The introduction of intensive activities may severly threaten the water supply functions of these, frequently the only scarcely inhabited, areas in Europe.

Several papers presented the work at the preparation of the professional bases for the legislation which should protect the vulnerable karst areas. They are protected within the

various landscape parks but the protection measures confront with the interests of the people living there, their traditional spatial use or with the interests of the touristic economy.

There were the papers delivered treating the polluted karst groundwater and its autopurification capacity, the determination of the protection zones of particular karst springs and the underground water tracing.

Several papers treated the use of caves and human impact on the underground. The last effect may be traced into the prehistory as the caves served as human dwellings thousands years ago and bones, the remains of the paleolithic hunters' preys, are found in them. The influence of the touristic visits on the changes of the cave climate were presented as well as the devastation of the caves due to ill-treatment. The use of caves for mass graves in our half past history was presented too.

During the symposium three excursions were organized. The first one to the Classical Karst from Vrhnika to Pivka, the second one to Karst between Pivka basin and the springs at Osp. The third excursion was in the Postojnska jama cave system.

During the Symposium the Commission for the Environmental Changes and Conservation in Karst Areas at the International Geographical Union and the Bureau of International Union of the Speleology have held two meetings.

Andrej Mihevc

THE INTERNATIONAL ROUND-TABLE "MARTEL AND THE SLOVENE KARST 1893-1993" (POSTOJNA, NOVEMBER 12 - 13, 1993)

Hundred years ago, in the autumn of 1893, the world famous speleologist Edouard A. Martel came to explore the Dinaric Karst within the Austro-Hungarian Monarchy. He visited a great deal of this karst, but trully important explorations he carried out in Carniola, in the Postojnska jama cave system.

To honour and to recall memories of these events, to reassess the Martel's work in our karst from the modern point of view and to review the significance of our karst in older French literature, the Karst Research Institute ZRC SAZU under the patronage of the Speleological Association of Slovenia and in the coperation with the Museum of Notranjska, organized this round table.

25 experts from five countries (Austria, France, Italy, Great Britain, Slovenia) have taken part; among them must be mentioned in particular Dr. Karl Mais, the director of the Speleological Institute, Vienna, Dr. T. R. Shaw, the author of a comprehensive book History of Speleology, and the representatives of France, Mr. D. Lopez, consul and Mr. J. Granon, the attach for science. In the last moment several eminent participants renounced their arrival, among them unfortunately D. Andr, connoisseur and collector of the material of Martel's biography and correspondence, who sent an interesting set of slides about Martel which were shown to the participants.

Due to short daylight the work was a bit unusually disposed: during the day the field work and late in the afternoon and in the evening the discussion part of the meeting. There have been presented seven main papers, four of them treating the Martel's work on the slovene karst (A. Kranjc, A. Mihevc, D. Rojšek, S. Šebela) and three Martel's activity and his significance with an accent on his work in the Dinaric karst (A. Kranjc, K. Mais, T.R. Shaw). These papers served as the basis for interesting and detailed discussion for which there was no lack of time as usually and which is the essential advantage of the round tables. The field work followed "the Martel's traces" in Postojnska jama, Otoška jama, Pivka jama, Črna jama and Magdalena jama and in Škocjanske jame.

For the organization there were no special financial means neither a cotisation was foreseen this is why the material support of Postojnska jama, Škocjanske jame and the Postojna commune was so welcome. Of course, the organiser still has difficult and responsable task to publish the presented papers and, as usually, we rely on financial support of the Ministry for Science and Technology.

Andrej Kranjc

K.-F. BUSCH, L. LUCKNER, K. TIEMER: GEOHYDRAULIK, 3. NEUBEARBEITETE AUFLAGE, 497 STRANI. GEBRÜDER BORNTRAEGER, BERLIN - STUTTGART 1993.

Že iz naslova vidimo, da gre za 3. predelano izdajo knjige o geohidravliki. Prva in druga knjiga iz let 1972 in 1973 sta na nemško govorečem območju postali temeljni deli o hidravliki podzemnih vod, zaradi hitrega razvoja predvsem matematično-analitičnega pristopa k obravnavanju problemov pa je bila nujno potrebna nova, predelana in razširjena izdaja, ki sedaj uspešno združuje že preizkušeno z novimi dosežki v znanosti in praksi zadnjih dveh desetletij.

V trde platnice vezana knjiga običajnega formata je sestavljena iz uvoda in petih poglavij. V uvodu so predstavljeni osnovni pojmi geohidravlike in opisan je njen praktičen pomen, nekaj več besed pa je namenjenih tudi matematičnemu modeliranju, ki je v zadnjem času že postalo nepogrešljivo orodje pri reševanju hidrogeoloških problemov. Na koncu so na kratko predstavljeni najpomembnejši znanstveniki, ki so se v zgodovini znanosti ukvarjali z raziskavami podzemne vode.

V bistvo problema nas uvede prvo poglavje, ki govori o osnovah geohidravličnega obravnavanja stanj in procesov. Temeljna je ugotovitev, da je podzemlje večfazni sistem in so njegove karakteristike določene z lastnostmi posameznih faz. Tako so prikazane osnovne značilnosti vode in zraka ter hidravlične karakteristike poroznega sredstva. Poglavje je zaključeno z opisom odpornosti krhkih kamnin na deformacije. Vsi prikazani parametri so obdelani podrobno in iz različnih zornih kotov, dodatno težo teoretičnim razlagam pa dajejo številni eksperimentalno podprti grafi in tabele ter posamezni praktični primeri.

Drugo poglavje obravnava matematično modeliranje procesov transporta fluidnih faz v poroznem mediju, na katerem temeljijo geohidravlični izračuni in analogne ali digitalne simulacije geohidravličnih procesov. Najprej so predstavljeni nekateri osnovni pojmi modeliranja, nato pa so podrobno opisani Darcyjev zakon kot osnovni dinamični zakon geohidravlike in prav tako pomembne bilančne enačbe. Vsa raznolikost in kompleksnost dogajanja v podzemlju se odražata v številnih različnih izpeljavah teh zakonov. Če pa hočemo tako dobljene matematične izraze uporabiti za reševanje konkretnih problemov, je potrebno najprej modelu primerno shematizirati realne pogoje pretakanja podzemne vode. Načini obdelave so v knjigi prikazani na teoretičnih in praktičnih primerih. Na koncu poglavja so pojasnjeni še nekateri pomožni matematični postopki, ki jih uporabljamo v geohidravliki.

Ker je analitična metoda v hidravliki podzemne vode sinonim za eksplicitno, v strnjeni obliki predstavljeno rešitev matematičnega modela, so v tretjem poglavju obravnavane analitične rešitve podzemnih tokovnih problemov, za katere so bile v prejšnjem poglavju izpeljane tokovne enačbe. Do zelo preciznih podrobnosti je obdelano računanje toka med kanali in v vodnjakih ter toka v vertikalni ravnini, ki ga predstavljajo primeri precejanja v kanalih, skozi nasip in pod jezom. Definirane so enačbe za številne različne karakteristike vodonosnikov in podzemnih tokov. Teorija je predstavljena zelo nazorno in matematični izrazi so opremljeni s številnimi slikami, diagrami in tabelami, za boljše razumevanje pa je prikazano tudi reševanje praktičnih problemov.

Četrto poglavje je v celoti posvečeno analognim in digitalnim metodam reševanja hidravličnih problemov, saj so opisani analitični postopki omejeni le na enostavne tokovne probleme. Najprej so obdelani različni tipi analognih modelov. Vsaka metoda je podrobno predstavljena s sistemom enačb ter s shemo in fotografijo naprave, ki so jo izdelali v laboratoriju. V logični zvezi z razvojem računskih tehnik sledi prikaz digitalne simulacije, ki podaja numerične rešitve infinitezimalnih matematičnih modelov s pomočjo računalnikov. V začetku so razložene osnovne zahteve modeliranja, nato pa sta predstavljeni analizi s prostorsko in s časovno diskretizacijo. Pri tem sta posebej izpostavljeni metoda končnih elementov in metoda končnih diferenc. Kot v vseh ostalih poglavjih se tudi tu podrobno razloženi postopki analize in izpeljave osnovnih enačb lepo dopolnjujejo s konkretnimi primeri iz prakse. V zaključku poglavja so prikazani še problemi, ki jih rešujemo s kombinacijo analitičnih in numeričnih postopkov.

Zadnje poglavje opisuje obratno pot reševanja nalog, za katere so podatki o hidravliki podzemne vode določeni s testi merjenja odvisnih spremenljivk in pri katerih je potrebno ugotoviti še številne nedokazane parametre modela. Potek reševanja problema je prikazan s shematskim diagramom, posamezni koraki pa so nato še detajlno razloženi v nadaljevanju. Primer takega sistema je interpretacija črpalnih poizkusov, ki jim je v tem poglavju namenjen osrednji prostor. Teoretično so definirane osnovne enačbe vodnjakov in prikazane metode obdelave rezultatov črpalnih poizkusov, praktična uporabnost pa je pojasnjena s podrobnim opisom zaporednih korakov obdelave na konkretnem primeru. V zaključku je prikazana metoda reševanja nalog razširjena še na numerične metode identifikacije parametrov. Knjiga se končuje s pregledom literature in seznamom ključnih pojmov, ki so obdelani v posameznih poglavjih.

Že na naslovnici je knjiga predstavljena kot učbenik za hidrogeologijo. Njen naslov pa nam pove, da obravnava geohidravliko, posebno vejo hidrogeologije, ki je definirana kot tehnično-aplikativna veda o ravnotežju in gibanju fluidnih mas v podzemlju ter medsebojnem učinkovanju med fluidom in trdno osnovo. Temu ustrezen je tudi pristop, ki ga lahko zasledimo med prebiranjem. Učbenik je pretežno posvečen matematičnim metodam reševanja problemov pretakanja podzemne vode in bralec brez potrebnega matematičnega predznanja bo imel velike težave pri razumevanju posameznih tem. Teorija geohidravlike je predstavljena zelo nazorno z osnovnimi opisi in matematičnimi izrazi, večjo preglednost in eksperimentalno podprto težo pa knjigi daje 238 slik in 50 tabel. Še posebej dobra orientacija vsakemu bralcu so praktični primeri, ki dodatno pojasnjujejo teoretične izpeljave. Knjigo zato priporočam vsem, ki bi se radi nekoliko bolj poglobili v zakonitosti procesov hidravlike podzemne vode in v metode reševanja s tem povezanih problemov. Kot pri večini tovrstne literature pa bodo verjetno tudi tokrat malo razočarani hidrogeologi, ki se ukvarjajo s pretakanjem podzemnih vod v krasu. Osnove so sicer podane tudi za kraško-razpoklinske vodonosnike, pri konkretni obdelavi pa takih primerov ne zasledimo več.

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