Cave Science

The Transactions of the British Cave Research Association

BCRA

Volume 19 Number 1 April 1992

Gypsum caves in the western Ukraine

Karst environments in Guizhou, China

Oligochaeta in Speedwell Cavern

Monkey caves of Cuba

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Cave Science

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Editor: Dr. T. D. Ford, 21 Elizabeth Drive, Oadby, Leicester LE2 4RD.

Production Editor: Dr. A. C. Waltham, Civil Engineering Department, Nottingham Polytechnic, Nottingham NG1 4BU.

Cave Science is published three times a year by the British Cave Research Association and is issued free to all paid up members of the Association.
1991 subscription rate to Cave Science is £16.00 per annum (postage paid).
Individual copies, back issues and details of annual subscriptions to Cave Science, and of Association membership, can be obtained from the BCRA General Administrator, 20 Woodland Avenue, Westonzoyland, Bridgwater TA7 0LG.
The Association's permanent address is: BCM BCRA, London WC1N 3XX.

ISSN 0263-760X

CAVE SCIENCE Vol. 19, No. 1, April 1992
Transactions of the British Cave Research Association

Large Gypsum Caves in the Western Ukraine and their Genesis

Alexander B. KLIMCHOUK

Abstract: The Western Ukraine is a unique region of gypsum caves with five of the world longest gypsum caves. These caves display a maze pattern with high density of passages. The problem of the genesis of gypsum maze caves is considered for the region and the previous speleogenetic concepts are critically reviewed. New evidence, models and theoretical background are presented for maze caves development under conditions of a multi-storey artesian system. It is shown that dispersed upward recharge from a basal aquifer is responsible for development of maze caves in the Western Ukraine.

There is a great number of publications devoted to the unique maze caves developed into the Neogene gypsum strata of the Western Ukraine. Five of the are the world largest caves in gypsum with 412 km of total length of mapped passages. Recently a review has been published in English (Klimchouk & Andrejchouk, 1986) of geologic and hydrogeologic settings of gypsum karst development in the region. In another work characteristics have been given of the main features of the principal caves and their genesis has been discussed (Klimchouk, 1986). Starting from the above works the present paper provides for further elaboration of the genetic problem of the maze caves in the region and a new speleogenetic concept is suggested.

GEOLOGIC AND HYDROGEOLOGIC SETTING

Only brief characteristics are given here of the main conditions of gypsum karst development; for details see Klimchouk & Rogozhnikov (1982), Klimchouk *et al.*(1985), Klimchouk & Andrejchouk (1986,1988), Andrejchouk (1988).

The gypsum strata of Miocene age are widely spread in the southwest outskirts of the East-European platform, in the transitional zone between the platform and pre-Carpathian foredeep (Figure 1). The most important feature of the transitional zone is an intense block-fault breaking of the stratigraphic construction and the plunge by steps of the gypsum strata from platform toward the foredeep. These features determine many important peculiarities of karst development (Klimchouk & Andrejchouk, 1986).

The gypsum strata of 10-40m in thickness lie on the sandy-carbonate sediments of the Lower Badenian Member and have a layer of homogeneous muddy limestones at the top. The gypsum and this limestone compose the Tyrassky Formation which is overlaid by argilo-carbonate sediments of the Upper Badenian Member (5-10 m) and by Lower Sarmatian clays (30-50 m, up to 100 m).

In the hydrogeologic region the territory belongs to the Volyn'-Podolian artesian basin, and to the Podolian and Bukovinian second-order drainage basins (Shestopalov, 1981, 1988). The presence of the Sarmatian clay caused confined hydrogeologic conditions in the whole region during the Pliocene. During the Pleistocene uplift and valley entrenchment of the Podolian subregion led to the uncovering of the upper section of the artesian system in most of the territory.

Modern hydrogeologic conditions of gypsum karst development are determined by the depth of erosional entrenchment and by the depth of the gypsum strata. Three typical settings have been distinguished there (Klimchouk & Andrejchouk, 1986; 1988). In the Podol'sky subregion, where most of known caves are situated, the aquifer system of the Miocene sequence is drained in full, and downward recharge occurs through it to the underlying aquifers (Figures 2 & 3). In the near-Dneister section of the Dneister-Prut intervalley area water-table conditions prevail into the gypsum strata. Aquifers in the Miocene sequence remains confined in the area neighbouring the foredeep, near the Prut river, except some of the uplifted blocks.

PREVIOUS SPELEOGENETIC CONCEPTIONS

Some Podolian caves have been known for a long time (Verteba Cave, Kristal'naya Cave), while other caves were discovered during 60s-70s (Mlynky Cave, Optimisticheskaya Cave, Ozernaya Cave, Atlantida Cave, Zolushka Cave, etc.). It was a period of an active systematic exploration of the main caves of the region. The basis of modern cave maps and basic data about cave morphology, deposits, microclimate etc. have appeared as the result.

These data were summarized by Dubljansky & Smol'nikov (1969) and Dubljansky & Lomaev (1980) who proposed a theory for regional speleogenesis that has been popular until recently.

According to this theory, caves were formed during Early and Middle Pleistocene due to sinking of perennial and intermittent surface streams into the gypsum strata (Figure 4-A). Development of caves occurred under shallow phreatic and water table conditions. It was thought an important role may have been played by individual streams migrating through gypsum strata. Underground lateral flow between subparallel river valleys was

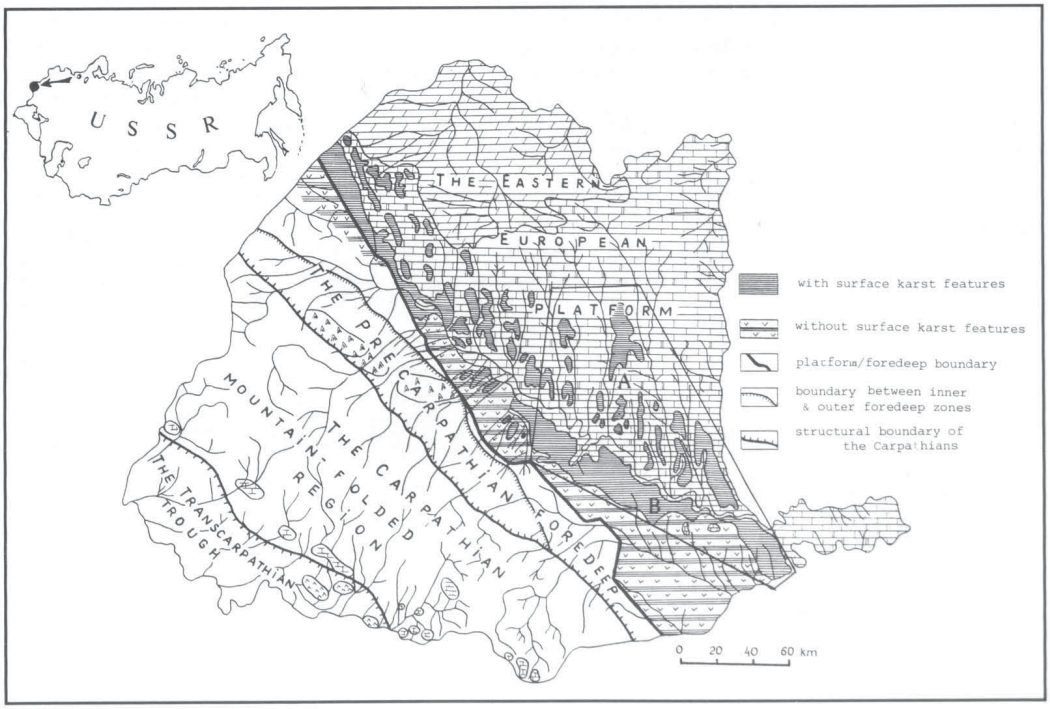


Figure 1. Gypsum karst and cave areas in the Western Ukraine.

Typical landscape of the western Ukraine near Ozernaja Cave (photo: Andy Hall).

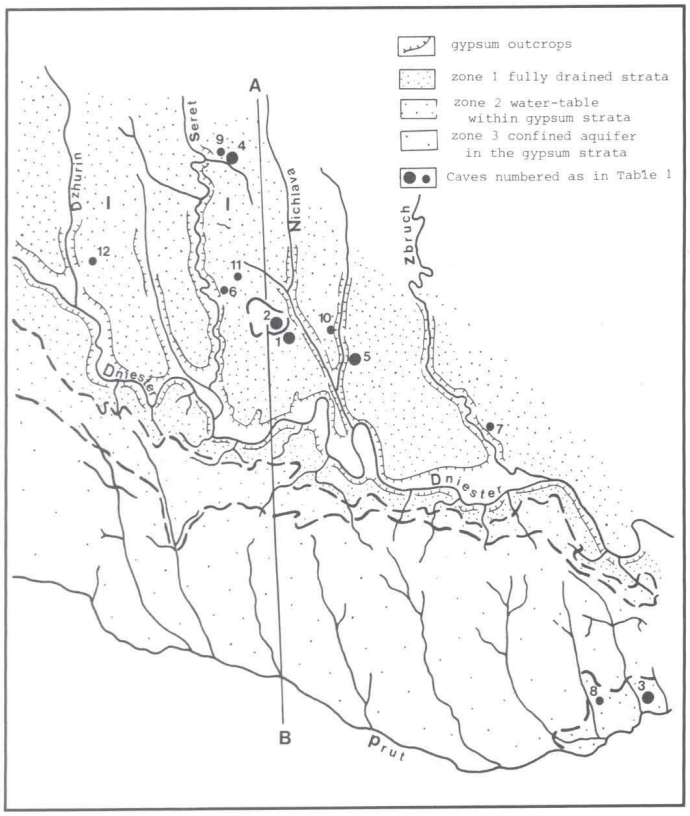


Figure 2. Tecto-erosional zones in Podolia and Bukovina, and the location of main caves.

assumed to occur through the gypsum strata. A multi-storey structure of cave patterns was assumed to result from cycles of uplift and stability, river valley entrenchment, and corresponding lowering of the karst water table (Dubljansky & Smol'nikov, 1969; Dubljansky & Lomaev, 1980).

These ideas are quite similar to the classic theories of speleogenesis and were widely accepted. However, many of properties of the maze caves of the region contradict these ideas, as will be considered below.

The only alternative has been suggested by Jakucs & Mezosi (1976). According to this interpretation cave development occurred under vadose conditions, from swallow holes located on the plateau in multiple ranks toward the nearest river valley (Figure 4-B). This model assumes that cave systems border river valleys. In fact, the actual occurrence and features of the caves do not correspond at all to the model shown in the figure. Mazes do not border valleys, but they are located in different positions throughout the intervalley areas, including the central parts of plateau. Mazes develop in any direction away from sinkholes, but not only toward the nearest river valley. In any case the suggested model cannot explain the maze patterns.

Detailed investigations of morphology and deposits of the principal caves in the region, together with careful analysis of the regional geology and hydrogeology have made it possible to suggest a new speleogenetic model.

OLD AND NEW DATA: NEW INTERPRETATION

Descriptions and maps of the main caves of the Western Ukraine one can find in many works (Dubljansky & Lomaev, 1980; Dubljansky & Iljukhin, 1982; Klimchouk, 1986; Courbon & Chabert, 1986; etc.). Only a few maps and the most common features of the caves are discussed below.

All the large caves of Podolia and Bukovina are mazes developed along vertical and steeply inclined fissures. High density and quasi-uniform distribution of channels in a plan view is common (Figures 5-7). Aggregating passages form lateral two to four storey systems which occupy areas of up to 1 km^2 each. Areas of concentrated passage development (cave fields) are situated not only near the valleys but also in the central part of the massifs.

Morphological analysis shows that the present entrances on valley slopes or on the plateau are not hydrologically related to the origin of the mazes. There are no regular areal trends in shape, size or frequency of passages. These features obviously contradict Dubljansky's concept of discrete point recharge and lateral flow between valleys through the gypsum.

There is much morphologic evidence that all the large caves in

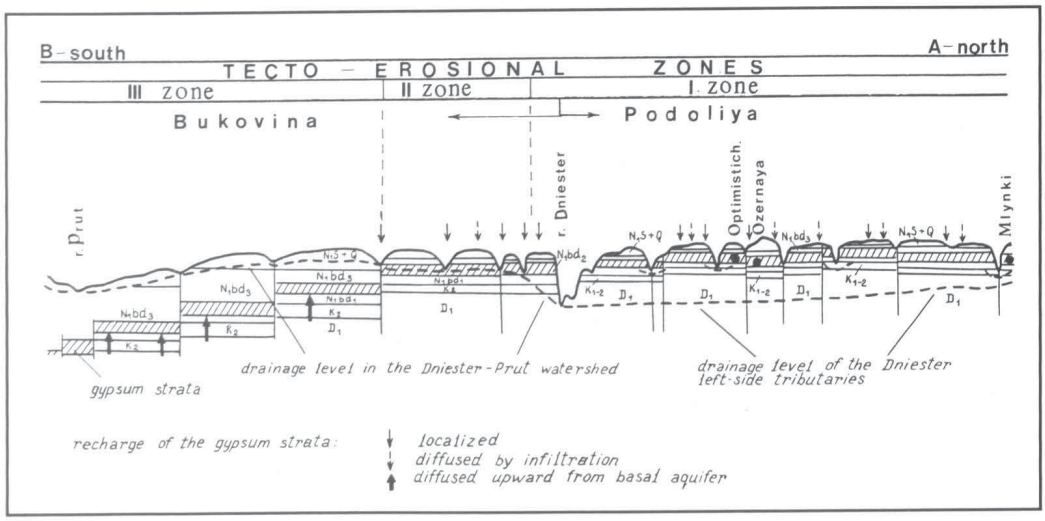


Figure 3. Modern hydrogeological settings of gypsum karst development in the Western Ukraine (profile A-B on Figure 2).

Figure 4. Previous ideas concerning the origin of the Podolian caves.

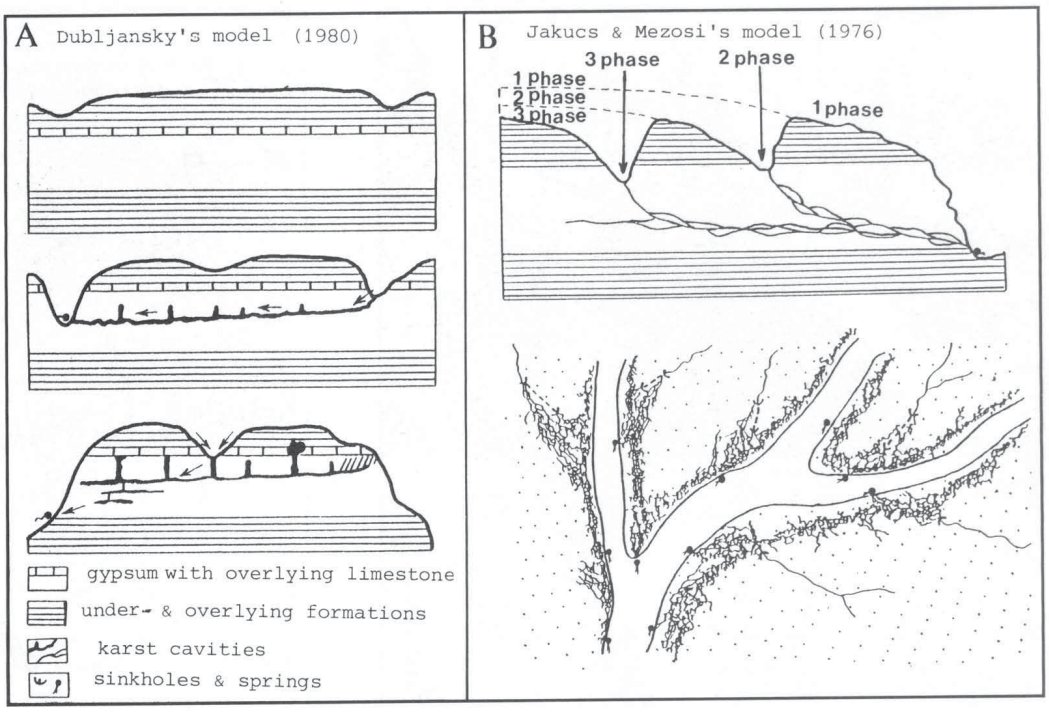
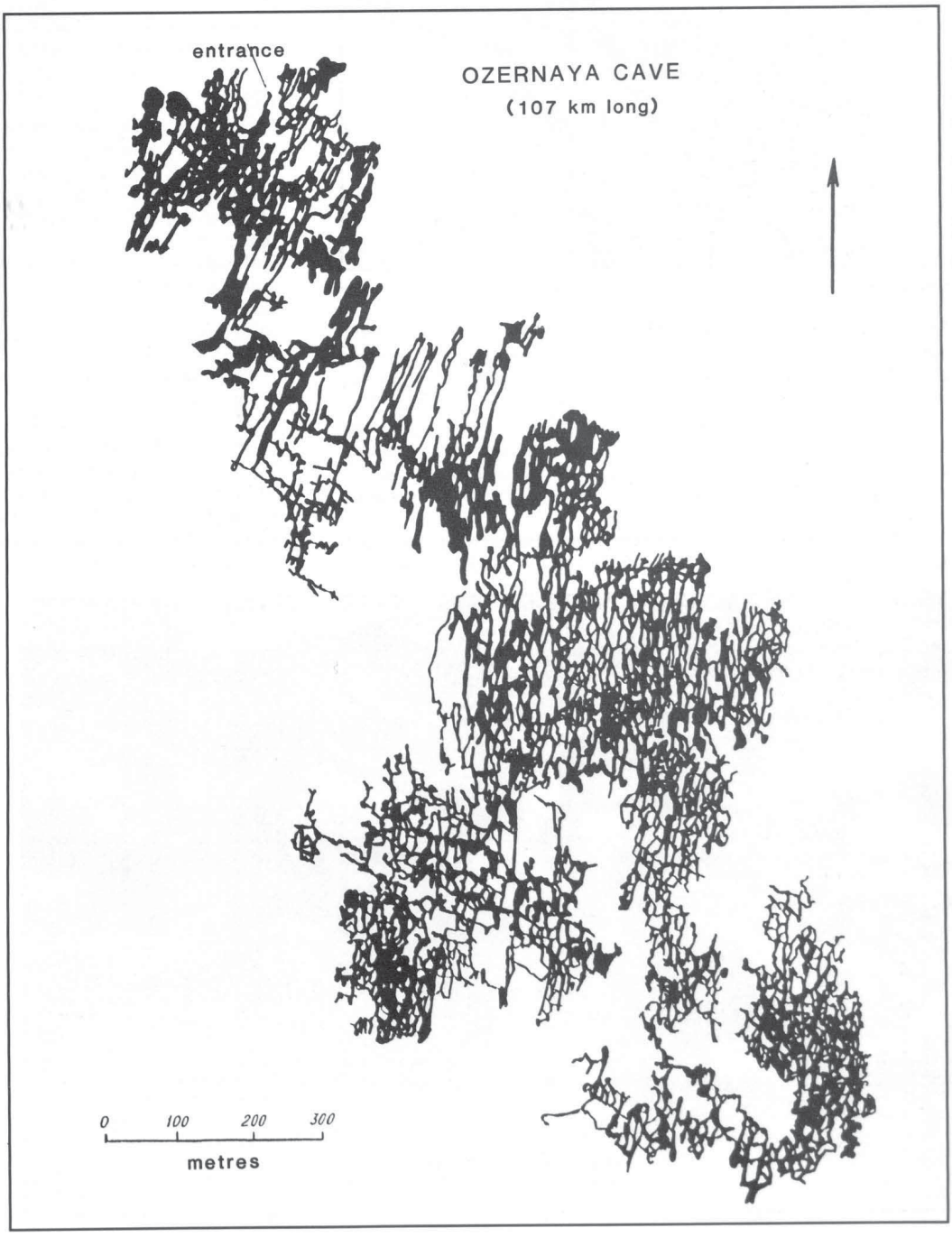
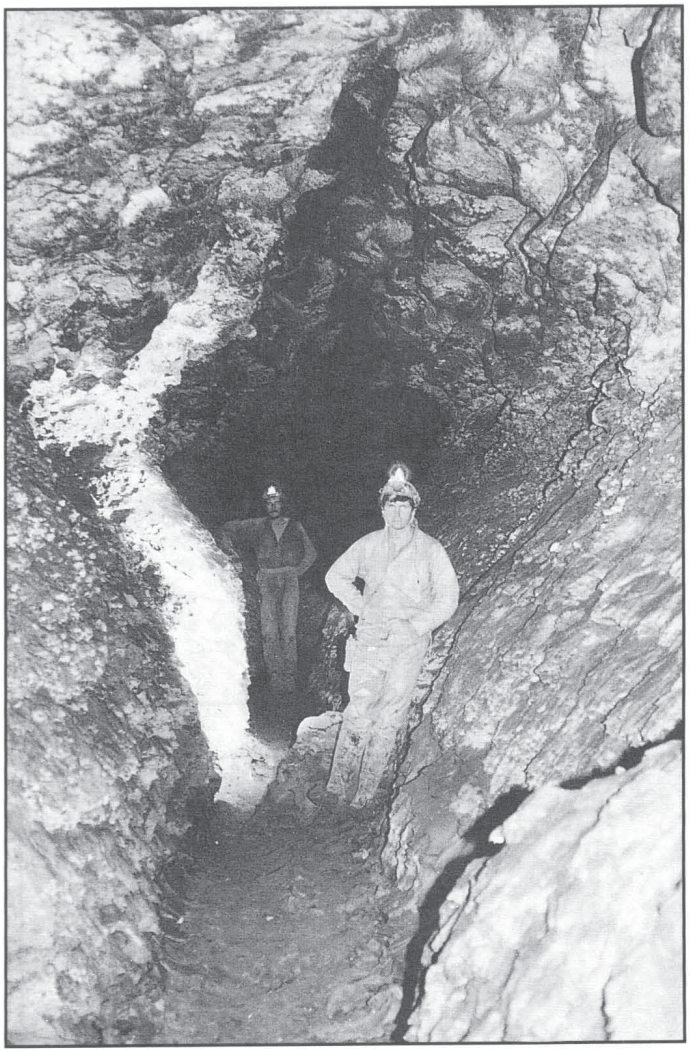


Figure 5. Map of Ozernaya Cave (107 km long).





Typical passage in Ozernaja Cave (photo: Gleb Semionov).

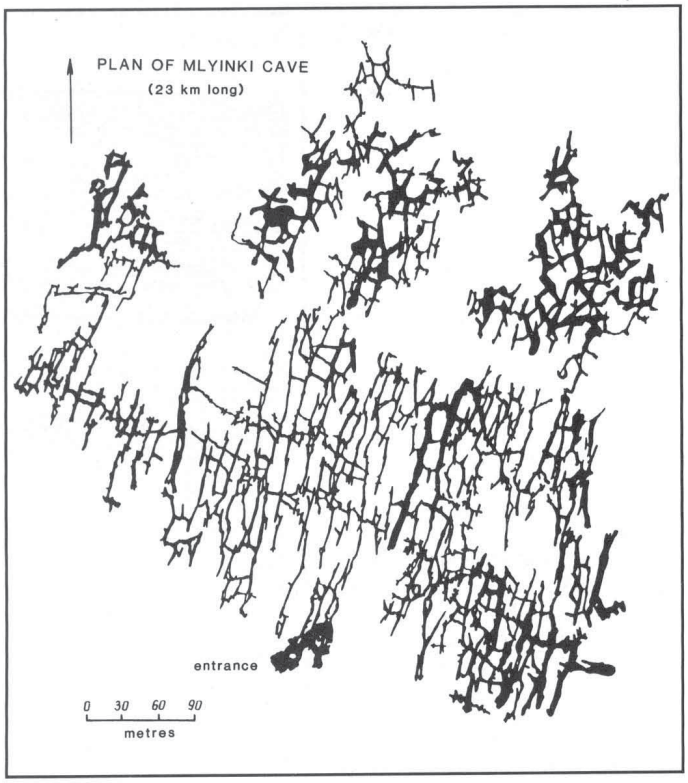


Figure 6. Map of Mlynki Cave (23 km Long).

the region developed under confined conditions. Morphogenetic analysis of the multi-storey Atlantida Cave (Klimchouk & Rogozhnikov, 1982) has suggested a model of upward development of the cave system from master passages at the base of the gypsum strata (Figure 8). Zolushka Cave (Figure 7), in the Bukovinsky subregion, revealed clear evidence for upward recharge from the base of the gypsum strata through large pits of an "ascending" morphology to the network of master passages in the upper level.

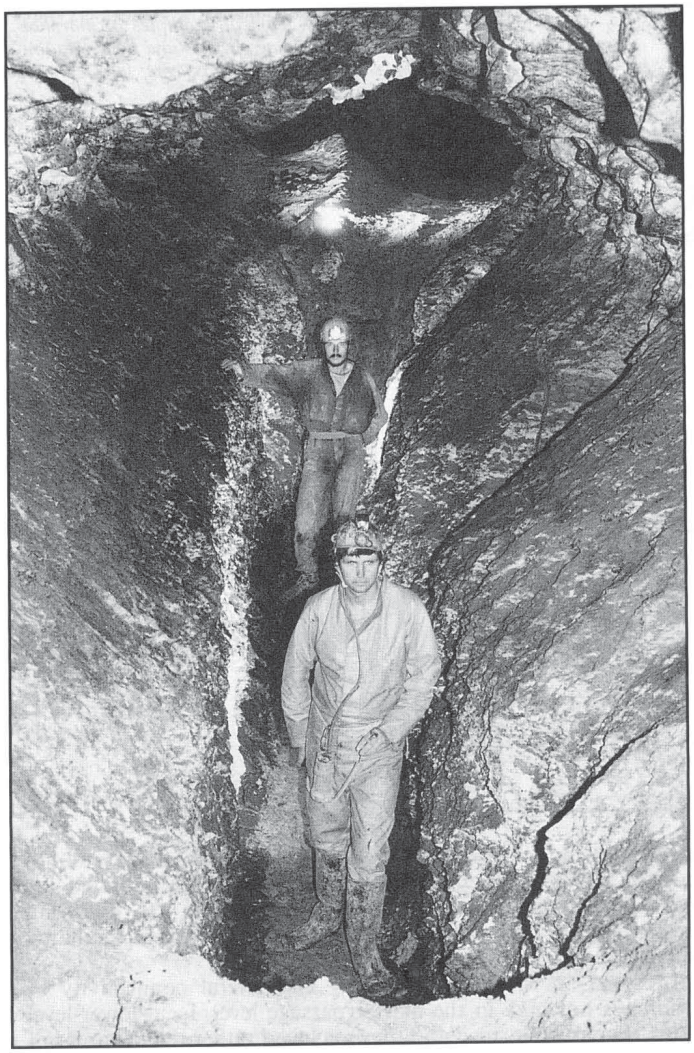
Eventually, the idea of maze cave development in a confined aquifer was suggested for the whole region, with an upward recharge into the gypsum strata from the underlying aquifer of Lower Badenian sandy-carbonates (Klimchouk, 1986). The latter represents an aquifer of regional importance.

During the last decade the author has performed morphogenetic mapping of some caves (Atlantida Cave, Dzhurinskaya Cave), and of some representative areas of large maze patterns (Optimisticheskaya Cave, Ozernaya Cave, Zolushka Cave, Mlynky Cave). In a result, a large number of solutional features were recognized that indicates an upward water flow into the cave systems from the underlying aquifer. Study of distribution and position of such features in the cave systems confirmed this idea.

It was shown by Klimchouk & Rogozhnikov (1982), Klimchouk & Andrejchouk (1988), that the multi-storey structure of cave systems in the region is controlled by fissures confined to certain lithological horizons (hypsometric intervals) in the gypsum strata. The fissure patterns at each level have their own characteristic frequency, orientation and degree of lateral interconnectivity. Vertical connectivity of the fissures between levels varies considerably from area to area.

Atlantida Cave (Figure 8) offers a simple example. Water rises

Gypsum banding in Ozernaja Cave (photo: Gleb Semionov)



Gypsum banding in Ozeraja Cave (photo: Gleb Semionov).

into the bottom of the gypsum strata, and flows laterally along the base of the gypsum and/or along fissures in the lowest gypsum beds forming the initial channels. These include so-called "cellars" in Atlantida Cave which are low, winding passages with complex shapes and which connect with large tunnel-shaped galleries called "magistrals" (master passages). Master passages are formed by lateral flow concentrated along certain routes by hydraulic competition among initial flow paths. As the diameter

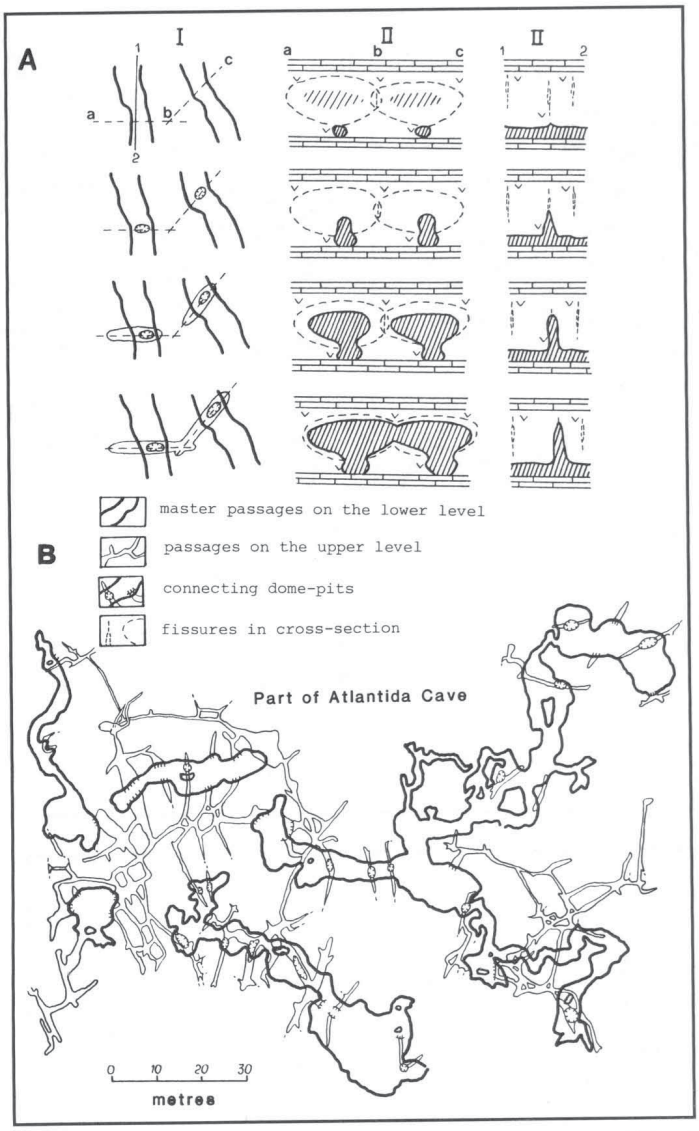
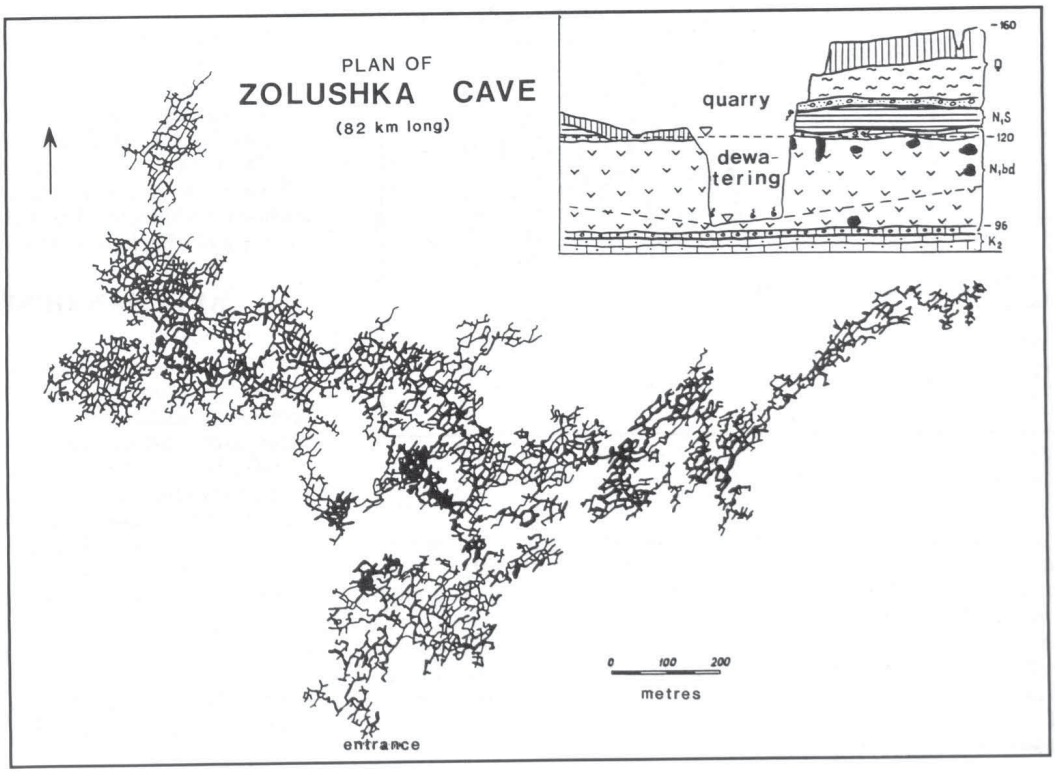


Figure 8. Model of upward development of multi-storey cave system (A) and map (B) of Atlantida Cave (from Klimchouk and Rogozhnikov, 1982).

of a master passage grows, it intersects fissures at the next higher level. Ascending blind cupolas develop in this way and eventually a network of connected passages can be formed as shown in Figure 8.

Figure 7. Map of Zolushka Cave.



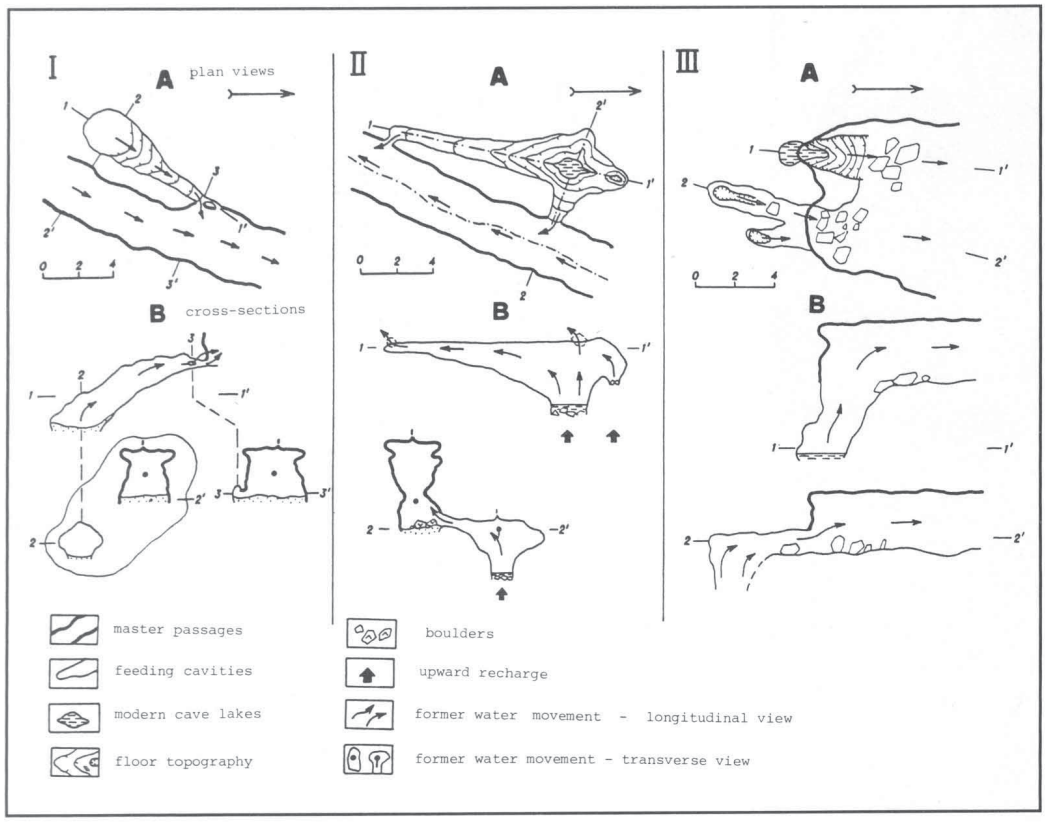


Figure 9. Typical examples of morphology of feeding cavities and their relationship to master passages in Ozernaya Cave.

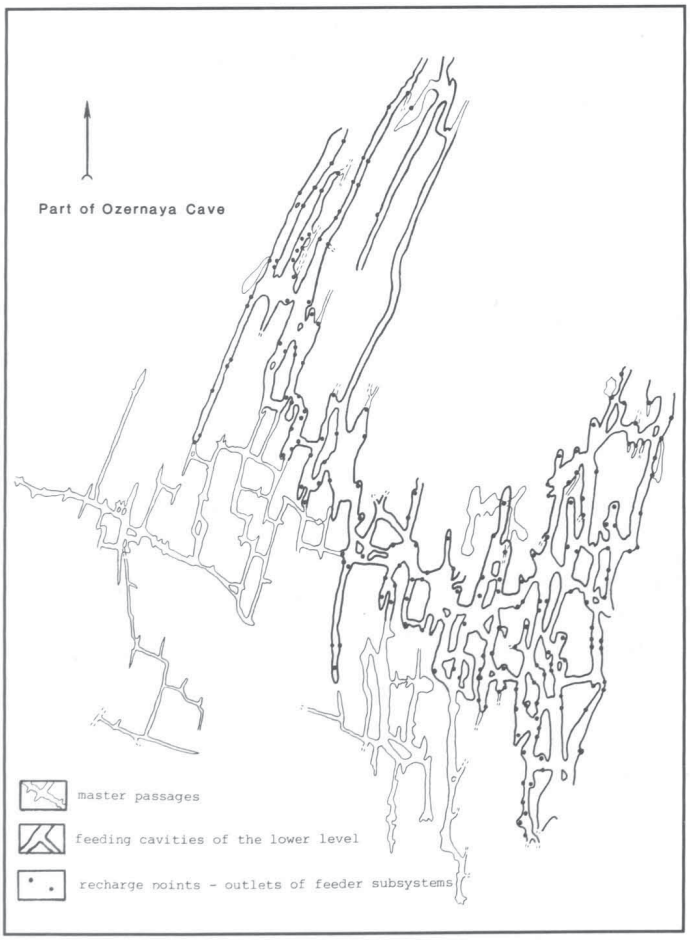


Figure 10. Part of the map of Ozernaya Cave, showing the distribution of outlets of feeding cavities through the network of master passages.

In most of the caves in the region, however, it is common for lateral water movement to occur in the higher fissure level, but not in the lowest level. Cavities of the lowest level are not laterally connected but serve as separate points, or local networks of upward recharge to the master level. Typical examples are shown in Figure 9. These recharge cavities may be inclined ascending channels, or pit-shaped forms connected to the side or to the end of a master passage. Careful mapping in the Ozernaya Cave has shown that there are thousands of such outlets distributed rather uniformly along the master passages network in the main (middle) level of the cave. They provide dispersed recharge required for maze development, a topic that is discussed in the following section. Figure 10 shows the location of points of upward recharge in part of Ozernaya Cave.

In some areas, where frequency and lateral connectivity of fissures is not high in the master passage level, local lower-level networks can be formed and they may feed rather remote areas of master passages and serve as a connection between them. A typical example of such a network, connecting two areas of master passages, is the Transitional Series in Ozernaya Cave. Part of this series can be seen in the south west corner of the map in Figure 10. Figure 11 shows the various models for the development of Ozernaya Cave under various recharge conditions.

In Optimisticheskaya Cave, passages are formed at three levels, and there are broad areas of continuous passage development in the lower level (the areas named Averbakh, Al'onushka, etc.). These areas have fed the neighbouring areas of the high level passages.

Dzhurinskaya Cave (Figure 12) displays one more variant of the general model. From this example the relationship between cavities at different levels can be clearly seen. In this cave, large master passages have two distinct levels of feeder systems.

Thus, new field data strongly support the concept of maze development in a confined aquifer system, with upward recharge entering the gypsum strata from the basal aquifer of sandy carbonate sediments. Further discussion of contrasting ideas and the theoretic background for artesian speleogenesis is given below.

ARTESIAN GENESIS OF MAZE CAVES

As pointed out above, quasi-uniform distribution of cave passages is common for the region, that is contradictory to the scheme of speleogenesis in which discrete point recharge takes place from above and groundwater flows laterally through gypsum beds to nearby rivers. It has been shown by many authors that hydraulic and chemical factors of initial flow-path development cause flows to localise as branchwork passages where there is a limited number of recharge points. Even assuming that diffuse lateral flow occurs through the gypsum strata, moving water will approach saturation over short distances, and, contrary to the view of Dubljansky, significant solutional enlargement of fissures would be impossible over distances of several kilometres. The morphology of maze patterns does not display regular areal trends which would be inevitable to appear if discrete localized point recharge and lateral flow through the gypsum strata is assumed.

Figure 11. Model for the development of Ozernaya Cave.

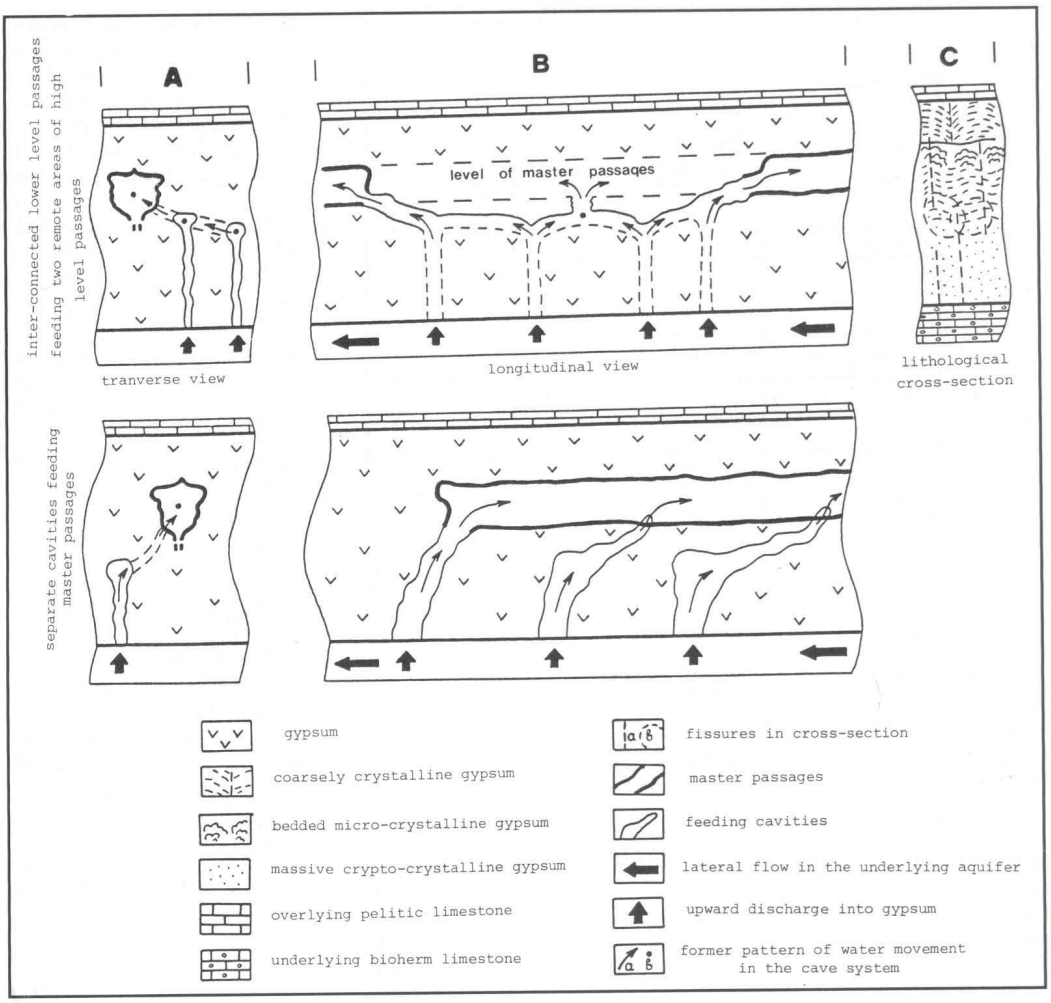
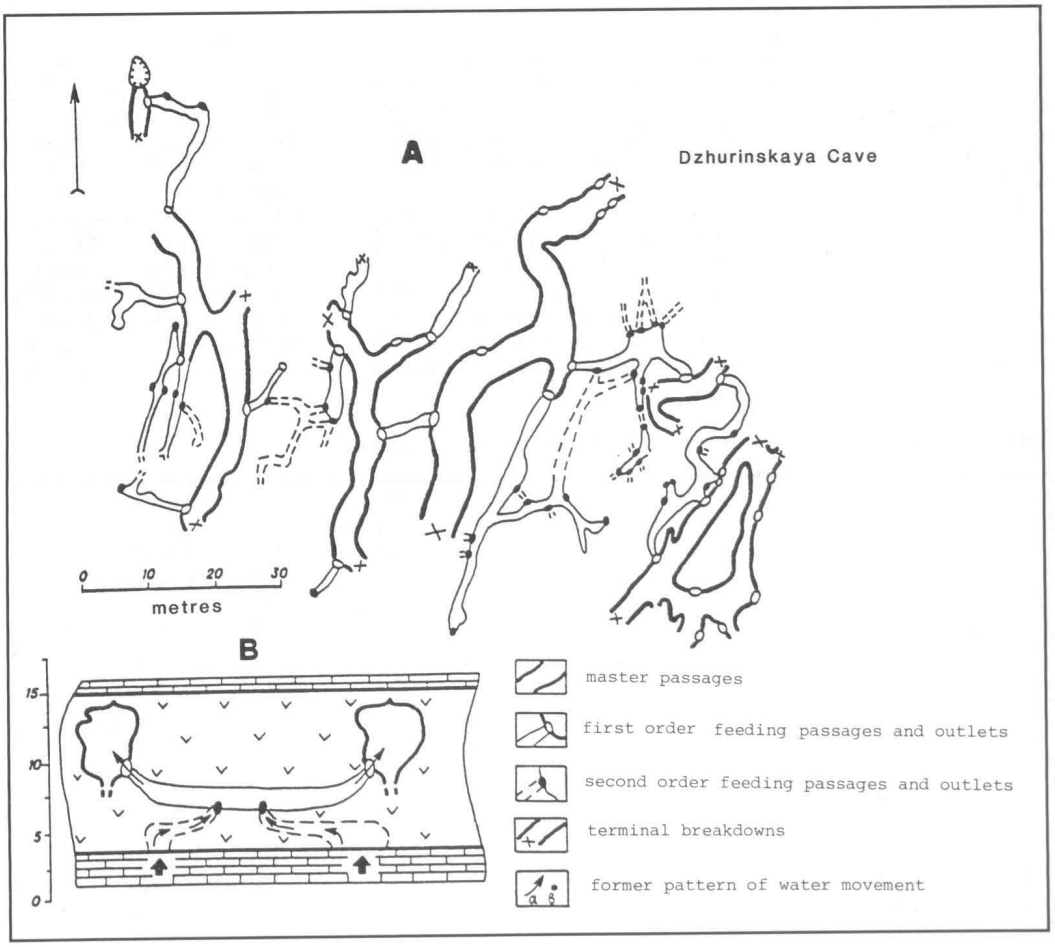


Figure 12. Morphogenetic map (A) and model of development (B) of Dzhurinskaya Cave, with two-ordered feeding subsystem for master passages.



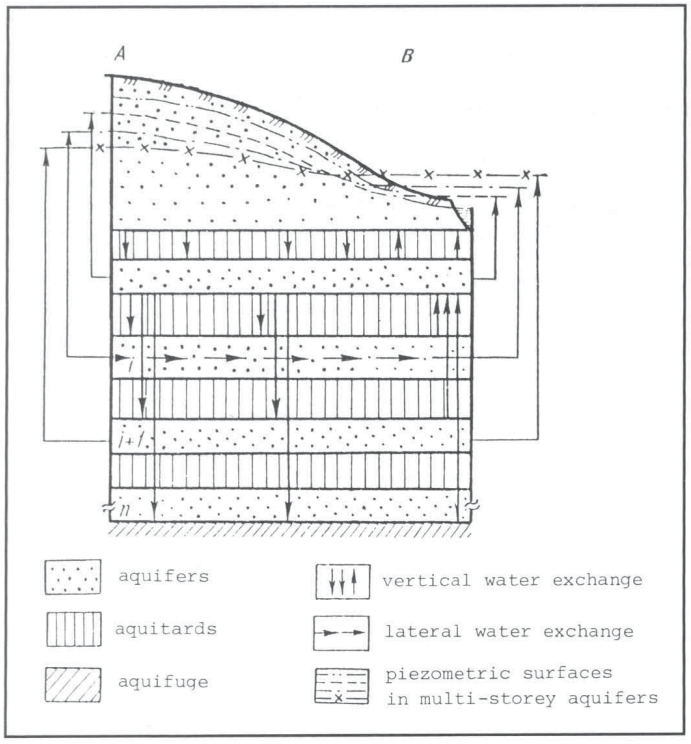


Figure 13. Flow pattern in the multi-storey artesian aquifer system (from Shestopalov, 1988).

Palmer (1975) carefully considered the problem of maze caves origin and distinguished two major situations favourable for their development: (1) where disperse, solutionally aggressive recharge takes place uniformly into all available fissures in a soluble rock unit, entering from an adjacent insoluble formation or from the overlying land surface; and (2) where floodwater recharge causes temporal variations in discharge and head in a growing cave system to be so great that no fixed passage configuration is allowed to stabilize with respect to the flow. The latter situation is found mainly in caves fed by sinking streams or in local floodwater mazes in stream caves (Palmer, 1975). A majority of maze caves considered by Palmer was developed in the first situation, directly beneath permeable formations, usually sandstones, through which a dispersed incident recharge occurred. In Ford & Williams (1989) another model was proposed, by which ground water is compelled to diffuse from a large conduit into a maze of smaller solutional passages in order to disperse into diffuse flow upwards through the sandstone granular aquifer. Therefore, a dispersed pattern of either recharge or discharge is assumed to be necessary for most maze patterns to develop.

Palmer (1975) emphasised the importance of artesian flow in the origin of maze caves, with particular reference to Jewel Cave and Wind Cave in the Black Hills of South Dakota. Traditionally, classic artesian flow is implied in the origin of such caves, with limited recharge areas along the exposed edge of an aquifer and artesian flow deep within the aquifer. The hydrodynamic graph of Palmer (1975) shows that the Black Hills cave networks would require impossibly large amounts of flow if they contained lateral artesian flow. The same argument holds true for the Podolian networks. For example, assuming that the average spacing between parallel fissures is 10 m, that passages are 1 m wide and 2 m high, that the cave is contained within an area 500 m wide on one level, and that hydraulic gradient is 0.001, then the discharge from this system should be about 100 $m^3\ s^{-1}$. In comparison, the groundwater flow in the entire Volyn'-Podolian artesian basin is estimated to be 235 $m^3 s^{-1}$ (Shestopalov, 1981).

In our artesian model of maze cave development in the Western Ukraine the most prominent feature is dispersed upward recharge. This recharge is available for all present fissures in the bottom of the gypsum strata and takes place uniformly. This causes dispersed aggressive water to enter the gypsum, so that all available fissures can be uniformly enlarged by solution. Lateral water movement through the strata takes place locally, but not regionally. It is very significant to understand the correlation between recharge and discharge of the gypsum strata in this speleogenetic model. This model is based on a non-traditional theory of water exchange in a platform-type artesian aquifer system.

According to the classic view of an artesian basin, the recharge area where the permeable rocks are exposed, the artesian through-flow area, and the discharge area are distinct from one another.

During the last decades new hydrologic information shows that there is considerable interconnection between multi-level aquifers in artesian systems and that vertical percolation is important through intervening beds. This idea is usually referred to in Russian publications as Mjatiev's hydrodynamic model. It was developed by Shestopalov (1981, 1988) to apply to the platform artesian basins of the Ukraine, including of Volyn'-Podolian. According to Mjatiev's model large areas of an aquifer in a multi-level system can act as recharge or discharge areas. The following applies to the local recharge areas:

$$\frac{-d^2H}{dx^2} + \frac{d^2H}{dy^2} > O$$

where H is the head in a confined aquifer and x and y specify the horizontal coordinates within the aquifer. The above relation corresponds to a prominent piezometric surface of the aquifer. For discharge areas the combined head terms are greater than zero, and they have a characteristic concave piezometric surface. The expressions are strictly valid only for laminar flow in uniformly permeable aquifers, but the concept can be modifed to fit other situations.

In the aquifer system, recharge takes place in the areas of highest head, and discharge takes place in the areas of lowest head. In the vertical section, there is a gradual transition between recharge and discharge in each aquifer in the multi-storey system. That is why Shestopalov (1988) calls the areas of highest and lowest head respectively the areas of downward (A) and upward (B) percolation (see Figure 13).

Shestopalov (1981, 1988) made a comprehensive study of hydrodynamics of the platform artesian basins of the Ukraine and has shown that vertical migration of underground water through aquitards (often incorrectly regarded as aquifuges) plays a great role in water exchange in artesian aquifer systems. The main characteristics of water exchange are:

Table 1. Dimensions of large gypsum caves in the Western Ukraine

	Cave Name	Development m	Area of passages sq.m. × 1000	Volume of passages cub.m. × 1000	Density of passages km (passages) per sq.km (cave area)
1.	Optimisticheskaya	178,000	220.8	461.7	301
2.	Ozernaya	107,000	310.0	640.0	175
3.	Zolushka	82,000	280.0	665.0	220
4.	Mlynki	23,000	43.3	75.4	120
5.	Kristal'naya	22,000	38.0	110.0	160
6.	Verteba	7,820	23.0	47.0	206
7.	Atlantida	2,525	4.4	11.4	170
8.	Bukovinka	2,408	4.3	6.0	320
9.	Ugryn'	2,120	4.0	8.0	190
10.	Jubileynaya	1,500	2.0	3.5	280
11.	Komsomol'skaya	1,244	1.7	2.6	120
12.	Dzhurinskaya	1,135	1.6	2.6	130

1) The direction of vertical flow between aquifers is determined, to a significant extent, by local topography. There is a prevalence of downward percolation in the topographic highs, and upward percolation dominates in the lowland areas.

2) Topography therfore influences the areal distribution of piezometric highs and lows, as well as the direction of lateral flow. The dip of the rocks is not a decisive factor in determining the direction of confined water flow.

This hydrodynamic model provides the theoretic background for the proposed model of speleogenesis and for developmental history of the maze caves in the Western Ukraine.

During the Late Miocene and Pliocene the study area was a wide lowland. Hydrogeologically it was an artesian basin, confined by the thickness of Sarmatian clay sediments. Water circulation was quite slow in the multi-level artesian system. The gypsum stata were sparsely fractured and acted as a regional aquiclude.

During the Late Pliocene — Early Pleistocene the region experienced differential block movements related to tectonic activity in the adjacent Carpathian folded region and pre-Carpathian foredeep. As large faults and numerous fault blocks formed, the initial hydrologic pattern was being established and geomorphic diversity arose. A regional pattern of piezometric highs and lows was formed in the Miocene aquifer system. Neotectonic movements further fractured the gypsum beds, so that upward recharge into gypsum was established in areas of relatively low head. Groundwater discharged into overlying aquifer and then to the surface through an overlying clay formation where it became thin or tectonically broken. On a local scale, flow in the gypsum beds had a significant lateral component in those levels where the fissures were well connected. Master passages were formed at those levels. Meanwhile, the maze patterns developed according to the models described in the previous section. Within each particular block the maze character was controlled by local distribution of fissures within the gypsum.

The valleys of Dneister and of its left tributaries were entrenched during the Early Pleistocene, exposing the artesian aquifer system and increasing the amount of groundwater flow through it. As the valleys entrenched into the gypsum, water-table conditions were established for a period of time. During this period passage cross-sections were significantly widened, due to the higher solutional activity of the subsurface layer of water in the caves (Klimchouk *et al.,* 1988).

By the Holocene, river valleys in the Podol'sky area had been entrenched to such a degree that both gypsum beds and the underlying aquifer were drained in full, except of some internal areas of wide plateaus remote from valleys. In the Bukovinsky subregion adjacent to the foredeep the gypsum strata lie at a greater depth and valleys are not so deeply entrenched, so that confined conditions persist today. The aquifer system is exposed only in some uplifted blocks, and water tables are present there. Zolushka Cave is an example (Klimchouk & Andrejchouk, 1986). However, this cave system has been dewatered within the last decades by gypsum quarry operations (see Figure 7).

As the aquifer system was being unconfined and drained, the karst landscape formed with large sinkholes. The clay thickness remains in most areas, preventing diffuse recharge downward into the gypsum. Localised input through sinkholes is the principal mode of recharge in the modern conditions.

It is interesting to note how the gypsum strata has changed its hydrogeologic function as the karst evolved. Initially the gypsum acted as an aquifuge in the aquifer system, then as an aquitard and eventually it was transformed into karst aquifer.

SOME CONCLUSIONS

1) Large maze gypsum caves in the Western Ukraine were formed under confined conditions of multi-storey artesian system of platform type, due to dispersed upward recharge from underlying regional aquifer.

2) For the suggested speleogenetic model a non-classic view of an artesian flow can be used as a theoretic background, which implies close interconnections between multi-level aquifers in the artesian system of platform type.

3) Dispersed area recharge from adjacent formations is necessary for development of maze cave pattern under artesian conditions.

4) In the case studied, development of multi-storey cave systems is not related to cycles of uplift/stability of the area and corresponding water table activity, but is controlled by the initial distribution of fissures within certain adjacent lithological horizons of the gypsum stata.

5) Ford (1988) has distinguished between the type of 2-D maze caves and the basal injection type of caves in his general classification of karst solution caves. The artesian model of speleogenesis described in this report appears to combine these two types into artesian type of caves, or type of "lifting mazes" as it has been termed by Ford in other publication (1990).

6) The theory of artesian speleogenesis is not specific for gypsum karst and may be applied to other caves and regions (for instance, to Jewel and Wind caves in South Dakota; see Ford, 1990), and it needs further elaboration.

ACKNOWEDGEMENT

I am indebted to my colleagues from the Karst-Speleological department of the Institute of Geological Sciences for their various assistance for so many years. I wish to thank Dr. Arthur and Margaret Palmer of the State University of New York at Oneonta, for their kind and valuable help in preparation of the initial version of this paper for publication in English.

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Alexander Klimchouk
Kiev Karst & Speleological Centre
P. O. Box 224/8,
Kiev-30, 252030
USSR

CAVE SCIENCE Vol. 19, No. 1, April 1992
Transactions of the British Cave Research Association

Karst Geomorphology and Environmental Implications in Guizhou, China

ZHANG Yingjun, YANG Mingde and HE Caihua

Abstract: The river profiles in the Guizhou plateau are of three types — normal, abnormal and stepped. According to the landform assemblages from the topographic divides to the river valleys, two major types of karst landform — the karst plateau and the karst gorge — can be classified, and the comparison of the environmental qualities of these types is made. The vertical karst development caused by the lowering of groundwater table shows itself in the multi-level cave systems, which exist in both the plateau and the gorge areas. The problems of pollution, surface collapse and engineering works are related to the karst geomorphological environments. The karst plateau area is a favourable environment for dispersing pollutants rapidly to a great extent. In gorge areas, the pollutants can go more directly down towards the rivers in the deep valleys. Surface collapses are liable to occur in the urban areas on the karst plateau, because the shallow water table is depressed by over-extraction of groundwater for industrial use. The Shuicheng example is cited. The benefits and defects of the dams sited in the gorges are discussed, and leakage related to the occurrence of low groundwater troughs parallel with the river is described.

China is one of the countries in the world with the greatest development and variety in the types of karst. The carbonate rocks outcrop extensively in 21 provinces and districts and occupy an area of 1.25 million km^2, amounting to 13% of the whole of the country. Guizhou is a province with the most concentrated distribution of carbonate rocks, and accordingly has a large karst area with a complicated development of karst geomorphology (Figure 1). With an outcrop area of carbonate rocks of 73% of the whole province, influenced by structural pattern, tectonic movement, climate, soil and vegetation, Guizhou has many karst geomorphological types; these are related to various productive activities of the local people, which in turn give significant impacts to respective karst geomorphological environments.

River profiles in the Guizhou karst

The river profiles on Guizhou plateau are mainly of three types.

In the normal type, the gradient changes from great to small down the profile of the river from upper to lower reaches. Narrow river valleys or gorges, are followed downstream by broad valley sections. This profile type can be found mainly in eastern Guizhou along Jinjiang, Wushui, etc. (jiang, shui and he all mean river in Chinese).

In the abnormal type, the gradient of the upper reach of the river is much smaller than that of the lower reach, therefore the order of occurrence of the gorge and the broad valley section is reversed. This profile type can be found over the main part of the Guizhou plateau, along the Wujiang's first and second order tributaries, and is the most important type of profile in Guizhou province.

In the stepped type of profiles, sections of normal and abnormal profile, one following another, make up the entire profile of a river, with gentle gradient and steep gradient sections occurring alternatively. A very good example is the profile of Dabang River, a tributary of Beipanjiang. From near Huangguoshu Waterfall to the confluence with Beipanjiang, three major knickpoints can be recognised at Huangguoshu, Hezuilai

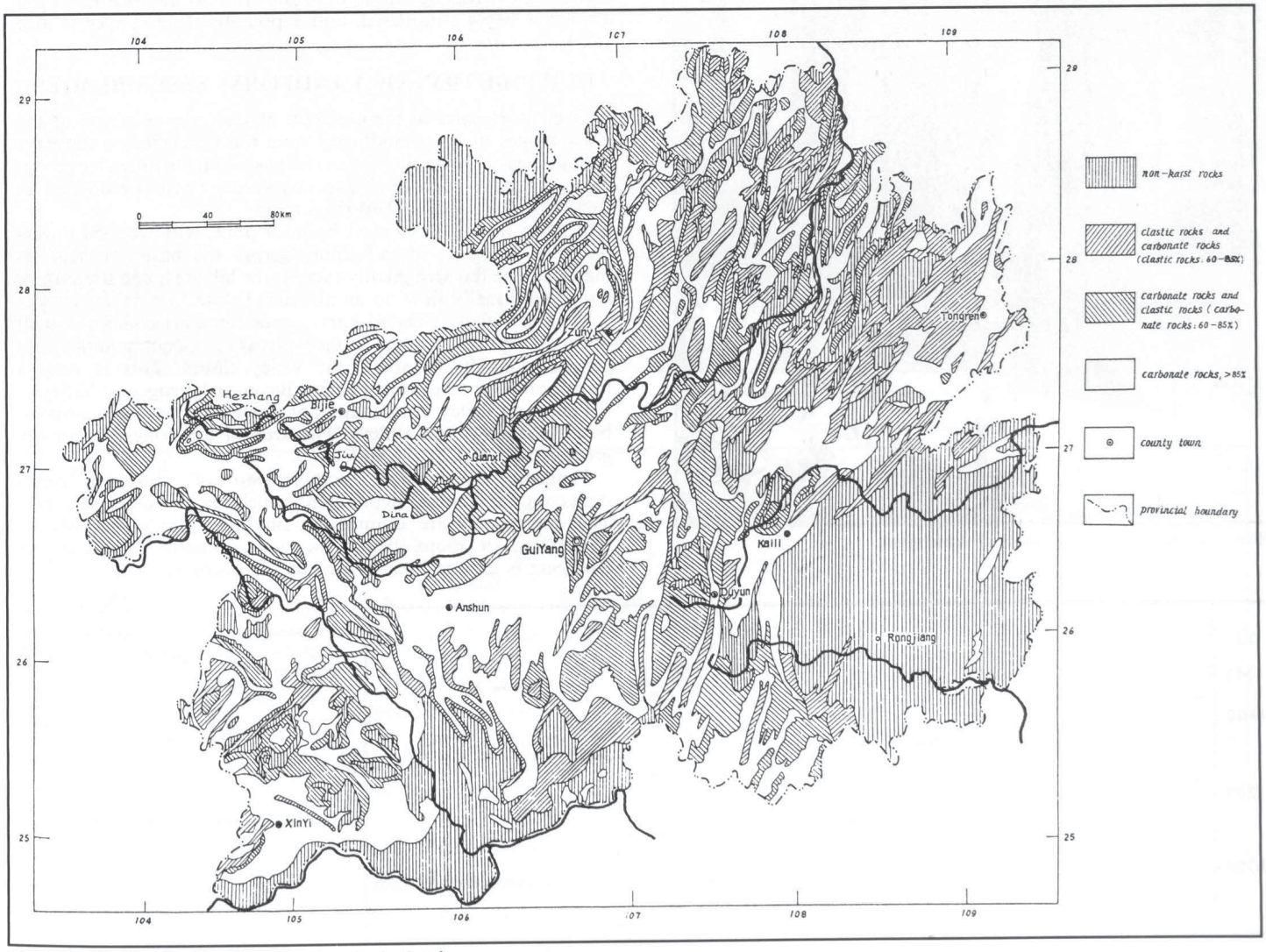


Figure 1. The distribution of carbonate rocks in Guizhou.

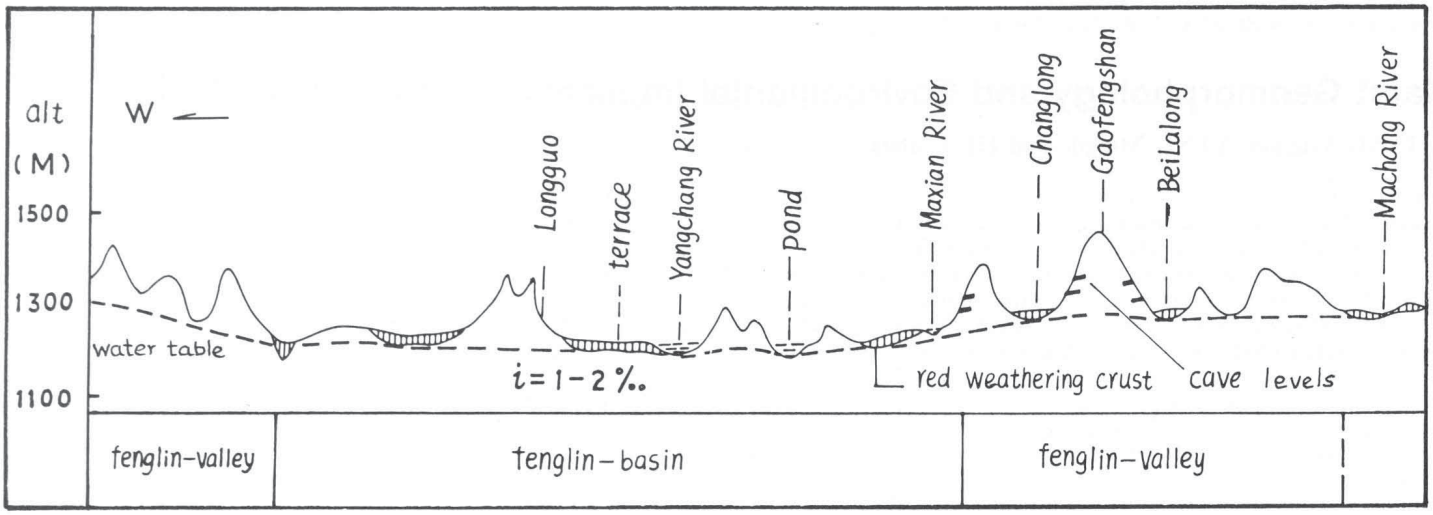


Figure 2. Karst geomorphology around some tributaries of the Maotiao River (a major tributary of the Wujiang), with i = gradient of the water table.

River cave between karst windows at Jiudongtian.

and Guanjiao with three steep gradient sections. This type of profile generally occurs in Southern and Southeastern Guizhou.

The river gradients generally determine various economic aspects of the karst environment. Along the river courses with steep gradients, there are commonly gorges, subterranean river sections or natural bridges which are hindrances for navigation and unfavourable for irrigation, but are advantageous to the selection of damsites for hydroelectric power stations and are good scenic locations for tourism. There is a very good example in Guizhou at the boundary of Dafang and Nayong counties along Guazhonghe (local name of Liuchonghe), the main tributary of Wujiang, where two subterranean flow sections exist (Figure 4). On top of the downstream section occur six karst windows through to the underground river; people can boat through this section and see the spectacular scenery. This section is known as Jiudongtian, and is being developed as a tourist spot (Figure 5). A hydroelectric station was built within the cave near its resurgence. Other good examples are the big and small natural bridges in Hezhang County, along the same river some 70 km upstream of Jiudongtian. A dam site close to the Small Natural Bridge is being considered, and a potential tourist spot is also being appraised.

DISTRIBUTION OF LANDFORM ASSEMBLAGES

Over most parts of the Guizhou plateau, the sequence of the assemblages of karst landforms from the watershed to the river valley is generally fenglin-basin/fenglin-valley/fengcong-valley/fengcong-depression/fengcong-gorge. These are defined as follows (Smart *et al.*, 1986) (Figure 6).

Fenglin Basin: Large karst basin or polje, with isolated towers or cones (fenglin) spread thinly across the basin or near its margins. The flat area greatly exceeds the hill area, and the surface streams normally flow on an alluviated floor.

Fenglin Valley: isolated karst cones (fenglin) combined with open valley containing surface streams. Cone summits are generally 80-150 m above the valley floors. This is only a transitional type between Fenglin Basin and Fengcong Valley.

Fengcong Valley: combination of clustered cones on a common base (fengcong) and valleys. The area of fengcong is normally greater than that of the valleys.

Fengcong Depression: combination of clustered cones (fengcong) and closed depressions which may be of great depth. The depressions are drained by sinkholes and commonly lie 100-200 m, or more, below the cone summits. The area of fengcong is greater than that of the depressions.

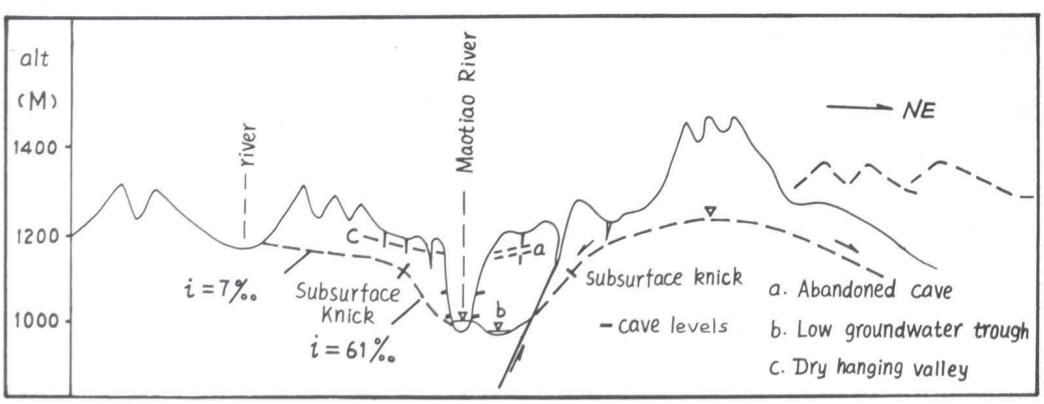
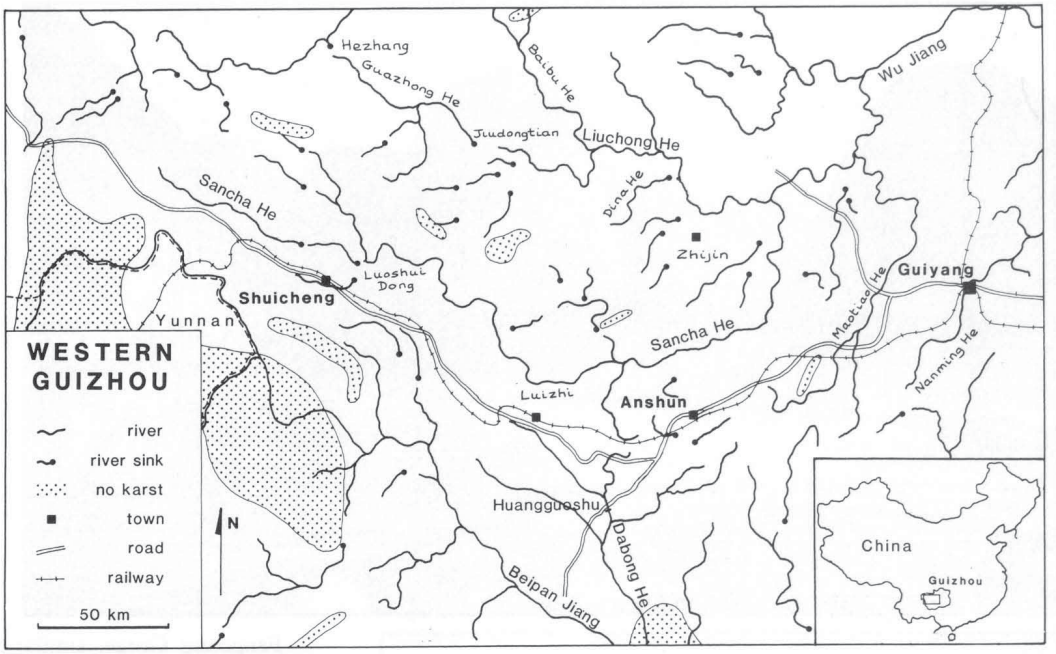
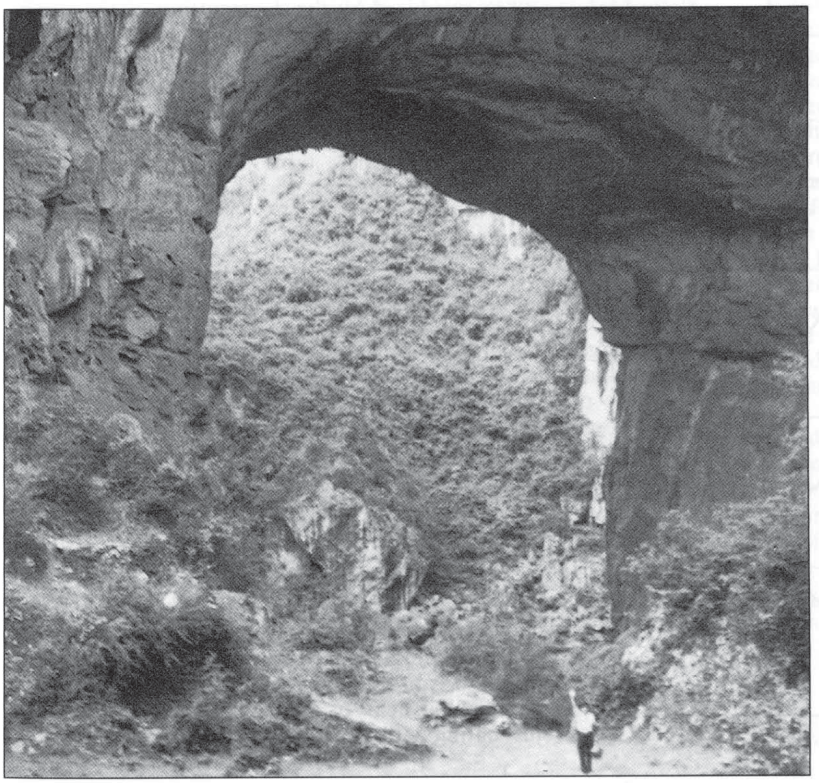


Figure 3. Karst geomorphology around the middle and lower reaches of the Maotiao River, related to water table gradients (i).

Figure 4. Location map of western Guizhou (after China Caves 85).

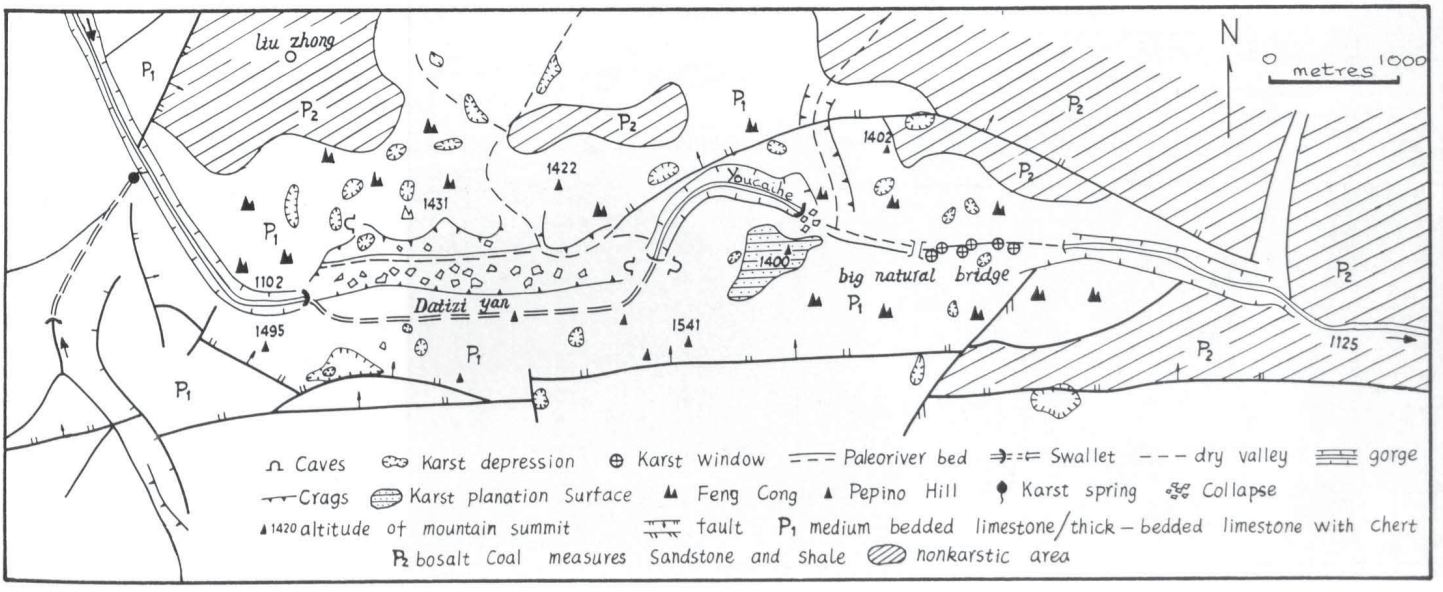


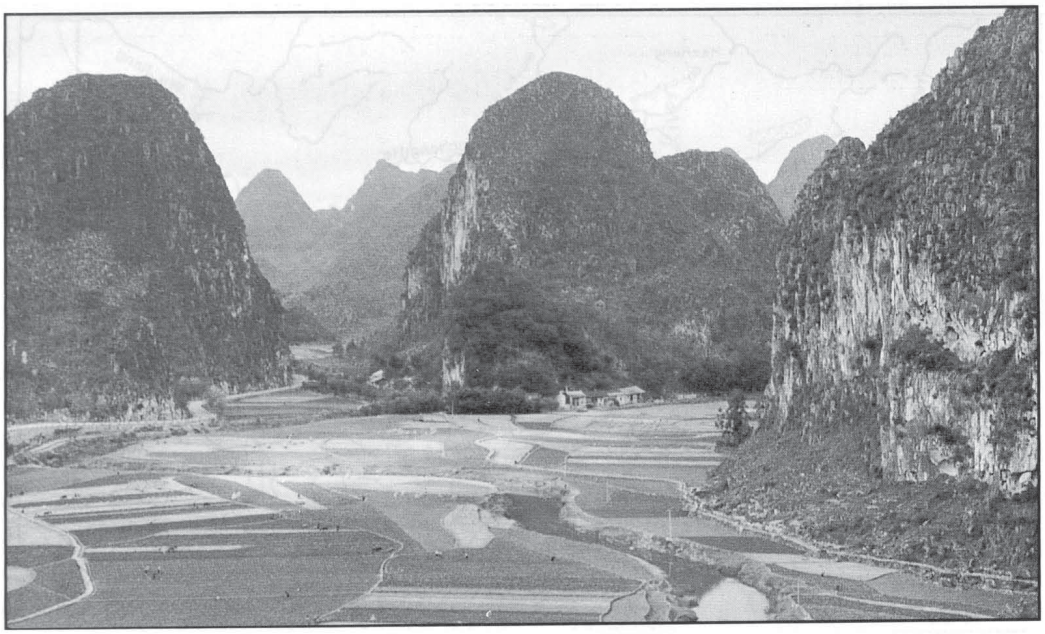


The big natural bridge at Jiudongtian.

Deep gorge on the approach to the Dina He sink.

Figure 5. Karst geomorphology of the Guazhong He area, with the karst windows and big natural bridge of Jiudongtian.





Fengcong valley karst near Xuantang, Anshun.

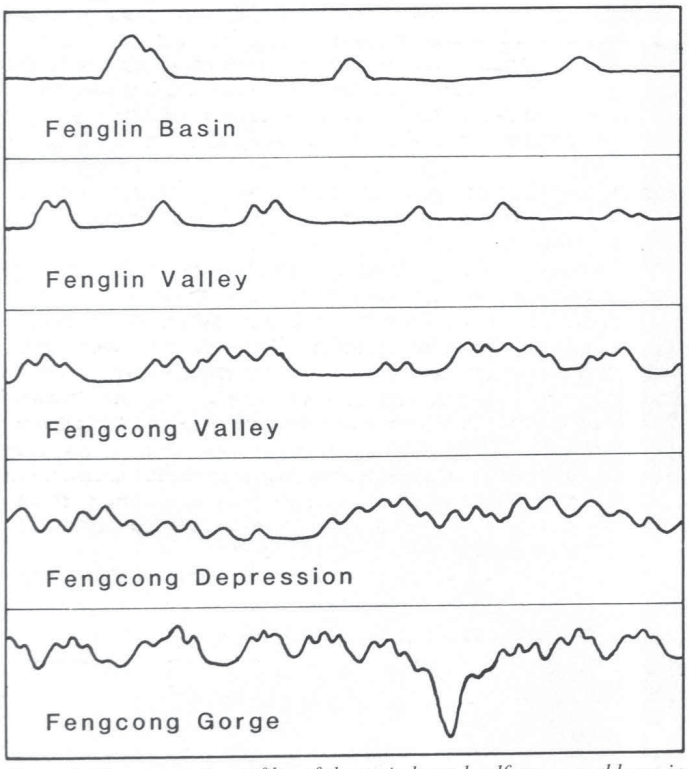


Figure 6. Diagrammatic profiles of the main karst landform assemblages in the Guizhou Plateau (modified from Smart, 1986).

Fengcong Gorge: similar with the term fengcong-canyon of Song Linhua (1986), produced by the downcutting of the trunk river in response to the uplift of the karst plateau. The fengcong-depression landscape near the gorge is produced by rejuvenation.

In broad terms, there are two main types of karst landforms: the extensive areas of karst plateau, and the relatively narrow zones of karst gorge. Different types of karst landform assemblages have different environmental qualities; table 1 makes comparison between the two main types of karst geomorphology.

Underground karst development

The vertical karst development caused by the lowering of groundwater tables shows itself as the multi-level cave systems, which occur on the Guizhou plateau both in the landform assemblage of fenglin-basin (fenglin-plain) in the watershed area and in that of the fengcong-depression in the gorge area.

In the plateau area, as in the Anshun-Pinba region, fenglin-basin dominates, but the landscape here has already reached its mature stage and is gradually progressing toward its later stage of development (for the rejuvenation caused by downcutting of the Wujiang has not reached here yet).

The multi-level cave systems formed in earlier times are residual ones left on the hillsides or near the tops of the hills. The lower cave systems are mostly still occupied by subterranean streams with here and there collapsed windows or natural bridges, so they are at the stage of gradual disintegration. Some of them run through the bases of the hills, where they can be called bottom caves or active caves (of different genesis from the foot caves).

In the gorge areas, as near or in the Sanchahe gorge, the landscape is rejuvenating with the rapid lowering of groundwater

Karst gorge on the Baibu He, a tributary of the Liuchong.

	KARST PLEATEAU AREA	KARST GORGE AREA
location	topographic divide and upper basins	middle and lower reaches of rivers
karst types	fenglin basin fenglin valley	fengcong valley, fengcong gorge, fengcong depression
karst development	inherited features	vertical development
drainage density	>0.25 km/km^2	<0.25 km/km^2
local relief	<150 m	>300 m
soil cover	thick cover	commonly bare rock, soil in depressions
groundwater	diffuse flow, water table 0-20 m deep, easily exploited	conduct flow, water table 40-300 m deep, difficult to exploit
microclimate	open topography, good sunlight conditions, high cumulative temperature	high relief, shadows in depressions, low cumulative temperature, high daily temperature range
moisture state	good moisture conditions, access to both surface and ground water	difficult utilisation of surface and ground water, karstic drought and floods
soil types	zonal and red soils on carbonate weathering crust	nonzonal calcareous soils
vegetation	zoned with latitude and altitude	limestone community
land type	karst plain and hills	rocky hills and depressions
cultivation	flat paddy field, flat non-irrigated land, terraced paddies	non-irrigated farmland, hill farm land, sloping terraces

Table 1. Comparison of environmental qualities in the karst plateau and karst gorge areas (after Yang, 1988).

level. The bottom cave resurgences often occur somewhere on the gorge walls not far from the valley floor and the earlier abandoned multi-level cave systems commonly overlie those which have recently formed and been abandoned.

Caves in different geomorphological locations with different hydrological conditions are of different environmental qualities that can be used in different ways (table 2).

KARST ENVIRONMENTS AND WATER POLLUTION

Apart from the ineffectiveness in self-purification of contaminated groundwater in all fractured dense carbonate rocks (which provide poor conditions for adsorption and ion exchange

	FOSSIL CAVES	ACTIVE CAVES
location	above local base level, in hillsides of cone karst (fenglin or fengcong), 2-3 levels, some through caves, higher are shorter	at or near local base level, gentle gradient with surface streams between caves in fenglin, steep gradient with waterfalls in fengcong
hydrology	dripwater, condensation, capillary flow	underground streams
processes	deposition and filling by collapse, speleothem and clastics	mainly erosion, local collapse and clastics
resistance to damage	small or extremely small	great or very great
utilisation	tourism and research	tourism and sport, hydropower

Table 2. Comparison of features of fossil and active caves (modified after Zhang, 1988).

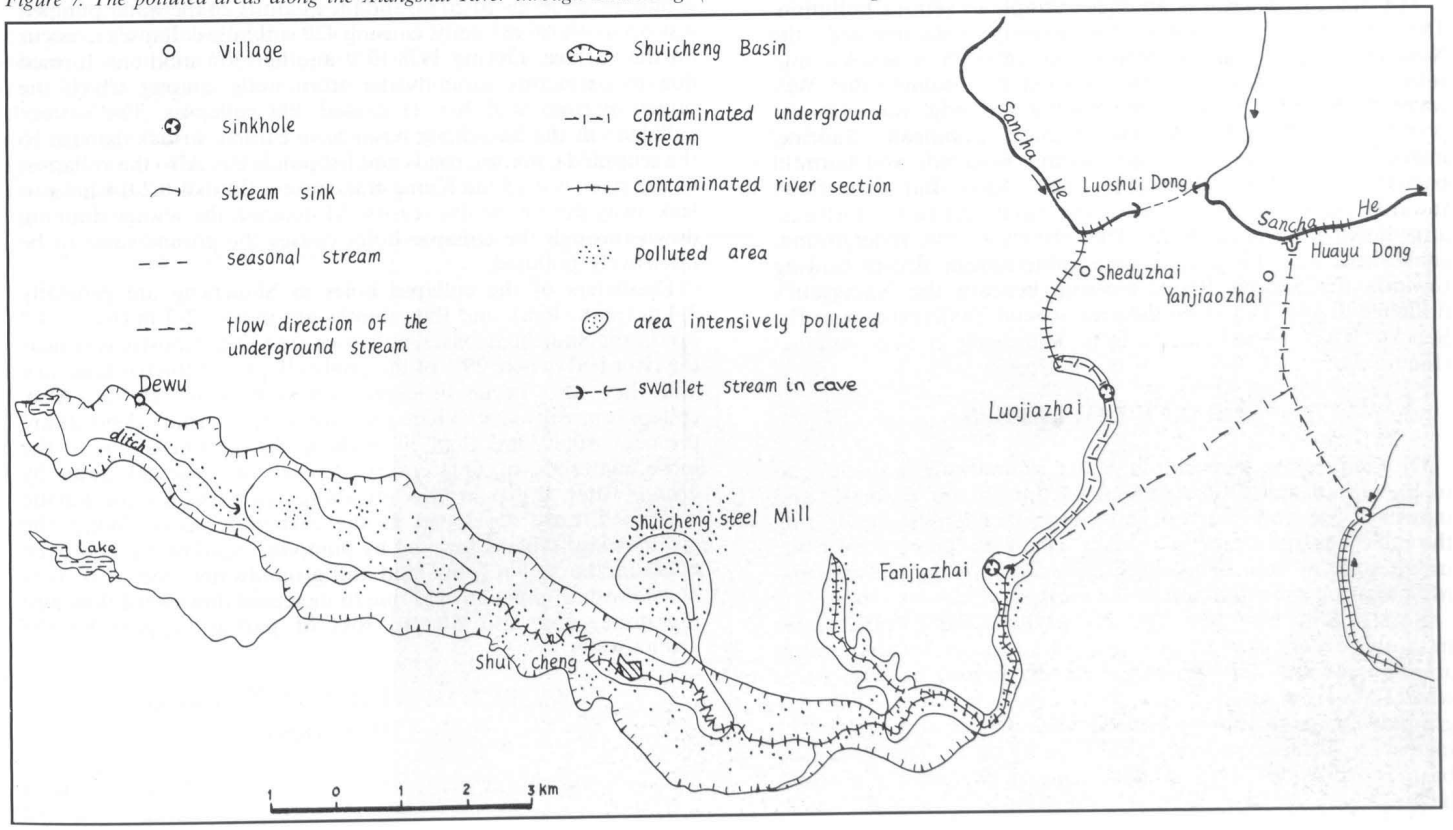
but are favourable for rapid infiltration and transmission of the groundwater), the Guizhou karst is susceptible to pollution also because of its well-developed underground drainage systems and because it has only thin soils in the large areas which have been deforested.

In the karst plateau area of Guizhou the karstification is intense, with many depressions, dolines, sinkholes and solution fissures on the surface linked with the interconnected subterranean tubes and streams which lie at shallow depths beneath the surface. Because the rejuvenation occurring in the gorge zone still does not affect the plateau area, the movement of groundwater is mainly in the lateral direction; wherever polluted water enters through a sinkhole or any other similar negative landform, it is very quickly transmitted through the interconnected underground tubes and fissures, and the pollutants and sewage spread rapidly from a point input, as if in a diffuse aquifer.

In the gorge type of the karst geomorphology, on the contrary, the karstification is less intense, but the depth of the karst development is great. Consequently, any pollutants or sewage entering a sinkhole descends quickly through the rather simple tube systems toward the main river, commonly cutting several hundred metres below the plateau surface; so the harmful pollutants are carried from a point only through a restricted zone and then directly from a spring into the trunk river. In this case the damage to the environment may be rather limited in space but pollutant materials are transported away by the main river and will be propagated far away to influence the quality of the environment more extensively downstream.

Cities, towns and villages are located mostly in the shallow

Figure 7. The polluted areas along the Xiangshui River through Shuicheng. (The Luoshui Dong is also known as the San Cha He Dong).



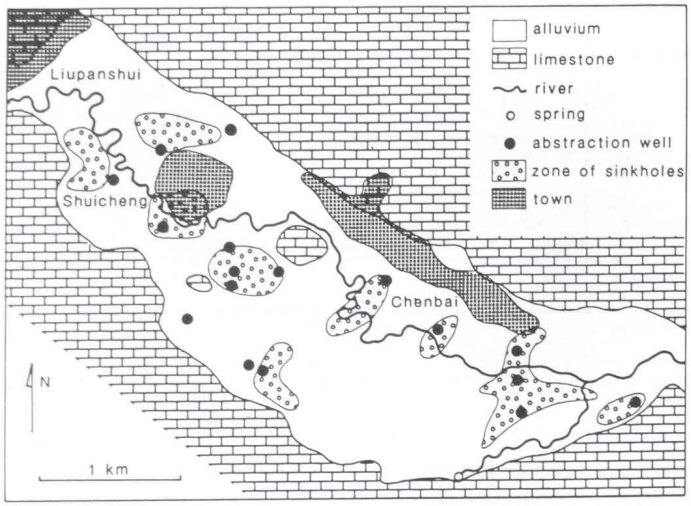


Figure 8. Map of the Shuicheng basin, where hundreds of sinkholes have developed in the thin alluvial cover on bedrock limestone. Most sinkholes are in well defined zones close to the groundwater abstraction wells (from Waltham, 1989).

karst basins and broad, shallow karst valleys on the plateau area, including Guiyang, Shuicheng, Liuzhi and Anshun, where the population is concentrated and many factories are located. These are the places where industrial and domestic waste easily enter the karst underground aquifer. Some factories and mines even use the natural collapse windows that connect with the subterranean rivers as convenient spots to dispose of their waste. The groundwaters there are seriously polluted and extremely harmful to the local people's health.

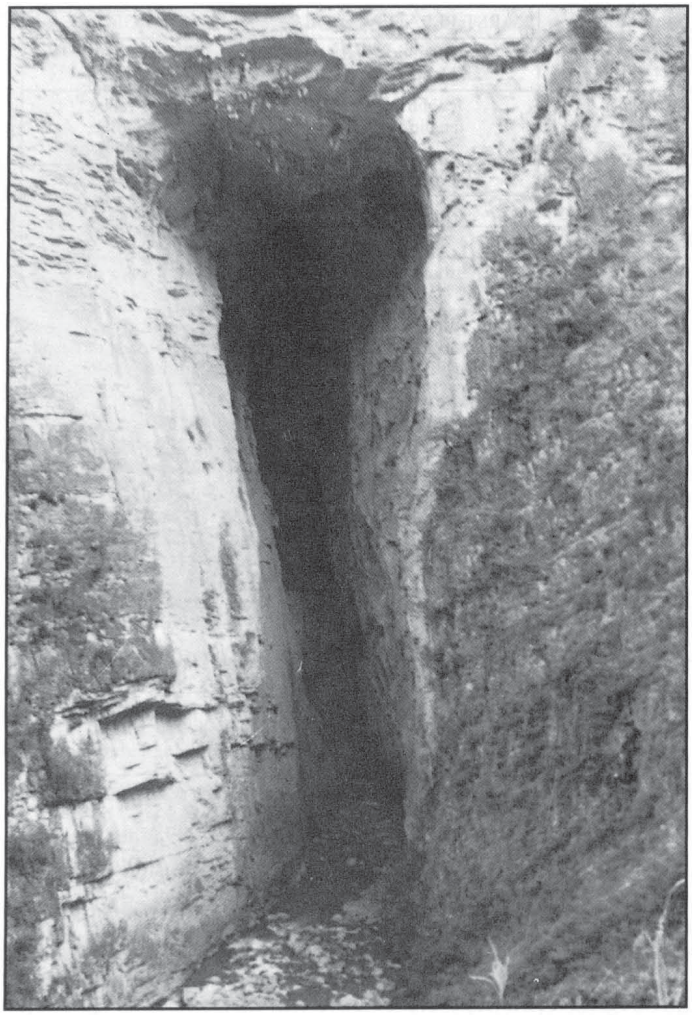
Nanminghe, the upper reach of a tributary of Wujiang, winds its way through the southern part of Guiyang city. Before the development of the industries of the city, more than 30 years ago, the water of the river was little polluted, and residents of the city even used the water for drinking. But in recent years the river has become very much polluted. The colour of the water in the river is dark and unpleasant. No fish can be found in the river section through the city. Various kinds of organic compounds, metallic elements and other organic materials that are harmful to the people's health, like phenol, cyanogen, arsenic, mercury, chromium and lead appear at high concentrations in the water. The concentrations of various kinds of pathogenic bacteria generally exceed acceptable standards by a hundred or even a thousandfold. The pollution of groundwater in Guiyang is also serious. All indicate that the environmental laws of the country are not being observed strictly.

The Shuicheng basin is another example of serious pollution. The industrial wastewater has heavily contaminated the Xiangshui river, and by infiltration through sinkholes and solution fissures has also contaminated the groundwater. Well water cannot now be used for drinking and irrigation as it was previously, for pollutants like phenol, cyanogan, fluorine, mercury, sulphur, arsenic, lead, organic materials and harmful bacterias far exceed acceptable levels. Xiangshui river flows towards the southeastern end of the basin and turns northeast after flowing out of the basin. Then the river sinks underground, somewhere near Fanjiazhal, as a subterranean stream flowing towards the Sancha River, crossing beneath the Xiangshui's drainage-divide. Thus even the area around Yanjiaozhai near the Sancha River about 20 km from Shuicheng is also polluted (Figure 7).

SURFACE COLLAPSES

On the plateau, the location of the groundwater is shallow, so in the urban areas, it is generally extracted for domestic and industrial use, and therefore cause surface collapses endangering the buildings and farmlands. Many examples can be seen in the urban areas of Shuicheng, Anshun, Guiyang and elsewhere, and in Shuicheng the condition is the most serious.

Both in Shuicheng and Anshun, surface collapses often occur in thinly covered karst areas with many open fissures and cavities and consequently fully developed karst aquifers. In these areas, wherever groundwater has been over-extracted and the groundwater level becomes considerably lowered and its gradient increased, surface collapses will inevitably occur. The Shuicheng basin is mainly developed in thinly covered karst, on top of which lie up to 30 m of Quaternary alluvium and lacustrine loose



River cave entrance on the Dina He.

deposits. The carbonate rocks beneath have abundant open fissures and cavities, and constitute an intensively karstified aquifer. Collapses are numerous within this shallow and flat basin of 5 km long and 1 km wide (Figure 8). On the floor of the basin, 16 wells had been drilled, of which 14 have caused subsidence sinkholes of different sizes to develop. By 1985 the total number of collapses amounted to over 1000. During the period of 1966-1977 there were ten deep wells pumped so as to lower the groundwater levels 10-20 m, and the quantity of the water pumped was up to 45,000 m^3 daily, causing 420 sinkhole collapses to occur on the surface. During 1978-1979 another 307 sinkholes formed due to extracting groundwater from wells, among which the pumping from well No. 11 caused 199 collapses. The surface collapses in the Shuicheng basin have caused serious damage to the cropfields, houses, roads and fishponds etc. Also the collapses in the river bed of the Xiangshui cause a flow of 0.2-0.4 m^3/s to leak away during the dry season. Moreoever, the sewage draining down through the collapse holes causes the groundwater to be intensively polluted.

Diameters of the collapse holes in Shuicheng are generally 3-4 m (max. 16m), and their depths are mostly 2-3 m (max. 14.2 m). In the Shuicheng basin, collapses are located mostly very near the river bed (where 29% of the total collapses in the basin occur), and they also occur in depressions and karst gullies. Also, collapses mostly occur where the cover of Quaternary deposits are thinner, usually less than 10 m thick. As the fine grains of the loose materials of Quaternary deposits are carried away by groundwater, soil pipes are left above open fissures and karstic cavities already developed in the carbonate rocks. When the groundwater table is lowered by pumping, equilibrium is broken between the soil regolith and the groundwater; then collapses occur, both as pipes enlarge due to increased downward flow into limestone, and also due to loss of partial support by the groundwater.

ENVIRONMENTAL ENGINEERING IN THE KARST

The engineering geomorphological problems of the building of hydropower stations are, firstly, the leakage of the dam sites and

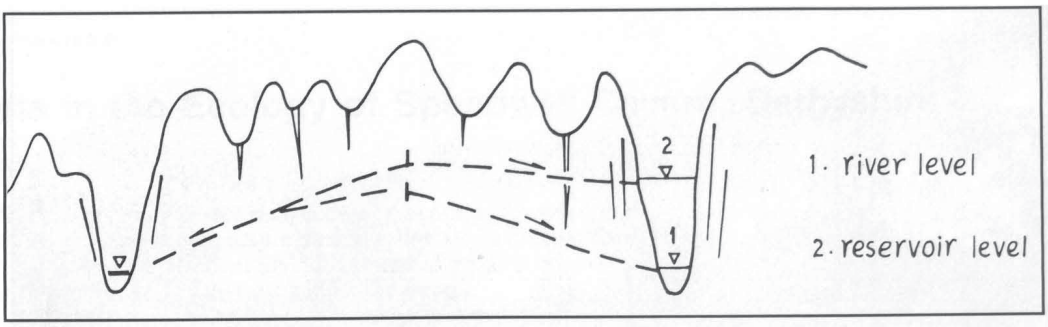


Figure 9. The high underground watershed beneath a broad topographic divide keeps water in the reservoir from leaking to the adjacent valley.

around the reservoir, and, secondly, the stability of the foundations and the reservoir slopes; both relate closely to the development of the karst geomorphology. In Guizhou, different problems are met in the different karst geomorphological types of the broad valleys and the gorges.

The terrains of broad valleys occur on the plateaus. The reservoirs and dam sites are often located in the open karst basins and depressions where horizontal caves are developed. Topographic divides around the reservoir are generally low with some cols breaching them. The groundwater is shallow with extensive catchment areas. The karst development is usually in close connection with the evolution of the drainage patterns, so some evidences of ancient river networks can be found in the field. The intensity of karst development is high but the depth of its development is shallow. It is usual not to build high dams in such a geomorphological environment, to avoid the flooding of large areas of cropland. When the dam is being built, attention should be paid to the karst leakage under the dam foundation, around the dam shoulders and beneath the low cols through the watershed divides.

The terrains of the gorge type occur generally along the river's middle and lower reach with fengcong-depression and fengcong-gorge as their essential landform assemblages. Here the karst develops in a vertical direction. The river valley cuts deeply, with steep gradients along its profile, and laterally the gradient of the ground water table also increases toward the valley floor which is the base-level of discharge of the groundwater.

When a dam has been built in the gorge all the retained water of the reservoir is within the gorge area. Generally, on both sides of the reservoir, the topographic divides are high and wide, without any deeper neighbouring valleys or depressions. Furthermore, the intensity of karstification is low in the gorge area, for it is the zone of recent rejuvenation too short lived for extensive lateral development of karstification. But in order to keep pace with the rapid valley-cutting, the karst development is deep, with concentrated conduit flows towards the river. So wherever a high dam is to be built, the area flooded by the reservoir will not be large and there will be less problems of leakage to the neighbouring valley (Figure 9). However in some cases if the geological, geomorphological and tectonic conditions are favourable, subterranean conduits may exist below the river bed, at both sides of which low troughs of the groundwater table may also occur. These can cause serious leakage round the dam and problems of stability of the dam foundation.

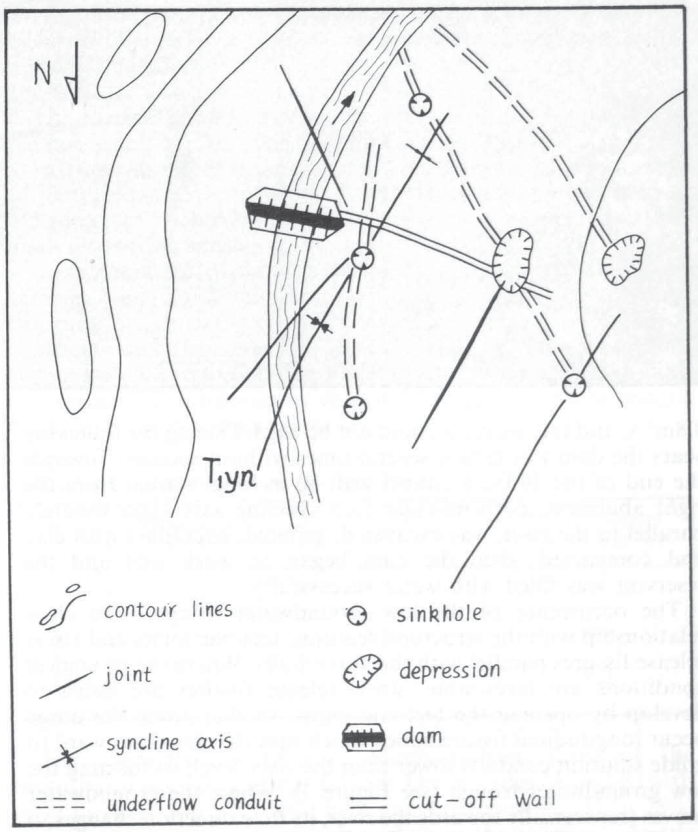
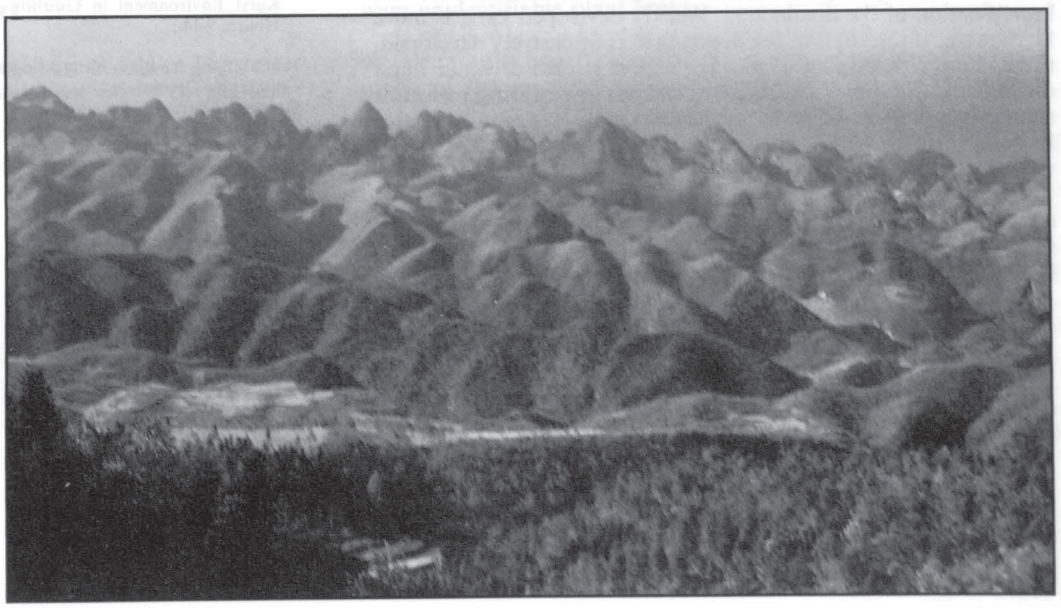


Figure 10. Engineering treatment of the limestone at the Hongyang Dam, Zhijin, to prevent water leaking from the reservoir (after Liao, 1990).

As an example, Hongyang reservoir, about 20 km to the southwest of Zhijin county town, was built in the fengcong-gorge area of Triassic limestones (Figure 10). Under the right bank of the river, karst conduits within low groundwater troughs parallel to the river changed the groundwater flow from transversal to longitudinal. In 1972 when the reservoir began to store water, two subsidence sinkholes occurred along the right flank of the reservoir. Some 300 m downstream of the dam, five resurgence points were found. The quantity of the water loss amounted to

Fengcong landscape south of Zhijin.



A large karstic depression near the Zhijin Cave.

4.8m^3/s, and the reservoir could not be used. During the following years the dam was rebuilt several times without success. Towards the end of the 1970s, a cut-off wall 80 m long, started from the right abutment, perpendicular to a syncline axis approximately parallel to the river, was excavated, grouted, backfilled with clay and compacted; then the dam began to work well and the reservoir was filled with water successfully.

The occurrence of the low groundwater trough is in close relationship with the structural features, tectonic joints and stress release fissures parallel with the gorge walls. Where the geological conditions are favourable, stress release fissures are liable to develop by opening the tectonic joints, so that along the gorge occur longitudinal fissure zones which may develop downward to guide solution conduits lower than the river level, so forming the low groundwater trough (see Figure 3). Where the groundwater moves transversally towards the river, its flow direction changes to longitudinal, down the valley, as the low groundwater trough is reached. Low groundwater troughs often occur in the limestone gorges in the Guizhou plateau. Furthermore, where stress release fissures occur, the compressive strength of the limestone rock mass decreases to cause problems of slope stability.

The favourable terrain for the selection of a rail route is the plateau area with broad karst valleys and shallow karst depressions. Some depressions have to be crossed by the railway, and in these cases the hydrology of the depressions should be made clear in advance. If a depression is flooded periodically, the foundation of the railway must be laid above the maximum flood level. If the location of a tunnel is to be selected to cross a water divide, it is very important to investigate the intensity of the karstification of the divide area. Weakly developed karst is more favourable. If the karst of the divide area is intensively developed, there is more possibility of meeting a cave stream or water burst during construction. In such caves various engineering measures should be adopted: filling the small dry caves; draining the water flow from fissures; even building a bridge across the cave stream within the tunnel if necessary.

In general, different karst environments have different problems of engineering geomorphology. To deal with these problems, land exploitation and industrial and communication construction must be preceded by adequate understanding of the karst processes.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Tony Waltham who read the manuscript and was kind enough to give suggestions for its revision, and also Miss Lin Junqing of the Department of Geography of Guizhou Normal University for giving us great help in drawing the maps and sketches.

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Profs. Zhang Yingjun, Yang Mingde and He Caihua
Geography Department
Guizhou Normal University
Guiyang, Guizhou, China

CAVE SCIENCE Vol. 19, No. 1, April 1992
Transactions of the British Cave Research Association

The Role of Oligochaeta in the Ecology of Speedwell Cavern, Derbyshire

Ronald THOMAS and Simon BOTTRELL

Abstract: Worm casting and bioturbation of sediment banks in Speedwell Cavern is described and the Oligochaetes responsible identified. The population structure and low levels of available food in the sediment indicate that the Oligochaetes are accidentally introduced during flood events (probably as cocoons), rather than forming a stable population within the cave.

Bioturbation was noticed on sediments in the Far Canal area of Speedwell Cavern by Simon Bottrell during the collection of sediment cores in early 1990. It is believed by the authors to be the first time that this phenomenon has been observed in Speedwell (T. D. Ford, *pers. comm.)*. In this paper we identify the organisms responsible for the casting and to try to constrain; a) their point of origin into the system, and b) food source and availability for these organisms. It was also hoped that this study may help to understand the possible influence of biological activity in the sediment on their organic carbon content as this organic carbon concentration decreases with depth in these sediments. (Bottrell, in preparation).

Speedwell Cavern (SK 139828), is a combination of both natural and mined passages within the Carboniferous limestones of the Castleton area of Derbyshire. The major input of water into the system is from a line of sinks close to the boundary of the Kinderscout Grit of Rushup Edge with the limestones above Castleton. The major surface resurgence of the system is from Russet Well (SK 148827) near the Peak Cavern gorge but during their underground route, the waters rise at both Main and Whirlpool risings in Speedwell Cavern and flow through part of the cave system (Gunn, 1991). The primary use of the land within the catchment area of this system is sheep farming, with some dairy herds.

The system was first entered by miners probably during the 17th century in search of profitable lead veins; they had a major influence on the system as a result of driving an adit (started in 1771) from the surface at the foot of Winnats Pass which intercepted the Main Stream and was then used as a canal in order to remove lead ore. The first section of the mined canal, as far as the Bottomless Pit (Fig.1) is now a show cave and access to the areas beyond the end of the show cave is severely restricted.

It was suspected by the authors that the organisms responsible for the casting would most probably be of the Order Oligochaeta, which due to their normal habitat and feeding requirements produce casts on the surface of the soil as a response to compaction during their search for food and living space.

In September of 1991, we entered Speedwell Cavern to map areas of sediment affected by bioturbation and to collect specimens of the organism responsible for the casting. At the same time sediment samples were obtained, firstly to find the numbers of cast-forming animals in an average mass of sediment and thus gauge their relative abundance of cast-forming animals, and secondly to try to identify their food source and establish the ecological status of the population of burrowing organisms.

SAMPLING

Areas where bioturbation was observed are shown in Figure 1. These were restricted to sediment banks composed of silt and sand. These areas are away from the main force of both rising and ebbing flood events (with the exception of site C). Due to very low water conditions most of the sites sampled were in sediment banks normally submerged, but on this occasion they were exposed above water level.

The method used to collect the samples was a simple scrape method removing 200-400g of sediment from the top 2-3cm, using a wide-mouthed plastic container. (Previous examination of cores of bioturbated sediment showed that turbation only extended to 1-2cm depth). A sub-sample of approximately 10g was taken for analysis and the remaining sample washed through a sieve, with a mesh diameter of 0.07mm to isolate Oligochaeta. The sub-samples were accurately weighed prior to drying at 110°C to constant weight to determine moisture content. The dried sediment was then washed in 1M HCl to remove calcium carbonate (determined by weight loss after washing and drying) and the residue subsequently analysed for organic carbon using a Carlo Erba 1106 Elemental Analyser.

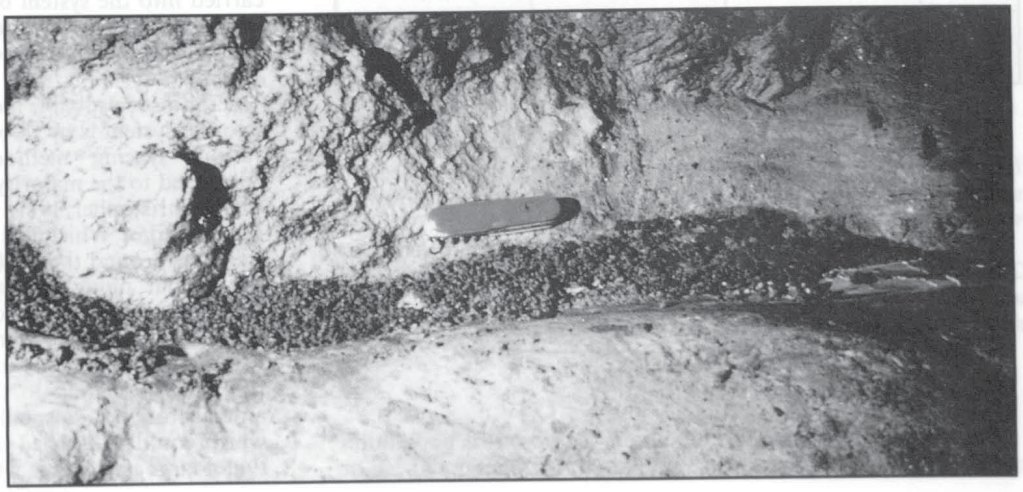
Table 1. The mass of sediment per Oligochaeta.

Site	Mass sediment collected (g)	No. animals	Mass sediment per animal (g)
A	204	4	51
B	286	5	57.2
C	404	14	26.9

The characteristics of the sediments from three of the bioturbated sites are given in Table 1. The two sites (A and B) with most bioturbation both have high moisture contents (37 to 38%) and approximately 1.5% organic carbon in the sediment. At site C the sediment which was bioturbated was both coarser-grained and higher above the water level and hence better drained (25% moisture content). The lower content of organic carbon here (0.34% of sediment weight), possibly results from an association of organic material with finer-grained material during sedimentary sorting.

Of the areas examined, the highest density of turbation occurred at sites A and B. Site A is approximately 55m from the viewing platform at the Bottomless Pit. At this point no Oligochaeta were observed on the sediment surface, however when the sediment sample collected from this site was processed, four juveniles of the genus *Aporrectodea* were found. Also found were unidentifiable plant areas.

At site B, which is located alongside of and inside of the sunken wooden tourist boat (this has acted similar to a sediment trap and much of the material inside of it was of a finer nature than



Worm casted sediment bank, Far Canal, Speedwell Cavern (photo: J. Gunn).

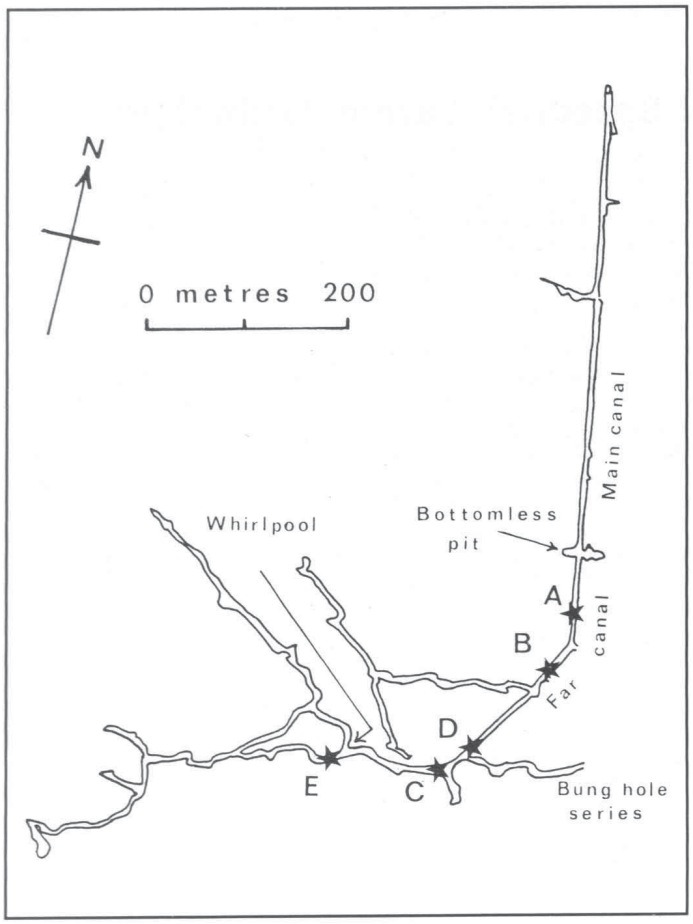


Figure 1. Location of sample sites in Speedwell Cavern.

outside it), two *Aporrectodea rosea* were found along with one specimen of *Allolobophora longa* on the sediment surface, all close to the water level, where the sediment was fully saturated. From the sediment sample collected at this site, five further *A. rosea* were collected after being sieved as above. Of these, four were juveniles and one a sub-adult. Also found in the sample was a small amount of vegetable matter, including one piece of woody-stemmed tissue (species indeterminate) and several seed cases from what appeared to be grass species.

Site C is at the junction of Pit Props Passage and Main Stream Passage. Here the sediment was of a coarser nature, with finer material higher up towards the top of the bank. At this site, seven mature *A. rosea* were observed on the sediment surface. From the sample collected, after sieving, fourteen Oligochaeta were found. Of these, one was *Lumbricus terrestreis,* two sub-adults of *A. rosea,* four juveniles of *A. rosea* and the rest juvenile Oligochaeta. From this site a large amount of vegetable matter was also collected. The average mass of sediment per animal found from these sites is shown in Table 2.

Table 2. Percentage composition of sediment.

Site	% Moisture	percentage of dry weight $CaCO_3$	Organic Carbon
A	37.1	19	1.45
B	37.9	19	1.59
C	24.8	7.1	0.34

At site D, next to the gate in the Far Canal, two *A. rosea* were found attached to the cave wall close to isolated pockets of sediment on the wall. At this point, the wall had a slight flow of water running down the surface (source unknown).

The last site investigated was E. This is a small area of sediment 25m upstream from the Whirlpool in Main Stream Passage in an alcove 2m above stream level. Here bioturbation was noted but no specimens were found.

DISCUSSION

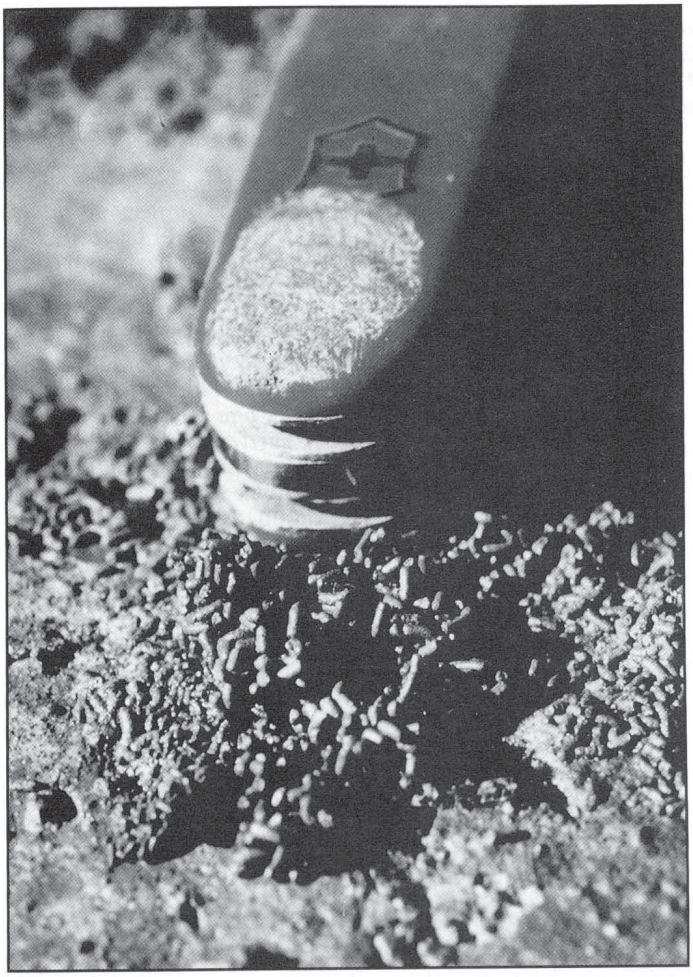
One of the first things to note about the observed population of Oligochaeta in this system is that out of the 30 animals seen or collected, the range of species is narrow, with only three species identified, as opposed to the potential nine species which could be found in the type of substrata which occurs within the cave and on the catchment area (Guild 1951). All three types identified are common species found on agricultural land (Guild 1951) of the type found in the Speedwell catchment area. During sampling in late September, of 1991, R.T. found that in the area of the P.8 catchment the commonest species was in fact *A. rosea* with a seven to one abundance ratio to that of *L. terrestris.* Why only one specimen of *L. terrestris* was found in the cave is perhaps most easily explained by the fact that this species is normally a deep burrower and therefore less likely to be involved in the movement of sediment into the cave system during flood events (except when there is massive sediment transport, e.g. bank collapses which bring a large mass of soil into the stream bed), or to be transported into the cave system on the equipment of the caver. However this one specimen was collected from a relatively deep (compared to the other samples) deposit and further observation of this site may lead to other specimens of this species being found.

A second point of interest is the very small number of animals which are capable of breeding. From this it seems unlikely that the populations we observed are stable populations but are in reality dependent upon migration into the system to maintain the current population. Furthermore, Evans and Guild (1948) showed that the number of cocoons produced was related to diet and that for maximum cocoon production to occur, the animals need a diet with a high nitrate content which is normally found in animal faeces. The only available food source found in the sediments was that of semi-decayed plant remains. Therefore due to both a lack of animals capable of breeding and the poor diet available it is very unlikely that a stable population can be maintained. Of course the events which are likely to introduce new members (flood incidents) are also likely to remove a large number of the existing population or to change the sedimentation pattern of which appears to provide the only source of food for these organisms. It appears that there are only two sources of possible nutrients: a) Plant material brought in by either floods or cavers, b) micro-organisms feeding on the organic content of the sediment. At this period in time there is a notable paucity of available literature on the affect of microbial decomposers on plant litter in cave sediments and is one of the areas which needs more detailed work to be carried out.

This then leads to the possible methods of introduction of these animals into the system. They may have been brought into the cave by the activity of cavers. Although this is a possibility, we consider it unlikely for the following reasons; the animals would have to be transported on the clothing of the caver entering the system and more than likely would have to be picked up en route to the cave. Most of the people who go past the show cave area either get changed in the car park and walk across the road to the entrance, which at no point brings them into contact with soil, or they change in the guides' room, again with no contact with the soil. It is unlikely that any animals which become attached to the caver's equipment during previous trips could survive the 'normal' storage methods employed by cavers, due to the reduction in water availability during drying and storage as this would lead to desiccation of the animals. One final point is the occurrence of bioturbation past the Whirlpool (a deep pool often necessary to swim in order to cross); anyone crossing this barrier would have any foreign matter removed and it would then be washed down stream. The same reasons also make it unlikely that a significant amount of the food for the animal population is carried into the system by cavers. Additionally, bioturbation has been observed on sediment banks in the Far Sump Extensions, Peak Cavern, only entered recently by divers. (J. Cordingley, *pers. comm.).*

A far more probable method for the introduction of the animals into the system is by flood transportation. It has been proved by various tracing methods that Speedwell is hydrologically connected to the majority of the sinks below Rushup Edge (Ford 1966; Christopher 1981; Gunn 1991). All of these rise at Main Rising and/or Whirlpool Sump (Gunn 1991). Because of farming practices around the P.9 (SK 108818) to P.6 (SK 104814) swallets, the regular ploughing of several fields in this catchment, and recent gripping in the catchment area for the P.9 stream all combine to provide a greater disturbance of the substrata and hence allow a greater number of Oligochaeta to be washed into the streams leading to the swallets. As to why the number of animals found is so small in relationship to the potential number which could be washed into the cave, it is reasonable to assume that a large percentage which enter the system become trapped in

silted sumps or die en route. One of the main modes of transport for the Oligochaeta in a stream would be as a cocoon. Schwert (1979), showed that this mode of transportation was possible with no detrimental effects to the animal. It would perhaps help to explain why there is a large proportion of the animals found which have not yet reached sexual maturity and there is little evidence of animals capable of breeding.



Close-up of worm casts (photo J. Gunn).

CONCLUSIONS

The Oligochaeta found in the Speedwell system probably entered via flood action from one or more of the swallets which accept drainage from Rushup Edge. They are able to maintain a limited life span using the organic remains found in the fresh sediments, but due to the limited number of viable individuals and/or limits on nutrient levels, they are probably unable to maintain the population by breeding and therefore are totally reliant upon flood incidents to; a) provide new individuals to the population (also with the loss of some individuals already present), and b) to provide and replenish the organic matter which the animals use for a food source. The small number of animals capable of breeding and the fact that only limited groups of animals, each within a particular age range with no mixing of age types, precludes the possibility that the animals found came from parents breeding within the cave system. Thus the populations of animals we found were almost certainly accidental introductions to the system. Although no previous sightings have been reported, it is possible that earlier flood events have introduced Oligochaetes into the cave system and they have not survived.

ACKNOWLEDGEMENTS

We would like to thank John Harrison of Speedwell Caverns for allowing access for sampling.

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Ron Thomas
Department of Biological Sciences
University of Lancaster
Lancaster LA1 4YN

Simon Bottrell
Department of Earth Sciences
University of Leeds
Leeds LS2 9JT

CAVE SCIENCE Vol 19, No. 1, April 1992
Transactions of the British Cave Research Association

The Monkey Caves of Cuba

Efren Jaimez SALGADO, Diwaldo Gutierrez CALVACHE, Ross D. E. MACPHEE and Gina C. GOULD

Abstract: Two small caves in western Cuba — Cueva del Mono Fósil and Cueva Alta in the eastern part of Sierra de los Organos — have yielded remains of a hitherto unknown (and now extinct) platyrrhine monkey, *Paralouatta varonai.* These sites represent the first new monkey localities to be reported from this island since 1910. This paper provides surveys and descriptions of the *Paralouatta* cave sites in light of fieldwork conducted in 1990 and 1991.

Evidence is accumulating that parts of the West Indies were a significant centre of primate evolution and diversification (MacPhee and Fleagle, 1991). Although none of these islands has native primates today, three of the Greater Antilles — Jamaica, Hispaniola and Cuba — had one or more endemic species in the recent past (Ford 1990). Interpreting the phylogenetic relationships of these monkeys has proven difficult, partly because of the paucity of good material, but also because of the unusual trait combinations of some species (e.g. *Xenothrix mcgregori;* MacPhee and Fleagle, 1991) that suggest very distant separation from surviving continental clades. Radiometric evidence indicates that at least some of these island primates survived well into the late Quaternary; it is possible that all of them — together with dozens of other vertebrate species — became extinct shortly subsequent to the entry of humans into the Caribbean, c.4500 bp (MacPhee *et al.,* 1989; Morgan and Woods, 1986; Rouse and Allaire, 1978). Cave deposits are virtually the only context in which remains of extinct Quaternary vertebrates have been discovered in the West Indies. Because most primates (and all New World platyrrhines) are forest-dwellers, it is unsurprising that primate fossils are extremely rare in such depositional settings. Accordingly, new discoveries merit special notice. In this note we present a brief account of caves in Sierra de los Organos of western Cuba that have recently yielded remains of a hitherto unknown primate, *Paralouatta varonai* (Rivero and Arredondo, 1991).

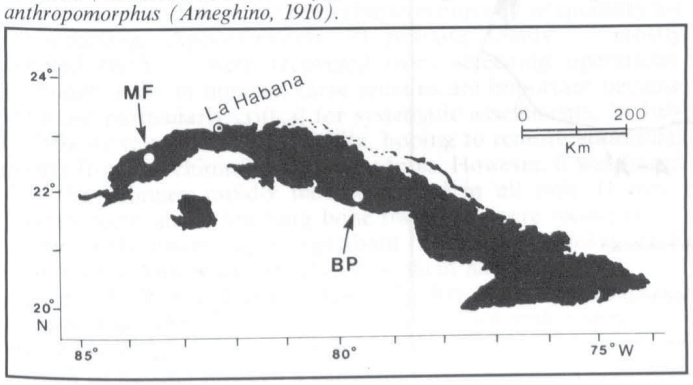
CONTEXT AND CAVE DESCRIPTIONS

Sierra de los Organos is composed of isolated, steep-walled limestone hills with flat or gently rounded tops — the classic karst inselberg landscape for which the term "mogote" was first developed (Monroe, 1976). The folded and tilted rocks comprising these mogotes are mostly of Late Jurassic (Malm) age, and are famous for rich ammonite faunas contained in widely-outcropping Guasasa and Jagua Formations (Wierzbowski, 1976). Substantial cave development is common in these limestones, and for this reason the mogotes of Sierra de los Organos have received considerable attention from Cuban speleologists and sport cavers (Núñez Jiménez *et al.,* 1984; Jaimez, 1990).

The mogote of chief interest in the present context is Sierra de Galeras, an elongate block situated in the eastern part of the Organos, some 4 km west of Abra de Ancon, Viñales municipality, province of Pinar del Río (Figure 1). The largest known cave system in Galeras is Gran Caverna Constantino, a large, complex river cave whose main passage runs completely through the middle portion of the mogote (total length so far explored, 10 km). Constantino communicates with Cueva del los Petroglifos, another cave system on the northern flank of Sierra de Galeras and historically important for its Indian petroglyphs.

Of the 17 known entrances into the Constantino system, the largest is the "main" entrance, the sink of the cave's river, Río Constantino (Figures 2, 3). This entrance, 20 m in height at the sill, is a large cleft on the south face of Galeras. On the western side of and communicating with this entrance are two much smaller caves, Cueva del Mono Fósil and Cueva Alta — the only known provenances of the newly discovered fossil Cuban monkey *Paralouatta varonai* (Rivero and Arredondo, 1991).

Figure 1. Location map of known monkey localities in Cuba. MF, Cueva del Mono Fósil and Cueva Alta (Sierra de Galeras), where Paralouatta varonai (Rivero and Arredondo, 1991) was recently discovered. BP, Boca (or Cueva) de Purial (Cordillera de Escambray), still the only locality known for Ateles anthropomorphus (Ameghino, 1910).



Cueva del Mono Fósil

Coordinates 22° 39' 18" N, 83° 48' 35" W. Altitude: 55.7 metres asl. Length: not established.

The entrance to Cueva del Mono Fósil (Figure 4) is located SW of the western lip of the main entrance of Caverna Constantino, approximately 3 m above the valley floor. The entranceway opens into a low, sloping chamber that continues horizontally into the hillside. The floor lacks appreciable sediment but the walls carry discontinuous shelves of pebbles and clay, indicating the former presence of a stream channel. Approximately 10 m from the entrance floor is interrupted by a narrow, longitudinal fissure

Figure 2. View of main entrance of Gran Caverna Constantino (sink of Río Constantino), taken from the approximate elevation of Cueva Alta, looking northeast. Individuals in foreground (situated near survey marker V-0, Fig. 3) are members of the 1990 team from the Museo Nacional de Historia Natural, Grupo Espeleológica "Pedro Borrás", and the American Museum of Natural History.

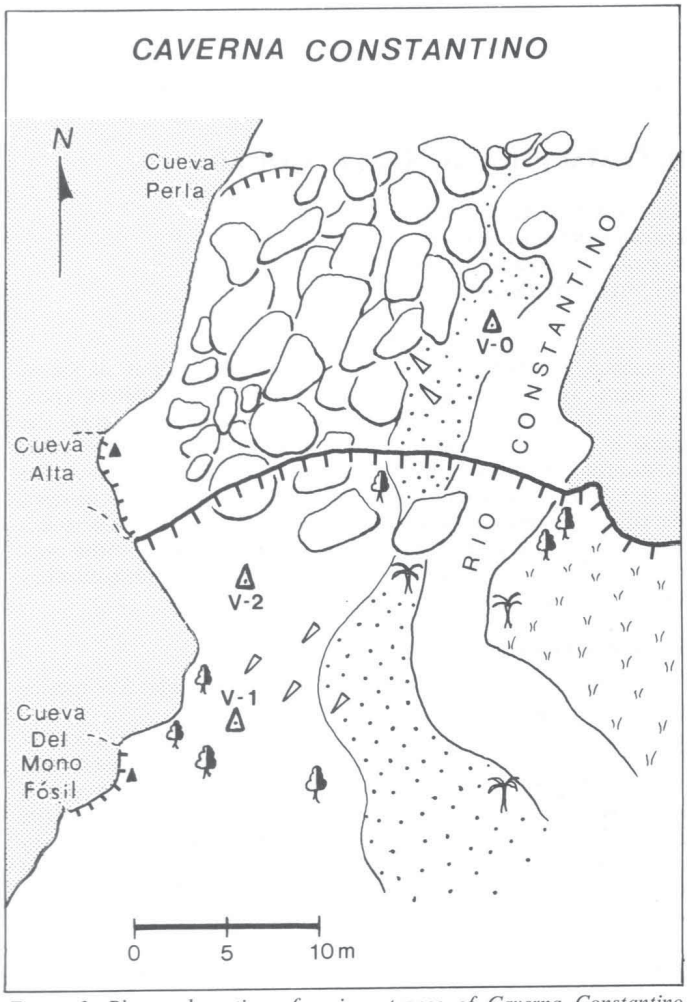


Figure 3. Plan and section of main entrance of Caverna Constantino. Surveyed altitudes: V-0, 40.2m; V-1, 45.3; V-3, 44.9m.

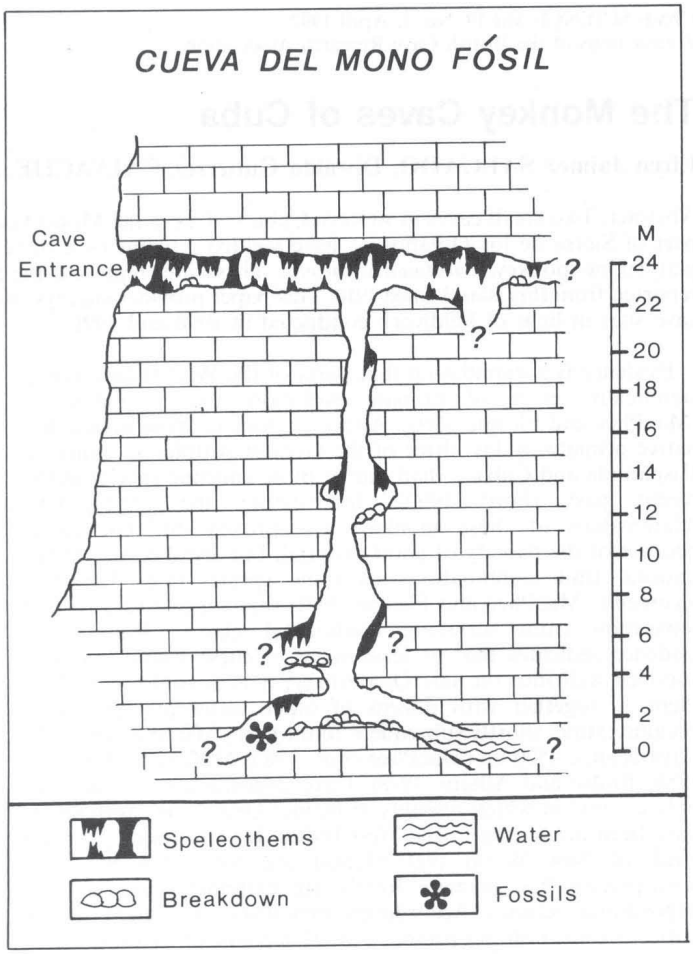


Figure 4. Section of Cueva del Mono Fósil. Exploration (at passages marked by question marks) has continued since this survey was conducted. Monkey fossils (asterisk) found at bottom of fissure.

23 m deep, which evidently opened subsequent to the period of stream activity. Other fissures, probably related to the same faulting episode, occur deeper within the cave (which ultimately links up with Cueva de los Petroglifos). Unlike the first fissure, these other fissures (not illustrated in Figure 4) contain permanent pools of water up to 5 m deep.

The first fissure was descended in August of 1987 by members of the Grup Espeleológico "Pedro Borrás" (GEPB) who were then trying to ascertain whether it connected with Caverna Constantino. Upon descent, mud-encased bones were immediately encountered on the fissure's floor. A few minutes work resulted in the freeing of a quantity of varied remains, including specimens of *Crocodylus, Mesocnus, Megalocnus* and *Capromys,* all well-known taxa typical of the Cuban Quaternary (Table 1). By far the most important find, however, was the well preserved and nearly complete skull of a previously unknown platyrrhine monkey (Figure 7), later named *Paralouatta varonai* (Rivero and Arredondo, 1991). Further scrutiny of the fissure sample led to the identification of another bone attributable to the monkey, an incomplete humerus. In cooperation with the American Museum of Natural History and the Museo Nactional de Historia Natural, collecting trips were made to Cueva del Mono Fósil in 1990 and 1991 for the express purpose of finding additional primate material. Although small quantities of vertebrate remains were recovered (including some from one of the deep pools), no further primate remains were encountered in this cave. Any future exploration of the fissures will require diving gear.

Although it is possible that some of the remains found at Cueva de Mono Fósil represent individuals that actually fell into floor fissures or were dropped there by raptors, it is far more probable that these bones were secondarily deposited, having washed out of some other, higher part of the cave. We were unable to locate a likely source, however. The excellent preservation of the skull of

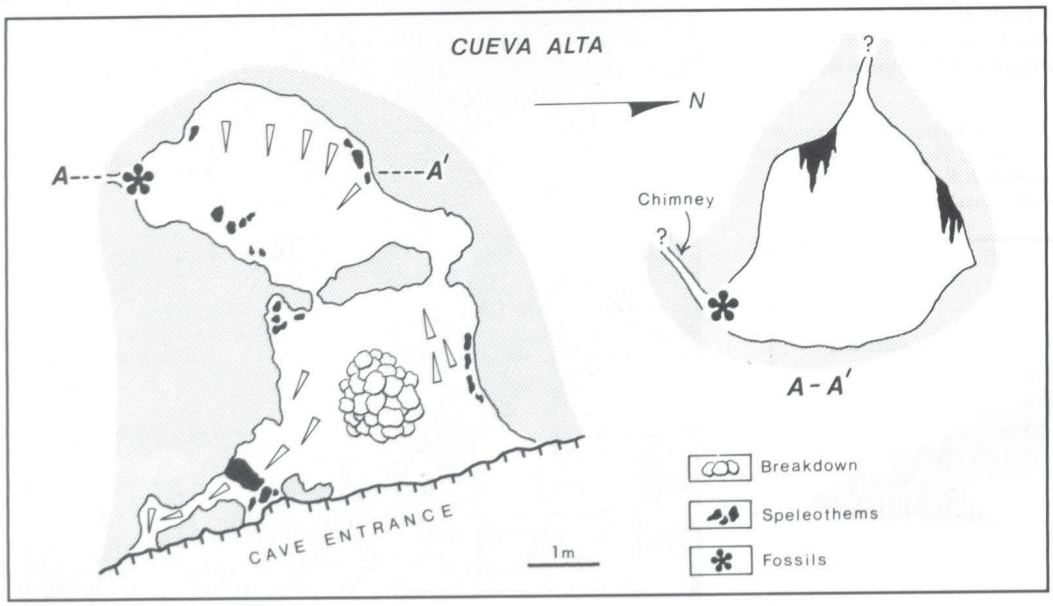


Figure 5. Plan and section of Cueva Alta. Monkey fossils (asterisk) found in deposit infilling chimney (length unknown). It has been possible to remove deposit along approximately 2m of the chimney's length, but passageway narrowing has prevented further extraction of material.

Figure 6. View of entrance of Cueva Alta.

P. varonai strongly suggests that it could not have fallen very far. Perhaps it was brought in along one of the side passages that open into the fissure (question marks in Figure 4); these are choked with indurated brecciated deposits at present and could not be investigated.

Cueva Alta

Coordinates: as for Cueva del Mono Fósil. Altitude: 59.8 m. Length: 27 m explored.

The entrance to Cueva Alta (Figures 5, 6) is located immediately inside the western edge of the lip of the main entrance of Caverna Constantino, thus very close to but some 4 m higher that the entrance to Cueva del Mono Fósil (and 15 m higher than the present level of Río Constantino). Whether it opens into the latter is not known. The forepart of the cave consists of a small balcony that continues on into a small chamber, deepy filled with sediments and ending blindly 5 m horizontally further on. The way on consists of vertical shafts that pass upward from the chamber roof, some of which have been ascended for a few tens of metres.

While exploring the entrance to this cave in March of 1990, GEPB members encountered several postcranial elements at shallow depth. Some of these proved to be primate, and, accordingly, when work in Cueva del Mono Fósil was completed in the July expedition of the same year, our team moved to Cueva Alta. It soon became evident that the material recovered in March had washed out of a narrow, chimneylike fissure located in the rear of the entrance chamber (Figure 5), because the slightly indurated sediment in this chimney was replete with isolated teeth of the monkey as well as an assortment of other vertebrate remains. No other fossiliferous areas were found then or later within this cave. The fissure fill is a chaotic clay and gravel conglomerate with no detectable stratification, and it is likely that it has been secondarily deposited, together with the fossils it contains, from some higher position in the cave.

Sediment was exposed only at the mouth of the chimney, but with hammer and chisel we were able to remove a fair quantity for dry-screening. Approximately 70 primate fossils — mostly isolated teeth — were recovered from screening operations. Although a few in number, these remains are important because teeth are particularly critical for systematic assessments. In July of 1991 we returned to Cueva Alta, hoping to remove additional matrix from the chimney with better tools. However, it was found that the chimney rapidly narrowed, and in all only 11 more primate teeth and a few long bone fragments were recovered.

One of the interesting things about the isolated monkey teeth from Cueva Alta is that nearly all of them have been worn to a high polish. Although it is conceivable that such a polish might be imparted to fossils in a turbulent pool filled with a very fine-grained sediment, it is more likely that the fossils suffered wear as a result of passing through a carnivore's gut. The likely culprit is

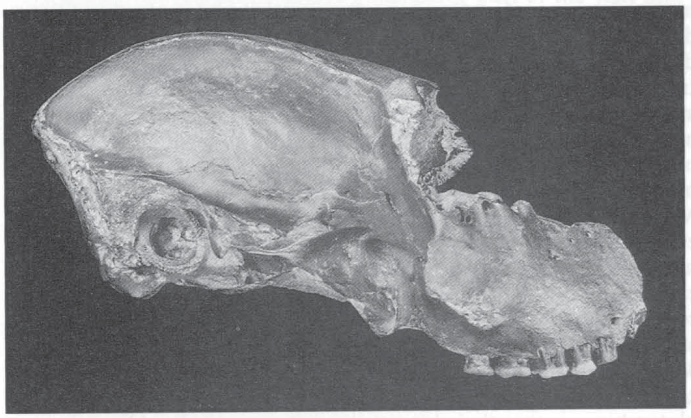


Figure 7. Holotype of Paralouatta varonai (Museo Nacional de Historia Natural 90-25), lateral view.

Crocodylus, remains of which have been found in Cueva del Mono Fósil, although it should be noted that these caves have also yielded remains of two of the enormous extinct owls that lived in Cuba during the Quaternary (Table 1; Arredondo, 1972, 1976).

Analysis of coarse fractions from sediments in which the vertebrate fossils were contained reveals that they consist mostly of quartz grains and modules composed of iron hydroxide (SiO_2: Cueva del Mono Fósil, 70-80%; Cueva Alta, 60%). Identification of quartz was confirmed by X-ray diffraction. The high loads of quartz in the sediments presumably originate from sandstones of the San Cayetano Fm, and not from the limestones of Sierra de Galeras per se. If the quartz was brought in by rivers, their beds must have stood at higher levels the current bed of Río Constantino. This, along with other indications that the high galleries of Caverna Constantino were cut by river action, implies that this cave system is relatively old.

DISCUSSION

Considered in light of other West Indian fossil monkey sites, the *Paralouatta* caves have been quite productive. At most of these other sites, only one or two bones or teeth attributable to primates have been recovered, which in some instances has severely complicated systematic interpretation (Ford, 1990; MacPhee and Fleagle, 1991). Although only a single skull of *Paralouatta* has been found so far, the total sample for this taxon is already several times better than for any other endemic Caribbean monkey.

Paralouatta is currently interpreted as a relative of *Alouatta,* the living howler monkey of South and Central America (Rivero and Arredondo, 1991). As such it is the first member of its particular clade (tribe Alouattini) to be identified in the West Indies; other finds on other islands have been variously linked to marmosets (Callitrichidae), titis (*Callicebus*), cebines (Cebinae) and spider

Table 1. Combined Faunal List for Cueva del Mono Fósil and Cueva Alta (We gratefully acknowledge the assistance of Oscar Arredondo in compiling this list.

Class Reptilia		
Order Testudines	Family Testudinae	*Geochelone cubensis*
Order Squamata	Family Iguanidae	*Cyclura* sp.
Order Serpentes	Family Boidae	unidentified material
Order Crocdylia	Family Crocodylidae	*Crocodylus* cf. *rhombifer*
Class Aves		
Order Strigiformes	Family Tytonidae	*Tyto riveroi*
	Family Strigidae	undescribed species
Class Mammalia		
Order Insectivora	Family Nesophontidae	*Nesophontes* sp.
	Family Solenodontidae	*Solenodon* cf. *cubanus*
Order Primates	Subfamily Atelinae	
	Tribe Alouattini	*Paralouatta varonai*
Order Edentata	Family Megalonychidae	*Neocnus* cf. *gliriformes*
		N. major
		Miocnus cf. *antillensis*
		Mesocnus cf. *torrei*
		Megalocnus rodens
		Meg. intermedius
		undescribed species
Order Rodentia	Family Capromyidae	*Campromys pilorides*
		Capromys sp.
	Family Echimyidae	*Boromys offella*
		B. torrei

monkeys (Atelini). The only other confirmed endemic primate from Cuba is the species originally named *Montaneia anthropomorpha)* (Ameghino, 1910), from very incomplete material recovered at Cueva (or Boca) del Purial in the Cordillera de Escambray in south-central Cuba (Figure 1). A much less distinctive form than *P. varonai,* the Cuban form has recently been transferred to the living spider monkey genus *Ateles* (as *anthropomorhus;* Arredondo and Varona, 1983). Although howler monkeys and spider monkeys are generally considered to be each others closest relatives (Kay, 1990), their lineages split early: monkeys of uncontestably alouattin aspect are known from the Miocene of Colombia (Kay *et al.,* 1987). Although there is no evidence bearing on the time at which the ancestors of the Cuban monkey colonized the island, terrestrial environments clearly existed on the proto-Cuban archipelago in the Eocene, and in central Cuba land vertebrates and plants have been identified in terrestrial facies of Early Miocene age (Iturralde-Vinent, 1984; MacPhee *et al.,* in press). At this stage of knowledge, the most concrete inference that can be made about the West Indian platyrrhines is that their known diversity practically demands the conclusion that several different initiators made the trip (MacPhee and Fleagle, 1991).

Most extant species of platyrrhines have rather large geographical distributions. Accordingly, it is puzzling that remains of *Paralouatta* have not turned up at any of the rich Quaternary sites in western and central Cuba (cf. Acevado and Arredondo, 1982). One possibility is that the fossils from Cueva del Mono Fósil and Cueva Alta are older than those known from elsewhere on the island. This argument would appear to be hard to defend, however, because with the exception of undescribed sloth and owl remains from Cueva del Mono Fósil (O. Arredondo, pers. comm.) that may represent new species, the faunal list for the monkey caves is exclusively composed of known taxa, some of which appear to have died out very recently indeed (e.g., *Nesophontes).* An alternative possibility is that the restricted distribution of *Paralouatta* was conditioned by environmental factors. The phytogeography of western Cuba indicates that this part of the island is markedly distinct in ecological character (Borhidi, 1985), but even so it is difficult to believe that an animal like *Paralouatta* should have been limited to one part of Cuba while other Quaternary taxa (save for the highly oversplit sloths) shows no such areal restriction.

Although it is reasonbly certain that *Paralouatta* was a "Quaternary" monkey, it is not yet possible to estimate when it finally became extinct (and probably will not be until several additional localities are discovered). Associated sloth bones from Cueva del Mono Fósil turned out to be too low in organic material for conventional 14C dating (M. Tamers, Beta Analytical, pers. comm.). Lack of adequate collagen and allied proteins in bone samples may be an indication of significant age, but much younger bones can yield the same analytical result as a consequence of diagenesis and deterioration. Future prospecting efforts in the monkey caves of the Sierra de Galeras will be aimed at finding good bone-calcite associations for uranium-thorium disequilibrium dating, a technique which has a much wider effective temporal range than does 14C and has proven invaluable for interpreating the age of other cave contexts in the West Indies (cf. MacPhee *et al.,* 1989).

ACKNOWLEDGEMENTS

We are extremely grateful to the members of the Grupo Espeleológico "Pedro Borrás" of the Sociedad Espeleológica de Cuba for their willingness to share their important finds and their great enthusiasm in undertaking paleontological prospecting at the cave sites described above. We also thank the Comite Espeleológico de Pinar del Río, Museo Municipal de Viñales, Museo Nacional de Historia Natural de Cuba, Marcos Portales, and Roberto Gutiérrez Domnech for various forms of logistical support during our expeditions. Manuel Iturralde-Vinent, Gilberto Silva Taboada, Oscar Arredondo, and Manuel Rivero de la Calle provided us with valuable scientific advice, Marta Calvache and Rene Rodriguez Horta helped with translations and the preparation of the manuscript version of this paper, and Francisco Salgado Alonso produced drafts of the surveys. Ing. Antonio Obregón Santoyo, C.Sc., Ing. Juan Elio González, C.Sc., and Lic. Alina Fundora and Gabriel Guerra Conde of the Instituto de Suelos of MINAG helped with soil analyses. Lorraine Meeker drew the final versions of the cave surveys and assembled the remaining figures. To these and the many other people who have helped us in Cuba and the USA, our warmest thanks.

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E. Jaimez Salgado,
Instituto de Suelos, Antiqua Carretera de Vento,
km. 8 1/2 Capdevila, Boyeros,
Ciudad de La Habana, Cuba.

D. Gutierrez Calvache,
Instituto Nacional de Recursos Hidraulicos,
Direccion Provincial, Calle 2 No. 259,
Ciudad de La Habana, Cuba.

R. D. E. MacPhee and G. C. Gould,
American Museum of Natural History,
Central Park West at 79th Street,
New York,
NY 10024, USA.

CAVE SCIENCE Vol. 19, No. 1, April 1992
Transactions of the British Cave Research Association

B.C.R.A. Cave Science Symposium, 1991

Abstract of papers presented at the meeting.

University of Leeds, November 1991.

HYDROLOGY AND GEOMORPHOLOGY OF THE MARBLE ARCH KARST, CO. FERMANAGH

John Gunn and Christine Hunting, Limestone Research Group, Manchester Polytechnic

The Marble Arch karst is situated on the northern flank of Cuilcagh mountain some 15 km south-west of Enniskillen in County Fermanagh, Northern Ireland. It is one of the north-west Ireland plateau karsts and contains some of the most spectacular limestone scenery in the British Isles. The summit (677 m) and upper slopes of Cuilcagh Mountain are composed of sandstones and shales overlain by glacial drift and large areas of blanket peat bog. In addition to being of considerable ecological interest some areas of the bog display spectacular pseudokarst landscapes with complex networks of pipes and collapses. The sandstones and shales are underlain by limestones of Tournaisian-Visean age which crop out in a 2-8 km wide belt around the mountain.

Three large rivers, the Sruh Croppa, the Owenbream and the Aghinrawn which have their headwaters on the sandstones and shales sink at various distances after crossing onto the limestones. The lowest sink on the Sruh Croppa is at Cats Hole but under normal conditions the river sinks in its bed 250-500 m upstream. The Owenbream normally sinks at the end of the spectacular Monastir Gorge although under summer low flows the sink point migrates upstream by some 100 m. The Aghinrawn also has a spectacular stream sink at Pollasumera but during the summer the bed may be dry for up to 1900 m upstream. It has long been known that sinking water from the Sruh Croppa and Owenbream re-appears in the Grand Gallery of Marble Arch Cave and that water from the Pollasumera sink re-appears in the Skreen Hill Passage of the same cave. Gunn (1982) undertook a series of water tracing experiments in the area which went some way towards clarifying the boundaries of the neighbouring catchments but the area draining to the March Arch Cave has never been adequately defined.

Part of the Marble Arch Cave System was opened as a show cave by Fermanagh District Council in 1985. Since 1989 there has been a perceived increase in the magnitude and frequency of flash floods within the system and these have caused particular problems at the 'Moses Walk' due to the constricted nature of the passage at this point. This has lead to concern over the safety of both visitors and guides within the cave. Fermanagh District Council have commissioned the Limestone Research Group to undertake hydrological investigations in the catchment of the caves and this paper covers part of these investigations.

TRACING OF WATER FLOW IN THE UNSATURATED ZONE ABOVE WHITE SCAR CAVE

Simon Bottrell, University of Leeds.
Jim Atkinson, University of East Anglia

The results of a series of both qualitative and quantitative dye traces in the unsaturated zone of the Carboniferous Limestone in Chapel-le-Dale, Yorkshire are presented. Dye was injected at a number of surface sites, generally fissures, below the soil horizon, and traced to a number of percolation inlets in the streamway of White Scar Cave.

The traces show a complex spatial pattern of water movement in the unsaturated zone. Distinct catchments for individual inlets cannot be defined and catchment areas overlap. The extent of lateral dispersion is large and increases during major flood events.

Quantitative dye traces show that water in the unsaturated zone behaves in fashion which can be characterized by a 'mixing-tank' model. Decay of dye concentration is approximately exponential, but dye is released from storage during rainfall events. Characteristic decay constants (equivalent to the ratio of flow rate to storage volume) range from 0.3 for initial throughflow down to 0.015. A longer residence time component has also been identified, as dye injected in September 1983 was still released periodically from storage up to December 1989.

PANT-Y-LLYN LAKE, A WELSH TURLOUGH

Paul Hardwick and John Gunn, Limestone Research Group, Manchester Polytechnic.

Turloughs are seasonal or 'ephemeral' lakes which are found in depressions in areas underlain by limestone. The lakes receive inputs of water from underground, usually during autumn to spring, and drain during the summer either via swallow holes or via estavelles (orifices which have a dual function, either discharging water as a spring or accepting water as a sink depending on groundwater conditions).

Until recently the only known turloughs in the British Isles were those described by Coxon (1987, a,b) on the Carboniferous Limestone in Ireland. However, the authors' attention was recently drawn to an ephemeral lake at Pant-y-Llyn near Llandybie in Dyfed which appeared to meet several of the accepted hydrological criteria for turlough status (Coxon, 1986). These criteria are:

1. Seasonal flooding to a depth of >0.5m for part of the year and a dry floor (apart from residual pools) for part of the year.
2. Recharge via ephemeral springs or estavelles.
3. Emptying to groundwater (lack of a natural surface outlet) via swallets or estavelles.

Subsequent research has confirmed the identification of the landform both as a turlough and as the only known example of this landform on the British mainland (Hardwick & Gunn, 1991).

In 1989, the boundary of the Carmel Woods SSSI, an area of Ancient Woodland, was extended to include the turlough and its immediate surroundings, although this was for biological rather than geomorphological reasons. A recent planning application to re-open and extend an adjacent limestone quarry (McAlpines Ltd., 1991) is likely to impact upon the hydrology of the turlough, leading to the cessation of seasonal flooding and to permanent drainage. This would result in the destruction of the scientific interest of the site. In October 1991, the Welsh Office called in the planning application and the authors are currently undertaking further hydrological investigations in anticipation of a Public Local Inquiry to determine the future of the site.

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DYE TRACING IN THE BEACON HILL PERICLINE, EAST MENDIPS

Peter Smart, Steven Hobbs and Alan Edwards, Dept. of Geography, Bristol University.

Repeat tracer tests using fluorescent dyes were made on four swallets in the Carboniferous Limestone Seven Springs catchment, East Mendip. Downhead Swallet feeds a predominantly vadose conduit, with a major distributory which underflows the Seven Spring but does not feed Holwell Spring. Dairyhouse Slocker is tributary to the conduit below this distributory, but the Bottlehead conduit is independent and feeds only the Main Spring. Dewatering at Torr Quarry has caused a change in the function of the phreatic conduit from Heale Swallet, which previously was tributary to the main Downhead conduit. The conduit has not been directly intersected by quarrying, but diffuse leakage induced by the steepended hydraulic gradient towards the quarry captures all the flow. The Bottleneck Slocker conduit is similarly affected, with leakage being large at low flow, but insignificant at high flow. The Downhead Swallet conduit is affected least by quarry dewatering, because of its vadose nature and greater distance from the quarry. Nevertheless movement of water from the conduit into the diffuse flow zone does occur, particularly during the periods of active swallet recharge.

(Published in Proc. Univ. Bristol Spel. Soc., 1991, 19(1), 67-82).

VLF RADIO FOR UNDERGROUND COMMUNICATIONS

David Gibson, 12 Well House Drive, Leeds.

Cave Radio design has taken a practical course with only limited attention being given to the underlying theory, or indeed to the electronic principles involved. To design a better radio these areas must now be covered.

Explanations of the electromagnetic theory which appear in caving literature are, in general, incorrect. This paper provides a brief overview of the theory, with indications of areas where cave radio design would benefit from further study., Geo-physics texts contain useful material.

On a more practical note, there are many areas where a careful analysis shows that commonly held ideas of the 'right' way to design a radio are in fact wrong. This paper will discuss the following aspects of cave radio design. In terms of cost factors (such as mass and power for the transmitter, and signal/noise ratio for the receiver) the number of turns on the loop aerials is not a contributory factor, but the type of metal is important — Aluminium is twice 'as good' as copper. The dimensions of the wire are important, but it is not true, to say 'the thicker the better'. There is an ideal ratio of battery mass to antenna mass for optimum performance. It is not always true that a larger aerial will receive a better signal. Q-factor is not critically important, and so-called Q-multipliers are of dubious use. Receivers benefit from a proper low-noise 'front-end'; transmitters from an efficient, matched, output amplifier.

Single-sideband modulation (SSB), often thought efficient, is not as good as double-sideband suppressed carrier with synchronous demodulation, while Frequency Modulation has no advantage over conventional A.M. By careful design it is possible to do away with much of the tuning and setting up procedures required in SSB systems, whilst allowing a much more versatile system than many that now exist.

GEOGRAPHICAL INFORMATION SYSTEMS IN KARST STUDIES

Christine Hunting, John Gunn and Sarah Cornelius, Limestone Research Group, Manchester Polytechnic.

The management of karstified limestone terrains poses particular problems since the spatial boundaries of the systems are often ill defined. Such terrain generally contains cave systems together with a tributary system of inaccessible conduits, fissures and fractures. Recharge to the karst hydrological system frequently comprises allogenic stream-sinks and both diffuse and concentrated autogenic recharge. In such a system effective environmental managment requires consideration of both the allogenic and autogenic catchments. Of necessity this will involve a large amount of spatial and temporal data the integration of which poses major problems. Geographical Information Systems (GIS) may provide an answer to these problems since they have the ability to accept, process and present data; to update and modify data and to combine datasets originating from different sources. They also have the potential to answer "what if" questions and it may also be possible to incorporate predictive/forecasting models into a GIS.

The potential for GIS in the management of karstified limestone drainage basins is being examined in a research project on Cuilcagh Mountain, County Fermanagh, Northern Ireland. The project has been jointly commissioned by Fermanagh District Council who require a Management Plan for a proposed Natural History Park on the mountain and the Department of the Environment for Northern Ireland (Countryside and Wildlife Branch) who have a more general interest in the value of GIS in the storage and analysis of environmental data. The project commenced in May 1991 and will run for three years. This paper will present the background to study and outline some of the issues which are to be addressed.

ACID SULPHATE REACTION AND THE GENERATION OF POROSITY IN THE LINCOLNSHIRE LIMESTONE AQUIFER

S. J. Moncaster and S. H. Bottrell, Dept. of Earth Sciences, University of Leeds.

The generation of acid sulphate by pyrite oxidation is traced in the groundwaters of the Lincolnshire Limestone aquifer by use of stable isotope signatures. The generation of the sulphate is shown to be intimately linked with the cyclical nature of the hydrogeological processes which characterise the aquifer and thus controlled by the annual movement of a front of oxidised water along the boundary between the limestone and the confining clays of the Upper Estuarine Series. A by-product of the oxidation reaction is the generation of acidic hydrogen ions and a model is proposed where these are shown to react with the limestone rock matrix, dissolving the calcite and resulting in the development of a significant flow zone along the base of the confining Upper Estuarine clays.

RADON PRODUCTIVITY IN PEAK DISTRICT CAVES

Roy Hyland, John Gunn and Stan Fletcher, Manchester Polytechnic,
Simon Bottrell, Leeds University.

To date the primary focus of cave radon research has been investigation of the spatial and temporal variations in atmospheric concentrations. This paper aims to identify the sources and processes by which radon enters the atmosphere and to explain some of the variations in observed atmospheric concentrations in Peak District caves.

Cave radon (radon 222) is primarily derived from the uranium 238 decay chain. Other radon isotopes from the uranium 235 and thorium 232 decay series are less important environmentally and will not be directly covered in this paper.

Radon is an inert radioactive gas and is therefore able to move from production sites (within minerals) to the cave atmosphere. The principal factors that control the amount of release are related to emanation, the mechanism by which radon moves from production sites on mineral grains to the pore spaces, and exhalation, the subsequent movement from the pores to the atmosphere.

There are three primary sources of radon within karst environments: water; the host limestone rock; and sediments. The relative importance of each of these to the subsequent atmospheric radon content will be considered.

CAVE SCIENCE Vol. 19, No. 1, April 1992
Transactions of the British Cave Research Association

Forum

Readers are invited to offer review articles, shorter scientific notes, comments on previously published papers and discussions of general interest for publication in the Forum section of Cave Science.

ERRATUM — PHREATIC PASSAGES

A significant printing error crept into the Forum item entitled "Water stratification in active phreatic passages" by J. N. Cordingley on page 159 of Cave Science volume 18 number 3. Seven lines up from the foot of the first column, "stopping" should read "stoping", referring to the upward enlargement of the cave passage roof. Editorial apologies to John Cordingley and to confused readers.

KARST AND CAVES IN CHINA: SOME BOOKS TO READ

Tony Waltham

The enormous area of limestone in China makes it the most important karst country in the world. Not only is China an area of magnificent potential for cave exploration, but it also has the extreme karst landform in the fenglin tower karst of Guangxi, besides having spectacular examples of nearly every other conceivable karst feature (it only lacks in any large areas of glaciokarst). Any modern review of karst or cave geomorphology must take full account of the landforms in China to be able to consider itself anywhere near complete.

A scatter of cave exploration expeditions, led by the British and since followed by the French, Italians, Americans and Belgians, have produced reports which give some insight into the splendours of the Chinese caves. The surface karst has not received the treatment that it warrants. There is, however, a mass of Chinese literature, some of which is now becoming more accessible through translations into English. Both karst and caves are described and illustrated in a handful of books now available from China, and Yuan Daoxian has produced the first English language textbook on the the Chinese karst.

Karst of China: Yuan Daoxian, 1991

This book is presented as a geomorphology text providing a comprehensive review of karst and caves in China, extensively illustrated with maps and diagrams, but short on photographs. It does cover all the main aspects, throughout the whole of China. Its approach is systematic, but tends to break down into a series of examples, regional reviews and case studies; so it is hard work for the reader to gain any real understanding of the complex geomorphological relationships between the multitudes of karst landforms.

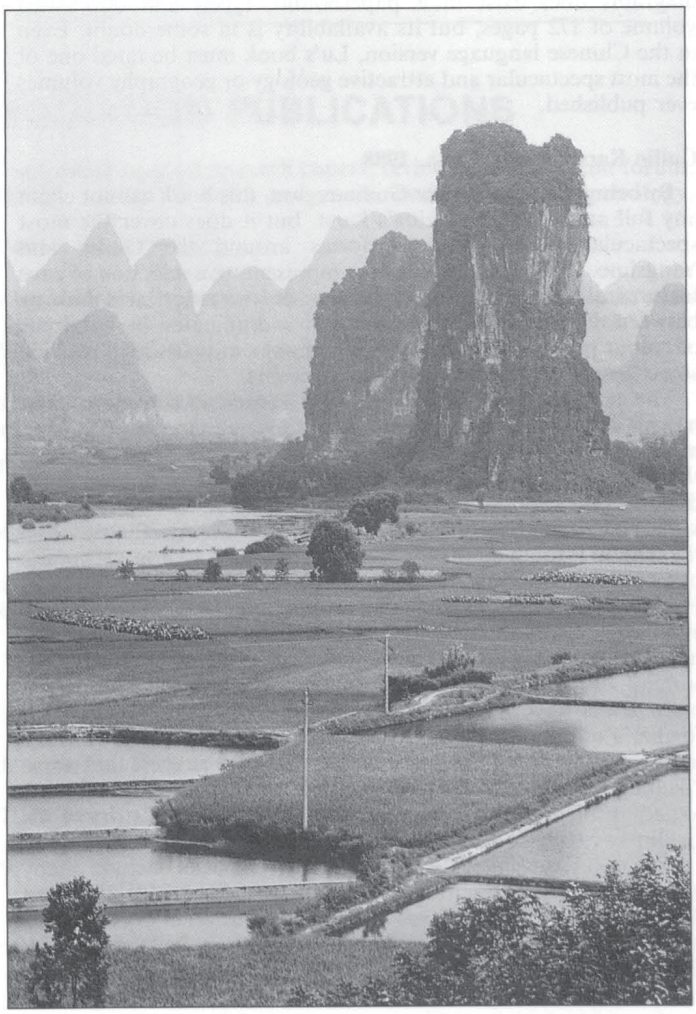
The third chapter opens with a section on the surface landforms of the tropical karst — so important because this is the ultimate in karst landform development. Yuan refers to the landforms collectively as tower karst, dividing this into fengcong (clustered cones) and fenglin (isolated towers on a karst plain). He describes the fenglin as existing on both the Guangxi lowlands (including the famous Guilin and Yangshuo areas) and on the central parts of the Guizhou plateau (where altitude is high but relief is low). He identifies the fengcong as being dominant round the plateau edges (where rejuvenation is more active). Cone karst is not distinguished as a separate geomorphological type; he describes the hemispherical Sewu type of cones as a variety formed on dolomitic limestones, and he includes the Guizhou type of pointed cones in his fengcong.

This division of landforms merely into fengcong cones and fenglin towers does seem a little inadequate. Many of the hills in the Guangxi fengcong peak-cluster karst do have steeper profiles, more like the fenglin towers and less like the fengcong cones of Guizhou, and the contrast is not genetically explained. Similarly, the isolated towers of the Yangshuo fenglin are clearly different from the isolated cones on the Guizhou plateau which Yuan still refers to as fenglin. The division also takes no account of the distinctive cone karst landforms of Java and Jamaica, so cannot claim to be applicable worldwide. Yuan does see the evolution of fengcong into fenglin, and he recognises the influence of tectonic uplift, but a complete geomorphological explanation demands more than he offers.

The chapter on karst types continues with variable coverage. The Chinese stone forests (pinnacle karst) are described in terms of evolving through subsoil and then subaerial phases, though on a timescale which may start back in the Tertiary or only in the Pleistocene. There is a long section on the minimal karst on the Tibetan plateau (long in comparison to the treatment of the Guangxi and Guizhou karsts). Yuan suggests that most Tibetan karst developed in the warmer interglacial stages of the Pleistocene; he rather dismisses the notion of fossil Tertiary karst (formed before the Tibetan and Himalayan uplift) as the landforms so little resemble those Guizhou and Guangxi, though there are huge limestone outcrops in Tibet, many not yet fully examined. Notable in a different context is the Huanglong valley in Sichuan with 3400 gour pools down a 15km long line of travertine terraces (for some beautiful photos of this site, see Lu, below).

Caves have their own chapter, with the geomorphology described differing little from Western concepts. There is some tabulated data, on 36 cave systems over 3km long, on 11 cave chambers larger than 14,000 sq.m., and on 28 underground rivers with dry season flows in excess of 1 cumec.

Aspects of applied and environmental geomorphology have their own chapters, and Yuan reviews the Chinese situations concerning groundwater resources, reservoir leakages, ground collapses, agriculture, mineral and oil resources in karst, with an extra section on the role and impact of tourism to limestone caves, gorges and stone forests. There are few surprising conclusions and some of the concepts are convoluted or lost, but there are many interesting examples.



Fenglin tower karst near Yangshuo, Guangxi. (Photo: T. Waltham).

Overall, Yuan's book is an invaluable statement on the karst and caves of China, particularly with respect to the regional distribution of the various landforms and geomorphological types. It significantly increases the data available to Westerners, and consequently is essential reading for anyone studying karst geomorphology.

Karst in China: Lu Yaoru, 1986

Inevitably, in the context of Chinese karst, reference must be made to this phenomenal tome. Essentially it is a coffee table book (nearly large enough to be a coffee table) with nearly 500 colour photographs. Lu was the author of the original 'Karst in China' book, which impressed everyone so much back in 1976 when it brought to the West the first really stunning photographs of China's caves and tower karst (though his name never made the credits in those days of Maoist anonymity). His enthusiasm for karst naturally led him to expand the original book in this more comprehensive volume.

The impact of that first book could perhaps never be repeated, but Lu's 1986 volume is still an incredible production. It covers the whole range of karst subjects, with something of a bias towards the applied aspects. Karst landforms and caves are well featured, but there are also large sections on the geology, mineralogy, hydrology and engineering aspects of limestone. Many of the photographs are visually splendid, and many others are remarkable for the karst features that they illustrate, though some weaker photographs have been included in order to complete the coverage. The book certainly is a very complete systematic record of China's karst. However the text is limited to little more than a series of picture captions, some longer than others, with diagrams and maps providing more links and co-ordination. In such a format, there can be no comprehensive discussion or treatment of geomorphological processes, so the reader is left to make his own deductions from his observations of the photographs.

The book is currently only available with a Chinese text — though that is a minimal distraction in what is essentially a book of photographs. Lu intended that is should appear with a second version in the English language, but despite his efforts, both Chinese and Western publishers have been daunted by the size of the task. An English translation of the text, captions and diagrams does exist in a paperbound, typed and duplicated volume of 172 pages, but its availability is in some doubt. Even in the Chinese language version, Lu's book must be rated one of the most spectacular and attractive geology or geography volumes ever published.

Guilin Karst: Zhu Xuewen, 1988

By being restricted to the Guilin region, this book cannot claim any full assessment of China's karst, but it does cover the most spectacular tower karst landforms around the Guilin and Yangshuo. It also illustrates a very representative selection of cave features, all from within the same area. Its presentation is midway between the Yuan and Lu volumes; it is dominated by hundreds of colour photographs, but also has chunks of text which provide some geomorphological data and concepts.

The text includes some interesting comment on tower karst morphology. Zhu recognises that the clustered fengcong hills are more conical in profile that the isolated fenglin towers, and also that the really rounded cones are mostly formed in dolomite. He describes the evolution of fengcong into fenglin, leaving fengcong karst mainly in areas of higher relief and left on interfluves, while the fenglin is more on the lowland and marginal to non-carbonate outcrops where allogenic water accelerates erosional evolution. He notes the importance of undercutting and foot caves in tower evolution, opposed by scree accumulation which degrades the hills to cones. Photographs show extensive concordance of summit levels, in some places at more than one level, yet multiple plain levels have not been found, and Zhu notes the need for further study in this area. He also recognises the role of tectonic uplift (greater in the fengcong areas), but also suggest that some "islands" of clustered fengcong, within the fenglin plains, are due to geological controls. Like Yuan, Zhu recognises a history of the Guilin karst reaching back into the Cretaceous.

The notes on caves and their calcite deposits include many interesting features, including comment on cave shields, the lotus flower vareity of gour deposits, and the formation of crystal cones by the sinking of calcite cave ice. Cave maps include one of the chamber, 240m x 90m, in Luti Dong.

Perhaps the strongest feature of the book is that it does provide the best record of the Chinese tower karst; the text is short but the many photographs range from the spectacular to the misty and artistic, and inlude numerous oblique and vertical air views.

Underground Worlds: Jin and Wang, 1984

This is purely a photographic book with no pretensions towards any geomorphological study. It is a very spectacular collection of, mainly large, colour cave photographs of very high quality. It only coves Guizhou province, but it does therefore include the enormous and liberally decorated Daji Dong (surely one of the world's great show caves). Calcite formations dominate the photographs; they include the 39m high world record stalagmite pillar in Daji Dong, and overall encompasses an amazing variety of crystal and flowstone cave decorations. They more than compensate for any lack of roaring cave streamways or action cave shots — the coverage feeds the Chinese tourist concept of decorated caves. Captions are in Chinese and English and many lack a location of the subject — perhaps deemed irrelevant in a book relying on visual impact.

Understanding China's Karst

All four of these books provide wonderful records of China's quite remarkable karst and caves; three of them are photographic (in colour) and one is basically a textbook; one of them just illustrates the caves, while the other three cover the full breadth of surface and underground karst landforms. Any follower of caves or karst would cherish each or all of these books.

The ultimate questions in the context of China's karst are just how did the spectacular fenglin towers of Guangxi evolve, how do the towers relate to other karst landforms, and why are they developed only in southern China on quite such a scale. A review must ask how well a book answers these questions.

To date, none of the geomorphology books published in the West gives any concise and reasoned answer to those questions. Almost the same applies to these books from China's own students of karst. Yuan and Zhu both address the tower evolution problem, but each only paints part of the picture and leaves some aspects not considered. Furthermore both books, and Lu's, suffer from problems of language; the use of English language scientific words by the Chinese authors is not always how a native English speaker would use them; subtleties are lost in the translation, and reading the texts becomes rather hard work. Valuable ideas are easily lost in convoluted arguments.

So none of these books really gets into the big question concerning the towers. For an answer, the western reader is perhaps best directed to either the excellent paper by Zhang Zhigan (1980) or the very clever diagramatic explanation constructed by Pete Smart (1986). Both of these explain tower evolution in terms of both erosion rates and tectonic uplift rates; both present a conceivable explanation of the landforms, though both recognise that there are still many aspects to understand. Short of protracted fieldwork in China itself, the Western student of karst can best gain a deeper understanding of the geomorphological problems by reading these splendid books by Yuan, Lu and Zhu.

None of these books is easily obtainable in Britain. Tony Oldham has some in stock and is trying to obtain more. Hopefully the situation will improve, but until then, snap them up when you see them.

REFERENCES

Jin Deming and Wang Zhaoyang, 1984. Underground worlds, Guizhou. Guizhou People's Publishing House. (128 pages, 140 large cave photos).

Lu Yaoru, 1986. Karst in China — landscapes, types, rules. Geological Publishing House, Beijing. (288 pages large format, 340 karst photos, 150 cave photos, 85 maps and diagrams).

Smart, Peter, Waltham, Tony, Yang Mingde and Zhang Ying-jun, 1986. Karst geomorphology of western Guizhou, China. Cave Science 13, 89-103.

Yuan Daoxian, 1991. Karst of China. Geological Publishing House, Beijing. (224 pages, 48 small photos, 151 maps and diagrams).

Zhang Zhigan, 1980. Karst types in China. Geo Journal 4, 541-570.

Zhu Xuewen, 1988. Guilin karst. Shanghai Scientific and Technical Publishers. (188 pages, 130 karst photos, 210 cave photos, 37 maps and diagrams).

A. C. Waltham,
Civil Engineering Department,
Nottingham Polytechnic NG1 4BU.

B.C.R.A. Research Funds and Grants

THE JEFF JEFFERSON RESEARCH FUND

The British Cave Research Association has established the Jeff Jefferson Research Fund to promote research into all aspects of speleology in Britain and abroad. Initially, a total of £500 per year will be made available. The aims of the scheme are primarily:

a) To assist in the purchase of consumable items such as water-tracing dyes, sample holders or chemical reagents without which it would be impossible to carry out or complete a research project.
b) To provide funds for travel in association with fieldwork or to visit laboratories which could provide essential facilities.
c) To provide financial support for the preparation of scientific reports. This could cover, for example, the costs of photographic processing, cartographic materials or computing time.
d) To stimulate new research which the BCRA Research Committee considers could contribute significantly to emerging areas of speleology.

The award scheme will not support the salaries of the research worker(s) or assistants, attendance at conferences in Britain or abroad, nor the purchase of personal caving clothing, equipment or vehicles. The applicant(s) must be the principal investigator(s), and must be members of the BCRA in order to qualify. Grants may be made to individuals or small groups, who need not be employed in universities, polytechnics or research establishments. Information and applications for Research Awards should be made on a form available from S. A. Moore, 27 Parc Gwelfor, Dyserth, Clwyd LL18 6LN.

GHAR PARAU FOUNDATION EXPEDITION AWARDS

An award, or awards, with a maximum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Rowlands House, Summerseat, Bury, Lancs. BL9 5NF. Closing date 1st February.

SPORTS COUNCIL GRANT-AID IN SUPPORT OF CAVING EXPEDITIONS ABROAD

Grants are given annually to all types of caving expeditions going overseas from the U.K. (including cave diving), for the purpose of furthering cave exploration, survey, photography and training. Application forms and advice sheets are obtainable from the GPF Secretary, David Judson, Rowlands House, Summerseat, Bury, Lancs. BL9 5NF and must be returned to him for both GPF and Sports Council Awards not later than 1st February each year for the succeeding period, April to March.

Expedition organisers living in Wales, Scotland or Northern Ireland, or from caving clubs based in these regions should contact their own regional Sports Council directly in the first instance (N.B. the closing date for Sports Council for Wales Awards applications is 31st December).

THE E. K. TRATMAN AWARD

An annual award, currently £25, made for the most stimulating contribution towards speleological literature published within the United Kingdom during the past 12 months. Suggestions are always welcome to members of the GPF Awards Committee, or its Secretary, David Judson, not later than 1st February each year.

BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

CAVE SCIENCE — published three times annually, a scientific journal comprising original research papers, reviews and discussion forum, on all aspects of speleological investigation, geology and geomorphology related to karst and caves, archaeology, biospeleology, exploration and expedition reports.
Editor: Dr. Trevor D. Ford, 21 Elizabeth Drive, Oadby, Leicester LE2 4RD. (0533-715265).

CAVES & CAVING — quarterly news magazine of current events in caving, with brief reports of latest explorations and expeditions, news of new techniques and equipment, Association personalia etc.
Editor: A. Hall, 342 The Green, Eccleston, Chorley, Lancashire PR7 5TP. (0257-452763).

CAVE STUDIES SERIES — occasional series of booklets on various speleological or karst subjects.
Editor: Tony Waltham, Civil Engineering Department, Trent Polytechnic, Nottingham NG1 4BU. (0602-418418, ext. 2133).

No. 1 Caves & Karst of the Yorkshire Dales; by Tony Waltham & Martin Davies, 1987.

No. 2 An Introduction to Cave Surveying; by Bryan Ellis, 1988.

No. 3 Caves & Karst of the Peak District; by Trevor Ford & John Gunn, 1990.

CURRENT TITLES IN SPELEOLOGY — annual listings of international publications.
Editor: Ray Mansfield, Downhead Cottage, Downhead, Shepton Mallet, Somerset BA4 4LG.

CAVING PRACTICE AND EQUIPMENT, edited by David Judson, 1984.

LIMESTONES AND CAVES OF NORTHWEST ENGLAND, edited by A. C. Waltham, 1974. (out of print)

LIMESTONES AND CAVES OF THE MENDIP HILLS, edited by D. I. Smith, 1975. (out of print)

LIMESTONES AND CAVES OF THE PEAK DISTRICT, edited by T. D. Ford, 1977. (out of print)

LIMESTONES AND CAVES OF WALES, edited by T. D. Ford, 1989.

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