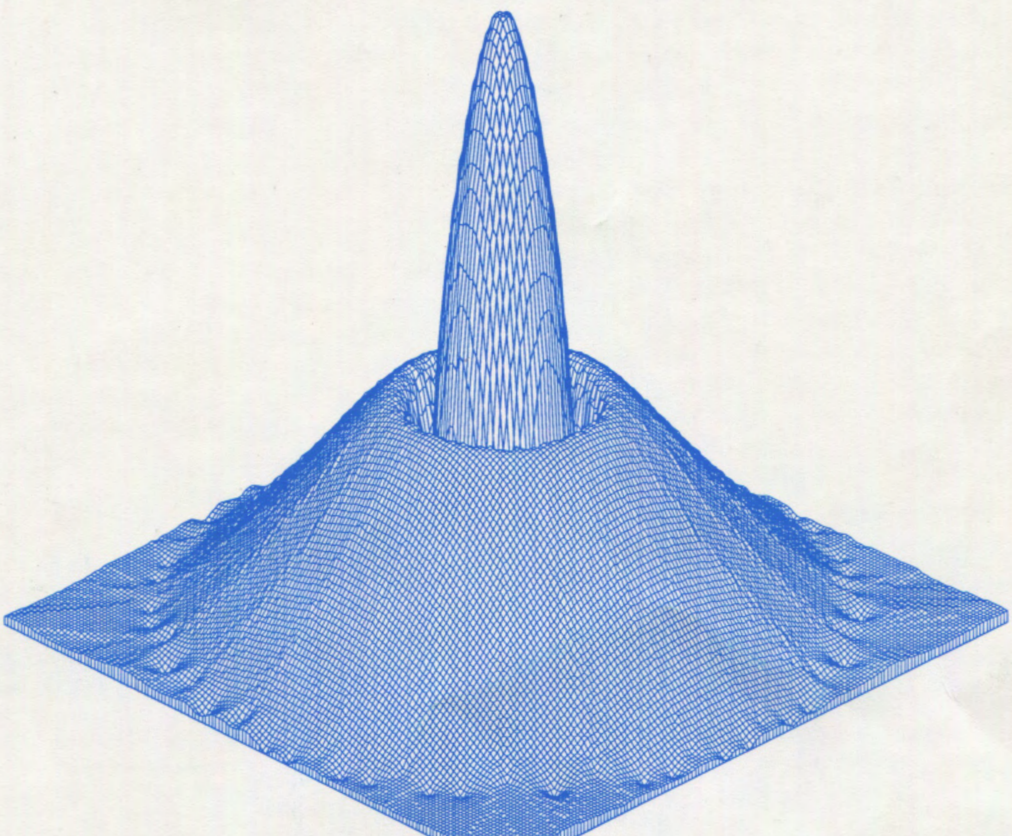
THE NSS BULLETIN

Journal of Caves and Karst Studies



Volume 53 December, 1991 Number 2

Published by

The National Speleological Society

ISSN 0146-9517

Material to be included in a given number must be received at least 90 days prior to the first of the month in which publication is desired. No submission will be accepted for publication unless and until one of the three options in our printed "Copyright Agreement" form has been selected by the author(s) and the form has been properly dated, signed, and returned to the Editor.

Discussion of papers published in *The Bulletin* is invited. Discussions should be 2000 words or less in length, with not more than 3 illustrations; they should be forwarded to the appropriate editor within 3 months of publication of the original paper.

A voluntary contribution of $25.00 per page is solicited from authors after their manuscripts have reached page-proof stage. This represents about one-quarter of the cost of publication.

A catalog of issues still in print and their cost can be obtained from our Business Office at no charge; facsimile copies of out-of-print issues can be supplied for a nominal fee.

The NSS Bulletin (ISSN 0146-9517) is published semiannually by the National Speleological Society, Inc., Cave Avenue, Huntsville, Alabama 35810. The annual subscription fee, worldwide, by surface mail, is $18 U.S. Airmail delivery outside the United States of both *The NSS NEWS* and *The NSS Bulletin* is available for an additional fee of $40 (total: $55); *The NSS Bulletin* is not available alone by airmail. POSTMASTER: send address changes to *The NSS Bulletin,* Cave Avenue, Huntsville, Alabama 35810.

Stoyles Graphic Services
Lake Mills, IA 50450

Cover: Theoretical prediction of the vertical magnetic fields on the surface due to a buried radio location transmitter. The vertical axis is logarithmic. The horizontal axes are both 1,200 feet in extent. The transmitter is located 100 feet beneath the surface. See the article by Shope, page 83.

Klimchouk, Alexander B.—Large Maze Caves in Gypsum in the Western Ukraine: Speleogenesis under Artesian Conditions: *NSS Bulletin* 53: 71-82.

LARGE MAZE CAVES IN GYPSUM IN THE WESTERN UKRAINE: SPELEOGENESIS UNDER ARTESIAN CONDITIONS

ALEXANDER B. KLIMCHOUK
Institute of Geological Sciences
Ukrainian Academy of Sciences
55-B, Tchkalov Street, Kiev-54, 252054

The problem of speleogenesis under artesian conditions is considered in this article, with special reference to the gypsum maze caves in the Western Ukraine. Previous speleogenetic interpretations for this region are critically reviewed. New evidence, models, and theoretical background are presented for multi-level artesian maze caves in platform settings. It is shown that dispersed upward recharge from an underlying aquifer is responsible for development of maze caves in the western Ukraine.

INTRODUCTION

There are many publications devoted to the unique maze caves in the Neogene (late Tertiary) gypsum strata of the Western Ukraine. Five of them are the world's largest caves in gypsum. Recently a review has been published in English (Klimchouk and Andrejchouk, 1986) concerning the geologic and hydrologic setting of gypsum karst in the region. In another work (Klimchouk, 1986), the features of the principal caves and their genesis has been discussed. The present paper elaborates further on the origin of maze caves in the region, and a new speleogenetic theory is suggested.

GEOLOGIC AND HYDROLOGIC SETTING

Only a brief description is given here of the main conditions of gypsum karst development. For details see Klimchouk and Rogozhnikov (1982), Klimchouk et al. (1985), Klimchouk and Andrejchouk (1986, 1988), and Andrejchouk (1988).

Gypsum strata of Miocene age are widespread along the southwest edge of the eastern European platform, in the transitional zone between the platform and pre-Carpathian foredeep (Fig. 1). The most important feature of the transitional zone is intense block faulting, which creates a step-like descent of the gypsum strata from the platform toward the foredeep. These features are responsible for many of the peculiarities of this karst area (Klimchouk and Andrejchouk, 1986).

The gypsum strata are 10–40 m thick. They lie on the sandy carbonate rocks of the Lower Badenian Member and are capped by a homogeneous layer of pellitic limestone. The gypsum and overlying limestone comprise the Tyrassky Formation, which in turn is overlain by shaly carbonates of the Upper Badenian Member (5–10 m) and by Lower Sarmatian clays (30–50 m, up to 100 m).

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

Today the distribution of gypsum karst processes is determined by the depth of erosional entrenchment and by the location of the gypsum. Three typical settings have been distinguished by Klimchouk and Andrejchouk (1986, 1988). In the Podol'sky area, where most of the known caves are located, the Miocene aquifer is completely drained, and downward recharge occurs through it to the underlying aquifers (Fig. 2 and 3). In the Dneister-Prut interfluvial area, near the Dneister River, water-table conditions occur in the gypsum. The Miocene aquifers remain confined in the area neighboring the foredeep, near the Prut River, except in some of the most uplifted blocks.

PREVIOUS SPELEOGENETIC INTERPRETATIONS

Some Podolian caves have been known for a long time (e.g., Verteba Cave, Kristal'naya Cave), whereas other caves were discovered during the 1960s and 1970s (e.g., Mlynky Cave, Optimisticheskaya Cave, Ozernaya Cave, Atlantida Cave, Zolushka Cave, etc.). The major caves of the area were explored systematically during this later period. Detailed cave maps and basic data about cave morphology, deposits, microclimate, etc., were produced.

These data were summarized by Dubljansky and

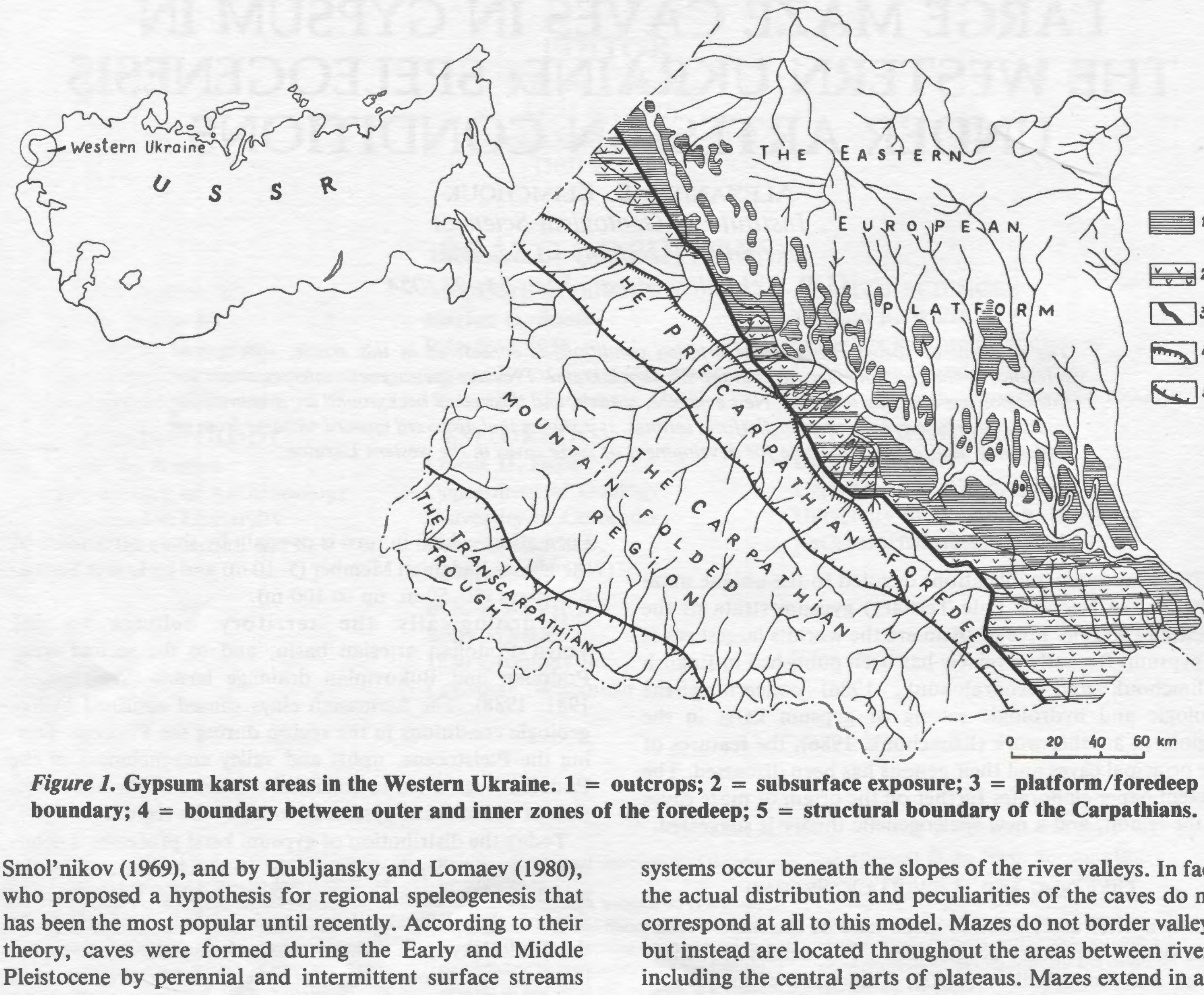


Figure 1. **Gypsum karst areas in the Western Ukraine. 1 = outcrops; 2 = subsurface exposure; 3 = platform/foredeep boundary; 4 = boundary between outer and inner zones of the foredeep; 5 = structural boundary of the Carpathians.**

Smol'nikov (1969), and by Dubljansky and Lomaev (1980), who proposed a hypothesis for regional speleogenesis that has been the most popular until recently. According to their theory, caves were formed during the Early and Middle Pleistocene by perennial and intermittent surface streams sinking into the gypsum (Fig. 4A). Development of the caves occurred under shallow-phreatic and water-table conditions. Individual streams migrating through potential cave areas were thought to have played an important role, causing underground lateral flow through the gypsum between subparallel river valleys. Multi-level caves were assumed to result from cycles of crustal uplift and stability, entrenchment of river valleys, and contemporaneous lowering of the karst water table. This idea is similar to the classic theories of speleogenesis and was widely accepted. However, many properties of the maze caves in the region contradict this idea, as is discussed below.

Until recently, the only alternative was suggested by Jakucs and Mezösi (1976). According to their interpretation, cave development occurred under vadose conditions, from swallowholes located on the plateau in multiple ranks related to entrenchment of the nearest river valley (e.g., Phases I and II in Fig. 4B). This model assumes that cave systems occur beneath the slopes of the river valleys. In fact, the actual distribution and peculiarities of the caves do not correspond at all to this model. Mazes do not border valleys, but instead are located throughout the areas between rivers, including the central parts of plateaus. Mazes extend in any direction away from nearby swallowholes, not only toward the nearest river valley. Furthermore, the model cannot explain the maze patterns.

Detailed investigation of the morphology and deposits of the principal caves in the region, combined with careful analysis of the regional geology and hydrology, made it possible to introduce a new speleogenetic model, which is described in the next section.

OLD AND NEW DATA: A NEW INTERPRETATION

Descriptions and maps of the main caves of the Western Ukraine can be found in many publications (e.g., Dubljansky and Lomaev, 1980; Dubljansky and Iljukhin, 1982; Klimchouk, 1986; Courbon and Chabert, 1986). Only the most diagnostic features are discussed below.

All the large caves of Podolia and Bukovina are mazes developed along vertical or steeply inclined fissures. A high

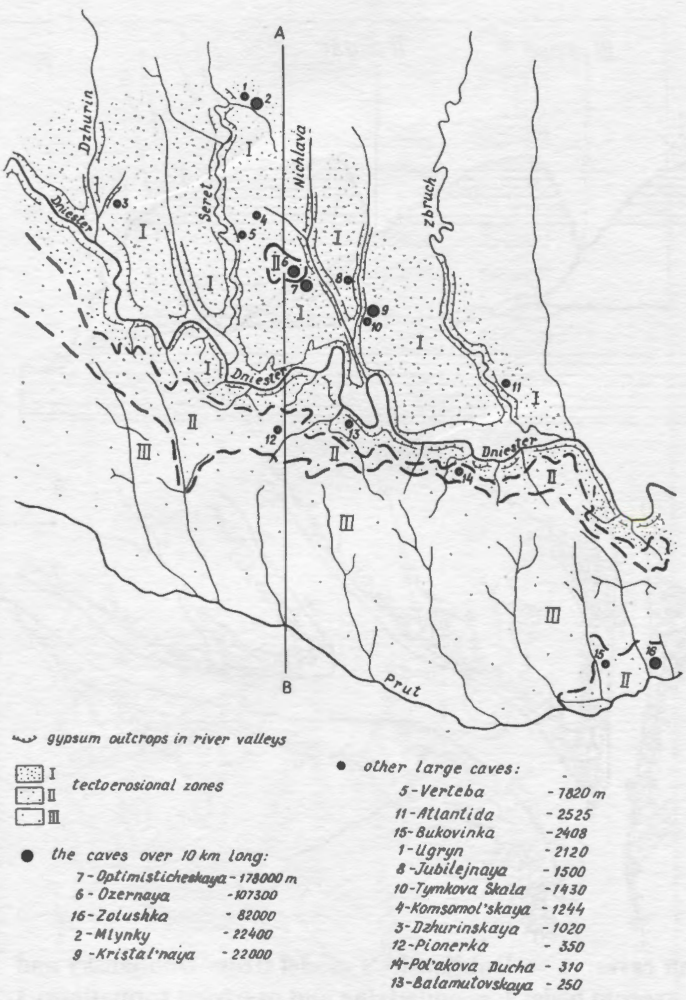


Figure 2. **Tectono-erosional zones in Podolia and Bukovina, and the location of the main caves. I = gypsum beds drained completely; II = beds with a water table; III = confined aquifer in the gypsum beds.**

frequency and nearly uniform distribution of passages in plan view is common. Clusters of passages form systems with two to four levels and occupy areas up to 1 km². Concentrated passage development occurs not only near the valleys but also in the central part of the massif. Analysis of cave morphology shows that the present entrances along the valley slopes or on the plateau are not hydrologically related to the origin of the mazes. The maze patterns show no regular trends in the shape, size or frequency of passages. These characteristics obviously contradict Dubljansky's concept of individual surficial recharge points and flow between valleys.

There is much morphologic evidence that all the large caves in the region developed under confined conditions. Analysis of Atlantida Cave (Klimchouk and Rogozhnikov, 1982) suggests that this multi-level cave system was formed by water rising from master channels at the base of the gypsum beds (Figs. 5 and 6). Zolushka Cave, in the Bukovinsky area, revealed clear evidence for upward recharge from the base of the gypsum through large shafts to a network of master channels in the upper level (Figs. 7, 8, and 9). Eventually the idea of maze-cave development in a confined aquifer was suggested for the whole region, with upward recharge into the gypsum beds from the underlying lower Badenian sandy carbonates, which form an important regional aquifer (Klimchouk, 1986).

During the last decade the author has performed morphogenetic mapping of Atlantida and Dzhurinskaya caves, and of some representative areas of large maze passages in Optimisticheskaya, Ozernaya, Zolushka, and Mlynky Caves. A large number of solutional features were recognized that indicated upward water flow into the cave systems from the underlying aquifer. The distribution and position of such features confirmed this idea. It was shown by Klimchouk

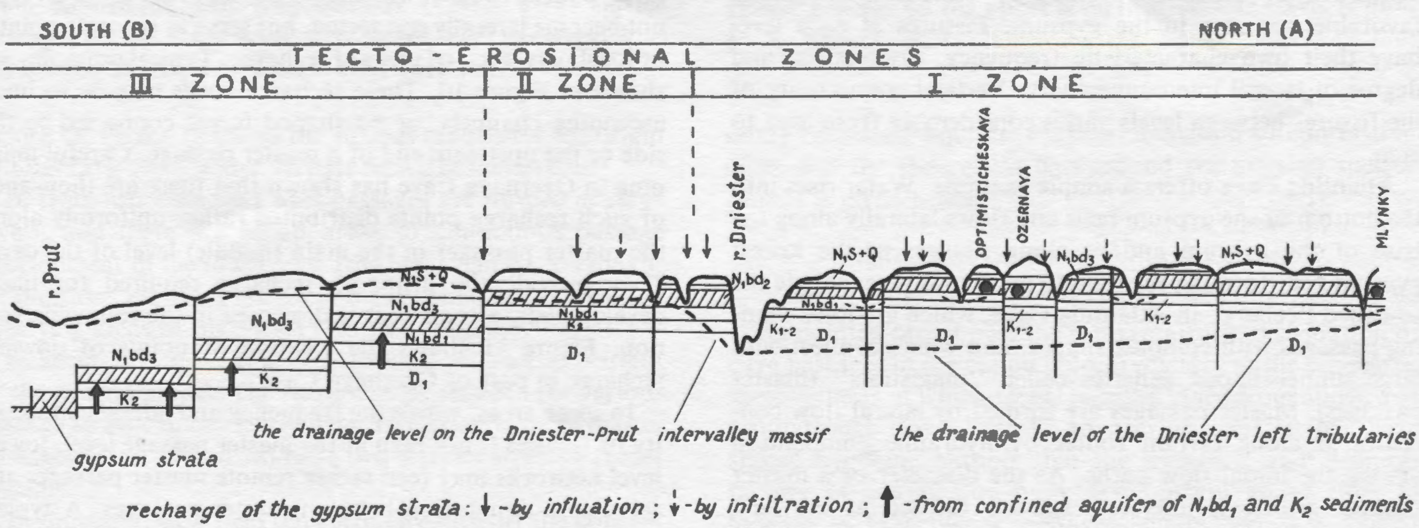


Figure 3. **Modern hydrogeological settings of gypsum caves (profile A-B on Figure 2).**

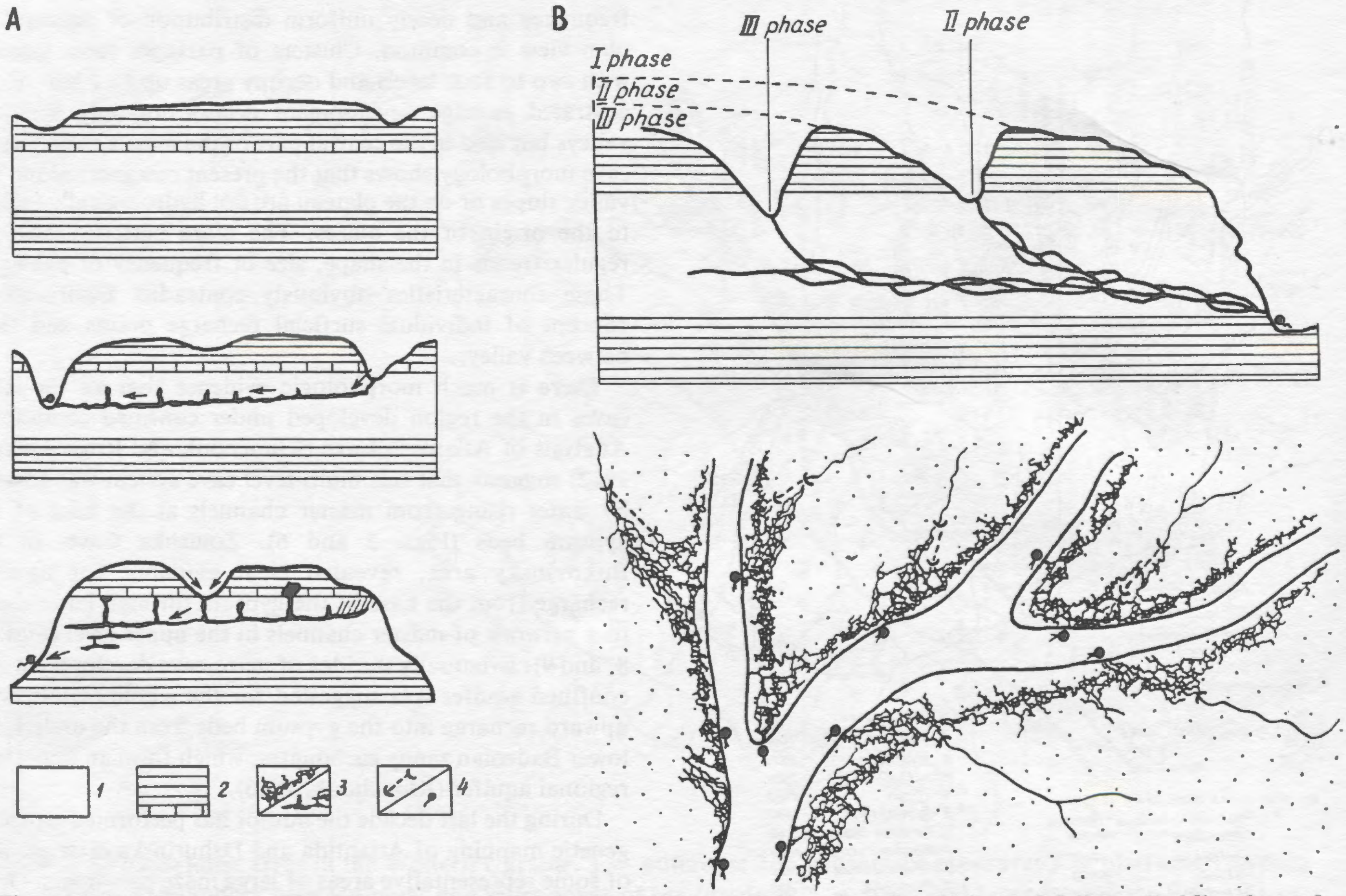


Figure 4. **Previous ideas concerning the origin of the Podolian caves. A = Dubljansky's model (from Dubljansky and Lomaev, 1980); B = Jakucs and Mezösi's model (1976). 1 = gypsum beds; 2 = underlying and overlying formations; 3 = caves; 4 = sinkholes and springs.**

and Rogozhnikov (1982) and by Klimchouk and Andrejchouk (1988), that the multiple levels of the cave systems are controlled by fissures confined to certain lithologically favorable horizons in the gypsum. Fissures 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 offers a simple example. Water rises into the bottom of the gypsum beds and flows laterally along the base of the gypsum and/or along fissures in the lowest gypsum bed, forming the initial passages. These include the 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 the initial flow paths. As the diameter of a master passage grows, it intersects fissures located 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 Figures 5 and 6.

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 lower level. Cavities in the lower level do not become laterally connected, but serve as separate points, or local networks, of upward recharge. Typical examples are shown in Figure 10. These recharge zones may be inclined ascending channels, or pit-shaped forms connected to the side or the upstream end of a master passage. Careful mapping in Ozernaya Cave has shown that there are thousands of such recharge points distributed rather uniformly along the master passages in the main (middle) level of the cave. They provide the dispersed recharge required for maze development, a topic that is discussed in the following section. Figure 11 shows the location of points of upward recharge in part of Ozernaya Cave.

In some areas, where the frequency and lateral connectivity of fissures is not high at the master passage level, lower-level networks may feed rather remote master passages and serve as a connection between master passages. A typical example of such a network connection between two master passages is the Transitional Series in Ozernaya Cave. Part of this series can be seen in the southwest corner of the map in

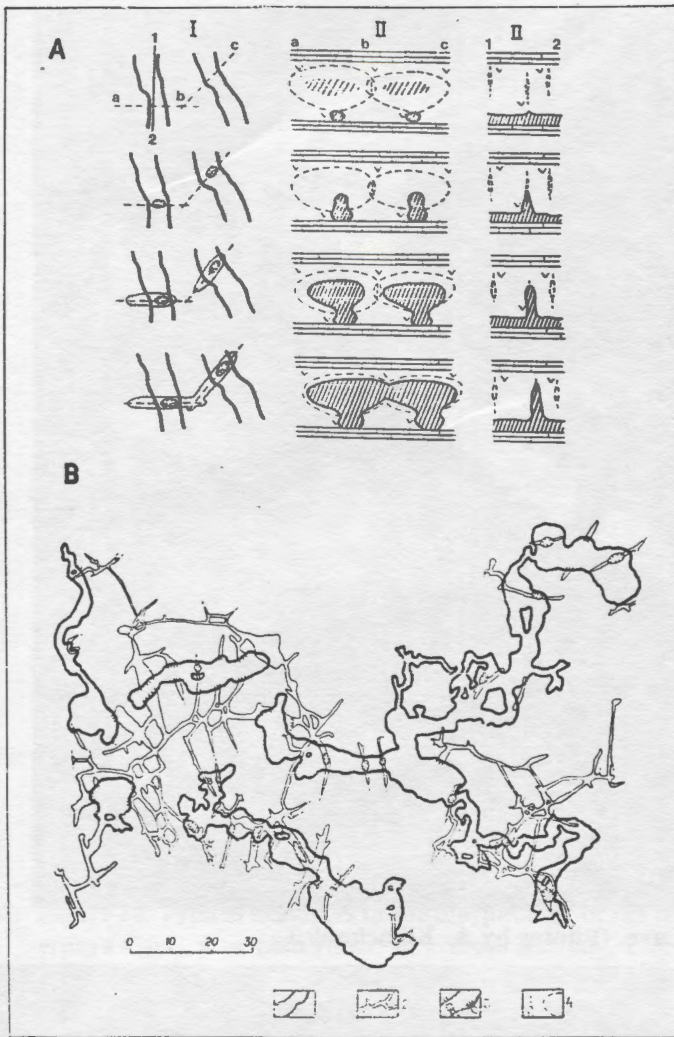


Figure 5. **Model of upward development of a multi-level cave system (A), and specifically for Atlantida Cave (B), from Klimchouk and Rogozhnikov (1982). 1 = master passages on the lower level; 2 = upper-level passages; 3 = connecting shafts; 4 = fissure configuration.**

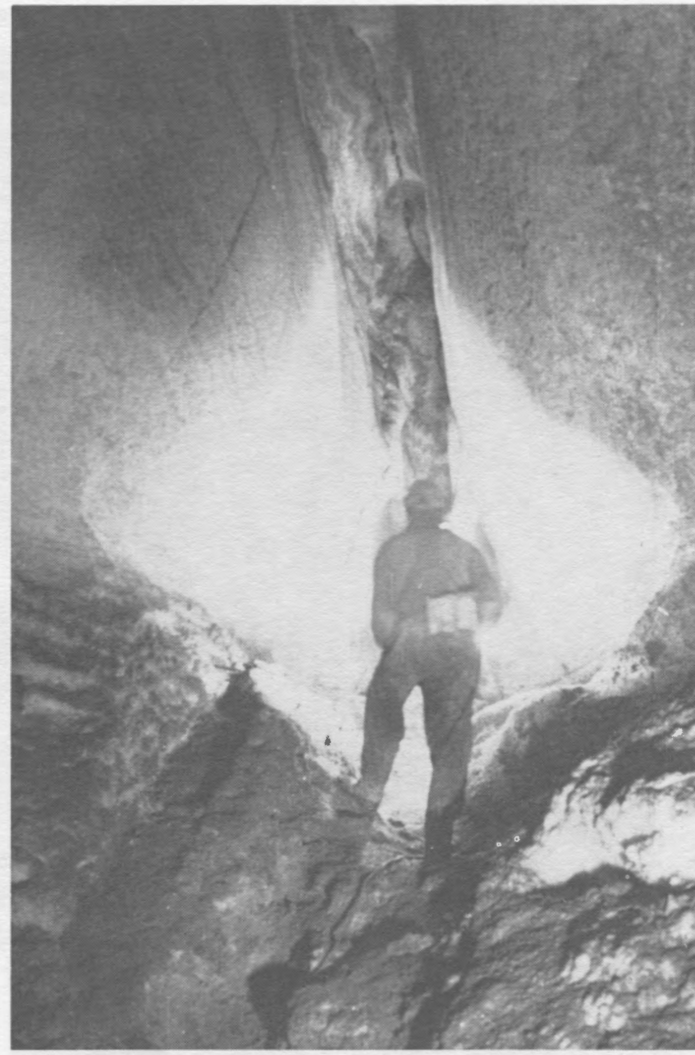


Figure 6. **Junction between the tunnel-shaped master passage of the lower level with a crosscutting "blind" fissure passage on the upper level in Atlantida Cave. (Photo by A. Klimchouk.)**

Figure 11. Figure 12 shows the various models for the origin of Ozernaya Cave under various recharge conditions.

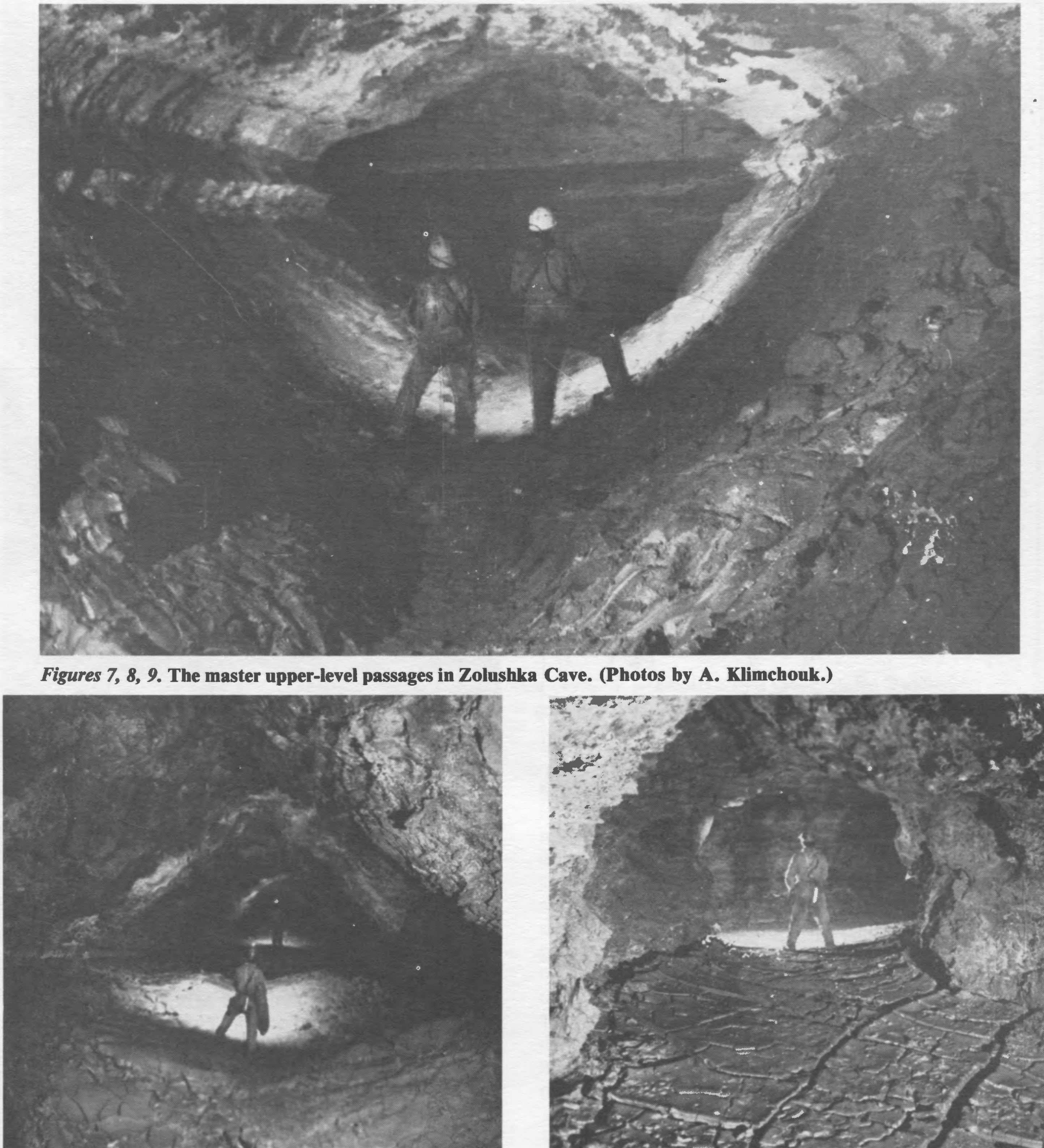
In Optimisticheskaya Cave, passages are formed at three levels, and there are broad areas of continuous passage development in the lower level (the areas named Averbakh, Al'onushka, etc., in Figs. 13 and 14). These areas have fed overlying areas of high-level channels (Fig. 15).

Dzhurinskaya Cave (Fig. 16) displays yet another variant of the general model. The relationships between the various passage levels can be clearly seen. In this cave, large master passages (Figs. 17 and 18) have two distinct levels of feeder systems.

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

Artesian Genesis of Maze Caves: Some Theoretical Aspects

As pointed out above, the rather uniform distribution of cave passages in the region is contradictory to the scheme of speleogenesis in which recharge takes place from above and groundwater flows laterally to nearby rivers. It has been shown by many authors that the hydraulic and chemical factors of initial flow-path development cause flow to localize as branchwork passages where there is a limited number of recharge points. Even assuming that diffuse lateral flow occurs through the gypsum beds, moving water



Figures 7, 8, 9. **The master upper-level passages in Zolushka Cave. (Photos by A. Klimchouk.)**

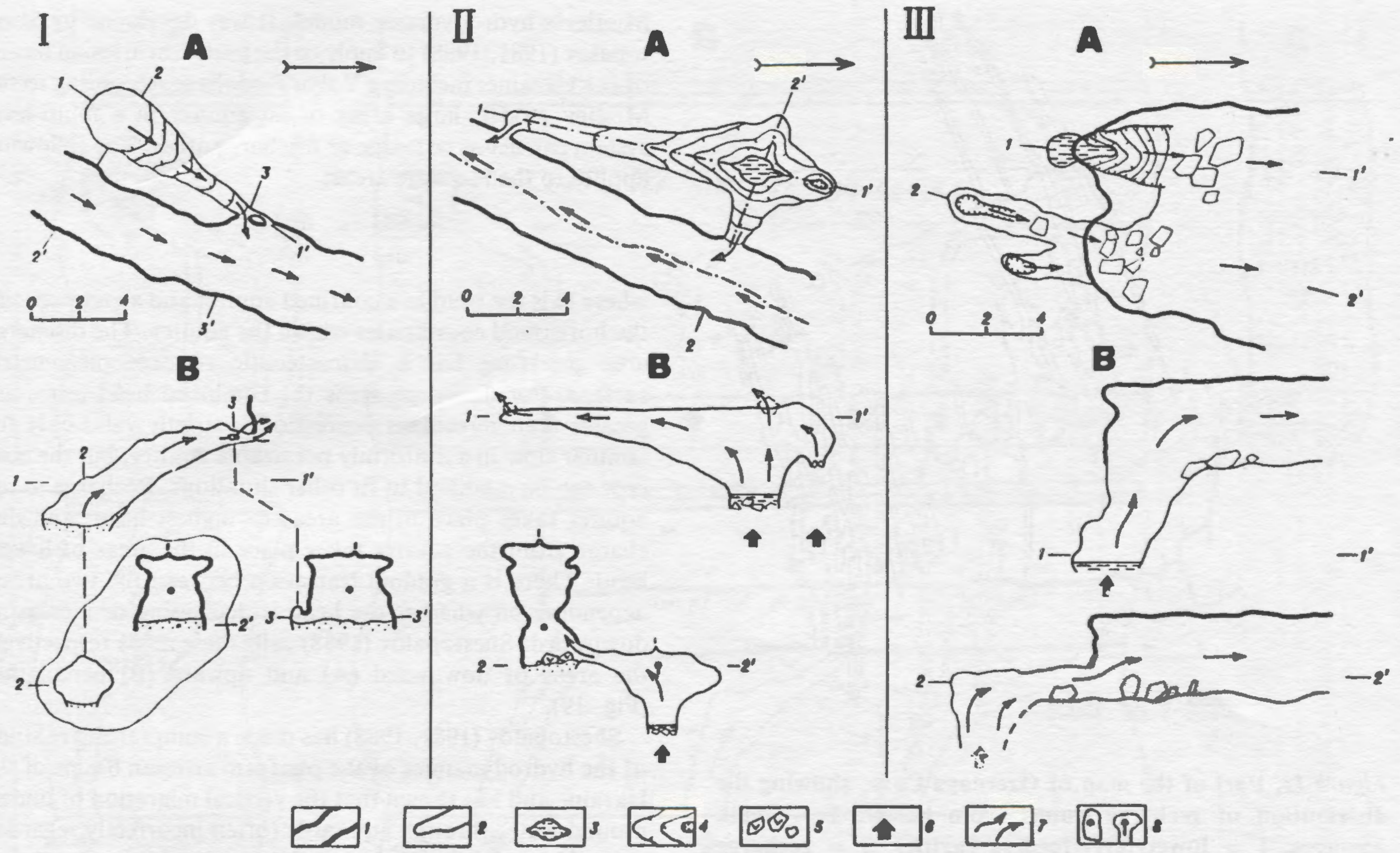


Figure 10. **Typical examples of the morphology of the recharge points and their relationship to the master passages in Ozernaya Cave. A = plan views; B = cross sections. 1 = master passages; 2 = recharge points; 3 = modern cave lakes; 4 = floor topography; 5 = boulders; 6 = upward recharge; 7 = longitudinal view of water movement; 8 = cross-sectional view of water movement.**

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 kilometers. The mazes are not distributed uniformly in plan view, which argues against lateral flow over long distances.

Palmer (1975) distinguished two major situations favorable for the development of maze caves: (1) where dispersed, solutionally aggressive recharge takes place uniformly into all available fissures in a soluble rock, entering from an adjacent insoluble formation or from the overlying land surface: and (2) where floodwater recharge causes the 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 the maze caves considered by Palmer were developed in the first situation, directly beneath permeable formations, usually sandstones, through which dispersed recharge occurred. In Ford and Williams (1989) another model was proposed, by which groundwater is compelled to diffuse from a large conduit into a maze of smaller solutional passages in order to flow upward through a granular sandstone aquifer. Therefore, a dispersed pattern of either recharge or discharge is assumed to be necessary for most maze patterns to develop.

Palmer (1975) deemphasized the importance of artesian flow in the origin of maze caves, with particular reference to Jewel and Wind caves in the Black Hills of South Dakota. Traditionally, classic artesian flow is implied in the origin of such caves, with a limited recharge area along the exposed edge of the 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 the 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 the hydraulic gradient is 0.001, then the discharge from this system should be about

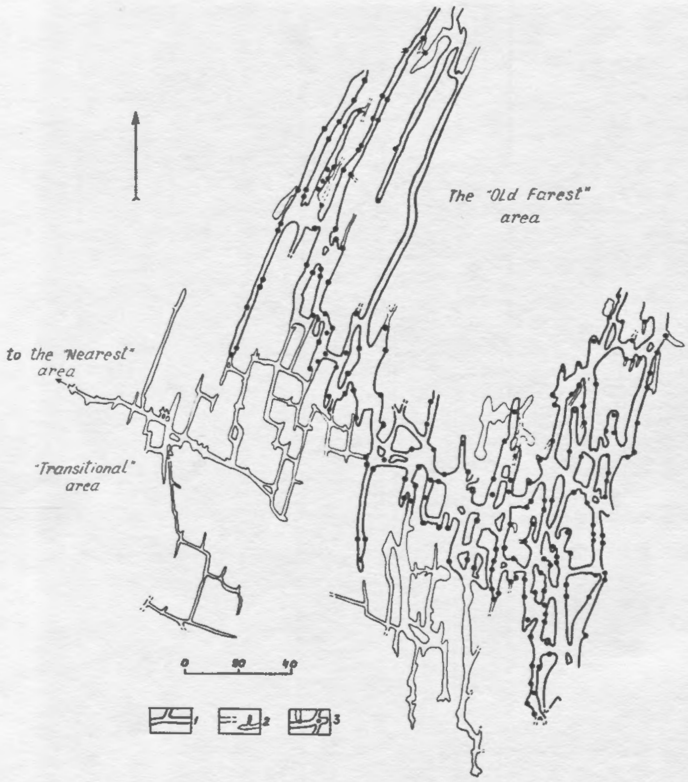


Figure 11. **Part of the map of Ozernaya Cave, showing the distribution of recharge points from below. 1 = main passages; 2 = lower level feeding cavities; 3 = recharge points.**

100 m^3s^{-1}. In comparison, the groundwater flow in the entire Volyn'Podolian artesian basin is estimated to be 235 m^3s^{-1} (Shestopalov, 1981).

In our artesian model of maze cave development in the Western Ukraine, the most prominent feature is upward dispersed recharge. This recharge is available to all the present fissures in the bottom gypsum beds 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 beds takes place locally, but not regionally. It is very significant to understand the correlation between recharge and discharge points in the gypsum beds in this speleogenetic model.

This model is based on a nontraditional theory of water exchange in a platform-type artesian aquifer. 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 several decades new hydrogeologic information shows that there is considerable interconnection between multi-level aquifers in artesian systems and that vertical percolation is important through intervening beds. The 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 Volyn'Podolian. According to the Mjatiev model, large areas of an aquifer in a multi-level system can act as recharge or discharge areas. The following applies to the recharge areas:

$$\frac{d^2H}{dx^2} + \frac{d^2H}{dy^2} < 0$$

where H is the head in a confined aquifer and x and y specify the horizontal coordinates within the aquifer. The discharge area therefore has a characteristic concave piezometric surface. For discharge areas the combined head terms are greater than zero. This expression is strictly valid only for laminar flow in a uniformly permeable aquifer, but the concept can be modified to fit other situations. Recharge to the aquifer takes place in the areas of highest head, and discharge from the aquifer takes place in the areas of lowest head. There is a gradual transition between the two areas, depending on whether the head is decreasing or increasing downward. Shestopalov (1988) calls these areas respectively the areas of downward (A) and upward (B) percolation (Fig. 19).

Shestopalov (1981, 1988) has made a comprehensive study of the hydrodynamics of the platform artesian basins of the Ukraine and has shown that the 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:

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

2) Topography therefore 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 theoretical background for the proposed model of speleogenesis and developmental history of the maze caves in the Western Ukraine.

During the Late Miocene and the Pliocene the study area was a wide lowland. Hydrogeologically it was an artesian basin, confined by the clay-rich Miocene sediments. Water circulation was quite slow in the multi-level artesian system. The gypsum beds 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 pat-

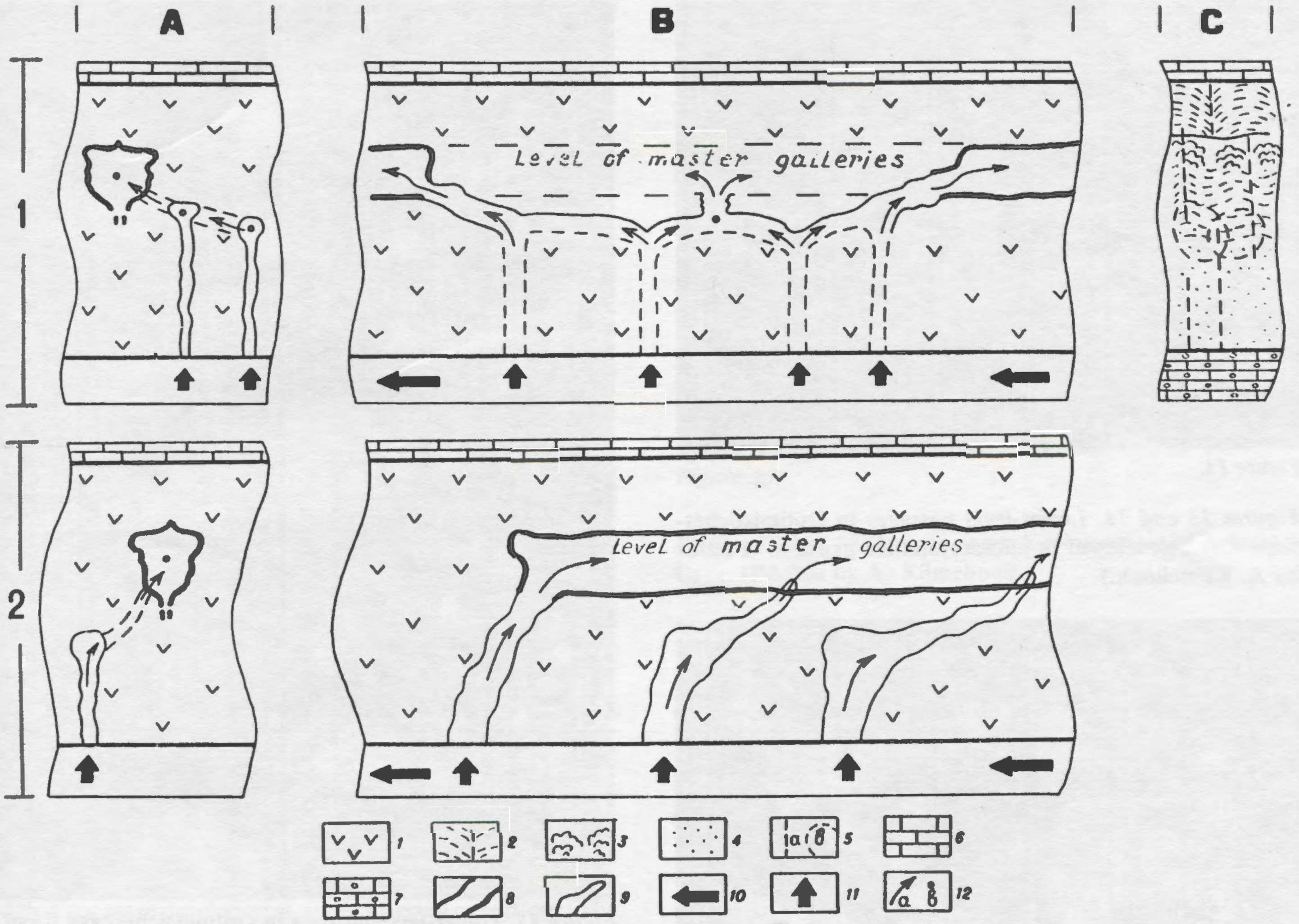


Figure 12. **Model for the development of Ozernaya Cave. 1 = interconnected passages in the lower level feeding two remote areas of higher-level master passages. 2 = separate passages feeding a single master passage. A = cross section; B = longitudinal view; C = stratigraphic cross section. Lithology: 1 = gypsum; 2 = coarsely crystalline gypsum containing mound-shaped structures; 3 = bedded microcrystalline gypsum; 4 = massive cryptocrystalline gypsum; 6 = overlying pelitic limestone; 7 = underlying sandy limestone. Morphology: 5 = fissures; 8 = master passages; 9 = recharge points. Water movement: 10 = lateral flow in the underlying aquifer; 11 = upward recharge; 12 = former pattern of water movement in the cave system.**

tern of piezometric highs and lows was formed in the aquifer beneath the gypsum beds. Neotectonic movements further fractured the gypsum beds, so that upward recharge into the gypsum was established in areas of relatively low head. 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 block the maze character was controlled by the local distribution of fissures within the gypsum.

The valleys of the Dneister and its tributaries were entrenched during the Early Pleistocene, exposing the artesian aquifer and increasing the amount of groundwater flow through the system. 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 ability of the subsurface 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 the gypsum beds and the underlying aquifer were drained, except for some areas of the wide plateaus remote from valleys. In the Bukovinsky region, adjacent to the foredeep, the gypsum beds lie at a greater depth and the valleys are not so deeply entrenched,

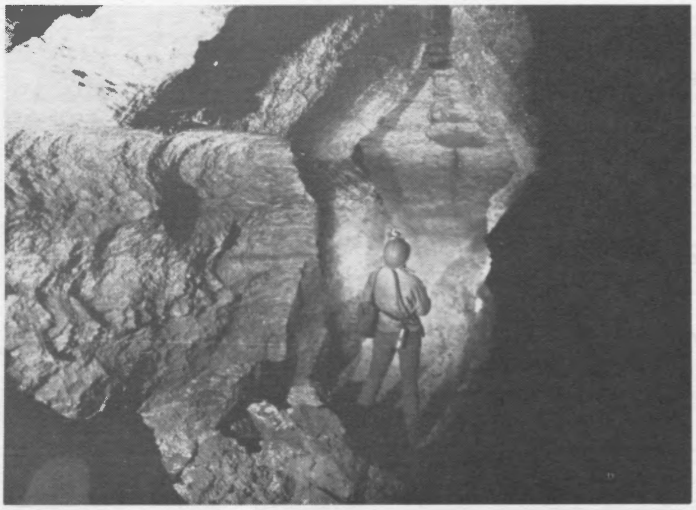


Figure 13.

Figures 13 and 14. **Lower-level passages in Optimisticheskaya Cave, developed in microcrystalline gypsum. (Photos by A. Klimchouk.)**

Figure 14.

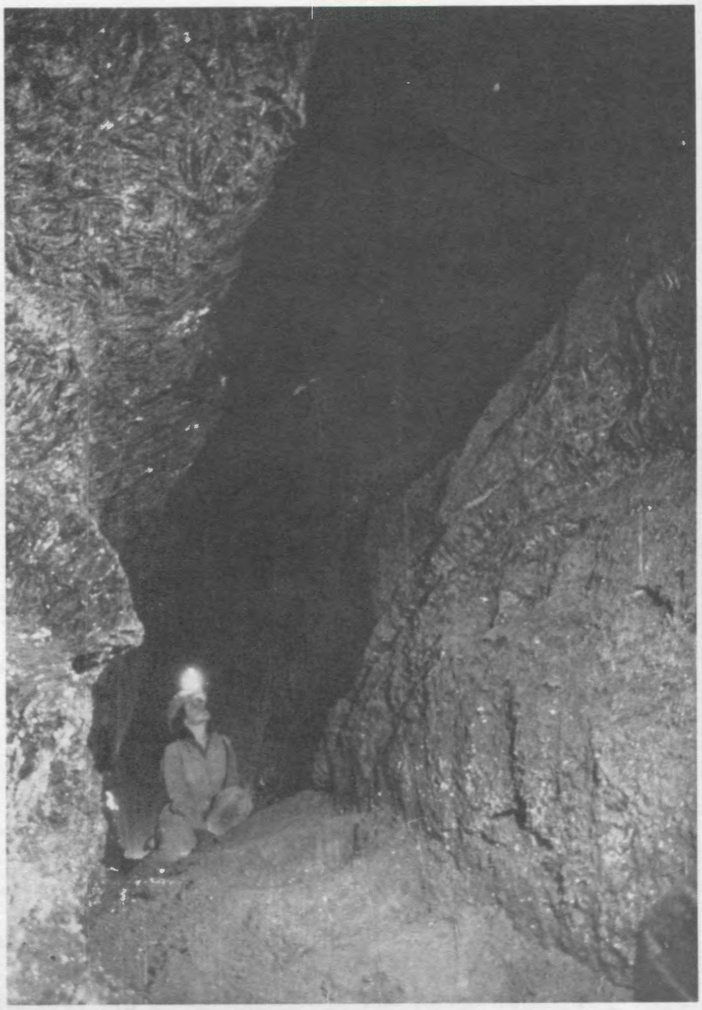


Figure 15. **Upper-level passage in Optimisticheskaya Cave, developed in coarsely crystalline gypsum. (Photo by A. Klimchouk.)**

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 and Andrejchouk, 1986); however, the cave system has been dewatered within the last decades by gypsum quarry operations.

As the aquifer system was being uncovered and drained, large sinkholes formed at the surface. Clay remains at the surface in most areas, preventing diffuse recharge downward into the gypsum. Today the principal recharge is localized at sinkholes.

It is interesting to note how the gypsum beds have changed their hydrologic function as the karst evolved. At first the gypsum acted as an aquifuge, then as an aquitard, and eventually as a karst aquifer.

Ford (1988) distinguishes between the 2-D type of maze caves and the basal injection type of caves in his general classification of karst solution caves. The artesian model of

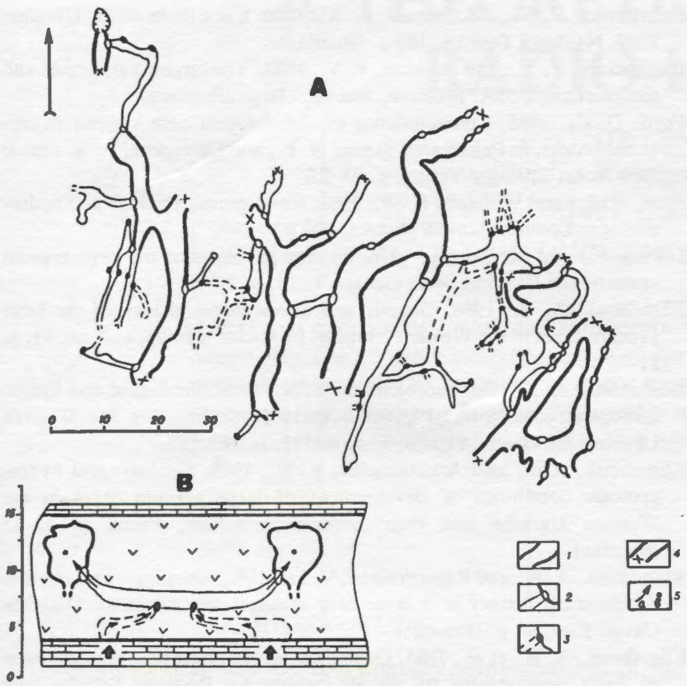


Figure 16. **Morphogenetic map (A) and model of development (B) of Dzhurinskaya Cave, with two levels of recharge passages feeding the master passages. 1 = master passages; 2 = first-order tributary passages and their outlets; 3 = second-order recharge tributaries and their outlets; 4 = terminal breakdown.**

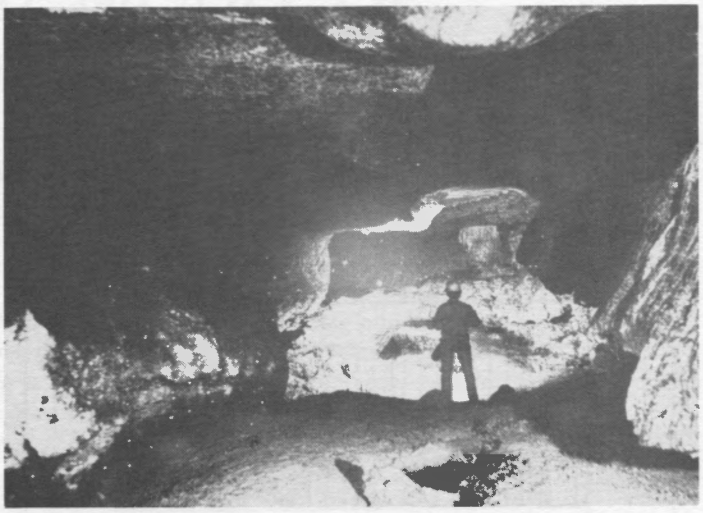


Figure 17.

Figures 17 and 18. **Master upper-level passages in Zolushka Cave. (Photos by A. Klimchouk.)**

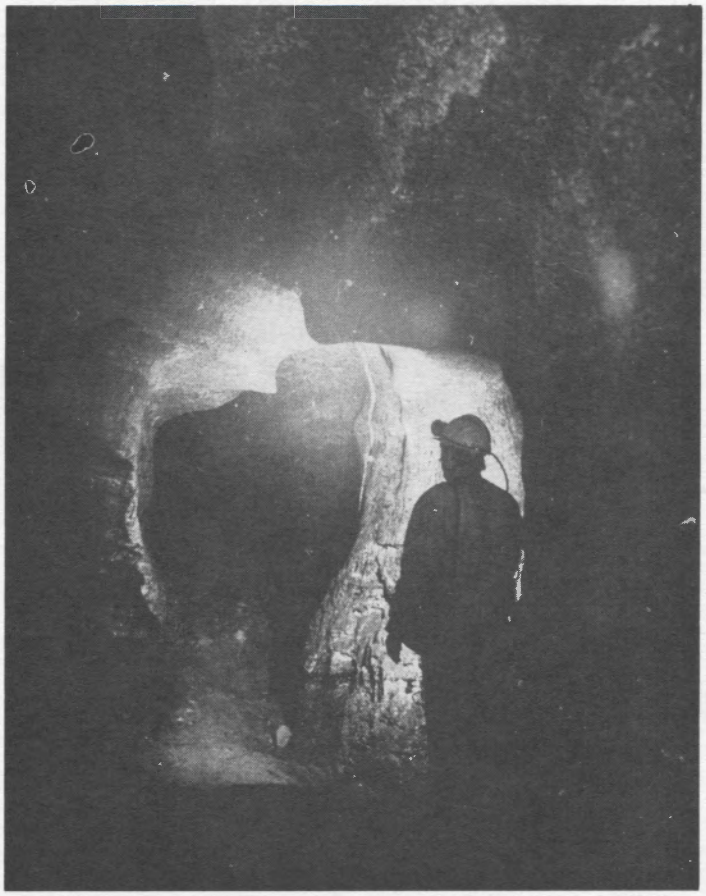


Figure 18.

speleogenesis described in this report appears to combine these two types. Basal recharge seems to be a necessary condition for maze development under artesian conditions. The theory of artesian speleogenesis needs further elaboration, and the author hopes that the present report will provide some background for this.

ACKNOWLEDGEMENTS

I am indebted to my colleagues at the Karst-Speleological Department of the Ukraine Institute of Geological Sciences for their assistance for so many years. I wish to thank Arthur and Margaret Palmer, of the State University of New York at Oneonta, for their kind help in helping to prepare the manuscript for publication.

REFERENCES

Andrejchouk, V. N., 1988, Tectonic factors in the karst development of Bukovina; Sverdlovsk, 50 p. (Russian).

Courbon, P. and Chabert, C., 1986, Atlas des grandes cavities mondiales: Union International de Speleologie, and Federation Francaise de Speleol., 255 p.

Dubljansky, V. N., and Smol'nikov, B. M., 1969, Karstological and geophysical researches of karst cavities of Pridnestrovsky, Podolia, and Pokut'e: Kiev, Naukova Dumka, 151 p. (Russian).

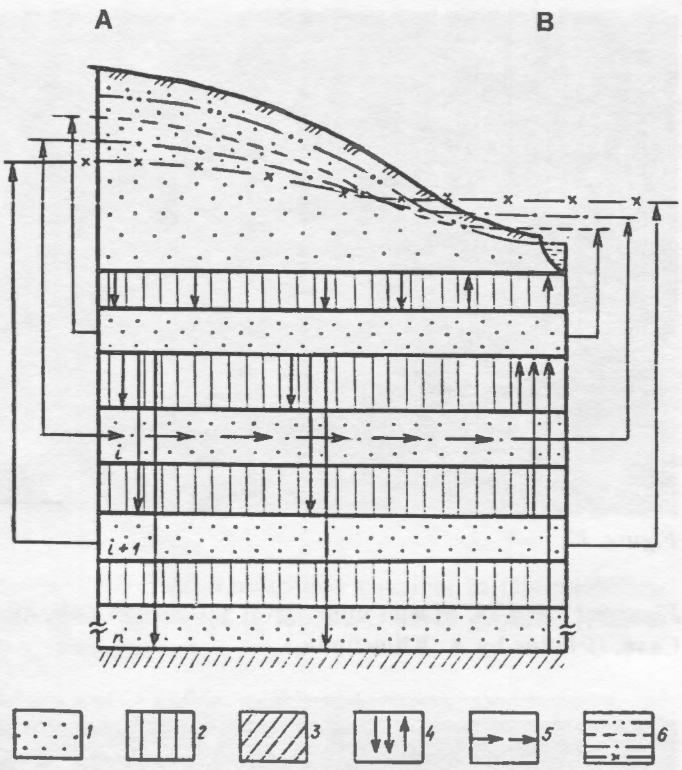


Figure 19. **Flow pattern in the multi-level artesian aquifer system (from Shestopalov, 1988). 1 = aquifers; 2 = aquitards; 3 = aquifuge; 4 = vertical water exchange; 5 = lateral water exchange; 6 = piezometric surfaces in the multi-level aquifers.**

Dubljansky, V. N., and Lomaev, A. A., 1980, Karst caves of the Ukraine: Kiev, Naukova Dumka, 180 p. (Russian).

Dubljansky, V. N., and Iljukhin, V. V., 1982, The largest karst caves and shafts of the USSR: Moscow, Nauka, 136 p. (Russian).

Ford, D. C., 1988, Characteristics of dissolutional cave systems in carbonate rocks, *in* Paleokarst: James, N. P., and Choquette, P. W. (eds.): New York, Springer-Verlag, p. 25–57.

Ford, D. C., and Williams, P. W., 1989, Karst geomorphology and hydrogeology: London, Unwin Hyman, 600 p.

Jakucs, L., and Mezősi, G., 1976, Genetic problems of the huge gypsum caves of the Ukraine: Acta Geogr., v. 16, p. 15–38.

Klimchouk, A. B., 1986, Genesis and development history of the large gypsum caves in the Western Ukraine: Le Grotte d'Italia, v. 4, no. 13, p. 51–71.

Klimchouk, A. B., and Andrejchouk, V. N., 1986, Geological and hydrogeological conditions of gypsum karst development in the Western Ukraine: Le Grotte d'Italia, v. 4, no. 12, p. 349–358.

Klimchouk, A.B., and Andrejchouk, V. N., 1988, Geologic and hydrogeologic conditions of development of large gypsum caves in the Western Ukraine and their genesis: Peshchery, Perm, p. 12–25 (Russian).

Klimchouk, A. B., and Rogozhnikov, V. Ja., 1982, Conjugate analysis of a development history of a large cave system (an example of Atlantida Cave): Kiev, 58 p. (Russian).

Klimchouk, A. B., et al., 1985, Geological and hydrogeological conditions of karst development of the Pridnestrovsky Podolia: Fizycheskaya geographija i geomorphologija, Kiev, v. 32, p. 47–54 (Russian).

Klimchouk, A. B., et al., 1988, Regime study of gypsum karst activity in the Western Ukraine: Kiev, 55 p. (Russian).

Palmer, A. N., 1975, The origin of maze caves: National Speleological Society Bulletin, v. 37, p. 56–76.

Shestopalov, V. M., 1981, Natural resources of underground water of platform artesian basins of the Ukraine: Kiev, Naukova Dumka, 195 p. (Russian).

Shestopalov, V. M., 1988, Methods of study of underground water natural resources: Moscow, Nedra, 168 p. (Russian).

Shope, Steven M.—A Theoretical Model of Radio-Location: *NSS Bulletin* 53: 83-88.

A THEORETICAL MODEL OF RADIO-LOCATION

STEVEN M. SHOPE
Sandia Research Associates, Inc.
3411 Candelaria, N.E.
Albuquerque, NM 87107

The use of cave radios for both communications and surveying is becoming increasing popular. This paper provides an exact analytical solution for the magnetic fields created by an underground loop antenna. Although the formulation is not unique, the objective of this paper is to present complex theoretical equations in a form readily useable by cave researchers. Common uses include the design of radio-location surveys, cave communication systems, rescue operations, and cave data telemetry links.

INTRODUCTION

During the first half of this century, employment in the mining industry of this country was an extremely hazardous occupation. Multiple-fatality accidents were commonplace. In November 1968, a tragic disaster struck a Farmington, West Virginia coal mine. In this accident, 78 miners were fatally trapped following a massive methane gas explosion. This accident prompted Congress to pass sweeping legislation in an attempt to make the nation's coal mines a safer place to work. This landmark legislation is known as the Coal Mine Health and Safety Act of 1969.

One consequence of this Act was a government-sponsored R&D program to develop technologies and methodologies for increasing the chances of evacuation, escape, survival and rescue of miners trapped underground following a disaster. This effort, conducted by the U.S. Bureau of Mines, became known as the Post-Disaster program.

As recommended by the National Academy of Engineers (National Academy of Engineers, 1970), one important element of this program was the development of technology for locating and communicating with trapped miners. Extensive through-the-earth radio research and experimentation was conducted. Over 125 Bureau of Mines-sponsored field tests of through-the-earth radio systems were conducted throughout the United States under this program. This program was very active throughout the 1970's and early 1980's. Ironically, other aspects of the Coal Mine Health and Safety Act were so successful that accident rates in coal mines dropped dramatically. Continued funding of the Post-Disaster program could not be justified. Although this effort is no longer active, many excellent theoretical and experimental projects were sponsored under this program. Much of this research is directly applicable to the radio-location and communication interests of the caving community.

Speleologists are using through-the-earth radio techniques for cave-to-surface communications, data telemetry, and radio-location. Radio-location is a method in which a surface observer can determine the location of an underground antenna. This is an extremely useful method that has a wide range of applications.

The purpose of this paper is to present an exact solution to the underground loop problem. In particular, the magnetic fields on or above the earth's surface due to an underground loop of wire carrying an oscillating current will be calculated. In this paper, the tedious mathematical derivations have been omitted. However, the final solution is straight forward and should be very pertinent to cavers and cave radio enthusiasts. A goal of this paper is to simplify and generalize the results for cave applications. The reader is referred to Wait (1951, 1971a, 1971b), Geyer et al. (1974), and Durkin (1983) for a detailed description of these types of theoretical derivations.

Many articles have addressed the question of the "best" frequency to use for through-the-earth cave radio systems. In general, no one particular frequency is optimal for all situations. The many site variables including depth, offset, elevation, conductivity, and atmospheric noise prevent such an analysis. Models such as the one described in this paper can be used to optimize a radio communications or location system for a given cave site.

A numerical analysis routine has been written to solve the equations shown in this paper. The software was developed for IBM-compatible personal computers. Sandia Research Associates, Inc. will make this software program available to any individual who would like to calculate magnetic field strengths for their custom applications. A description of this software is included in the appendix.

THE PROBLEM

The problem is to calculate the magnetic fields created by an underground loop of wire. An oscillating current flows in the buried loop. The field observation point can be anywhere on or above the earth's surface. Much of the notation used in this paper is consistent with previous research in this area. SI units will be used; however, the solutions are easily adaptable to any unit system.

Assumptions

The solutions presented in this paper are exact for a loop buried in a homogenous earth. This model of the earth is often known as a homogeneous half-space model. At real field sites, a homogeneous earth model may not be realistic. Deviations in the form of layering, scattering, and sloping terrain can often influence the fields. Experience has shown that for low frequencies ($\approx$ 10 kHz or less), the homogeneous half-space model is usually adequate. In some situations, this model is not sufficient; better models can be developed at the cost of increased complexity in derivation and usage.

The earth is assumed to be infinite, isotropic, and homogeneous. The electrical properties of the earth are described by the conductivity, σ, the magnetic permeability, μ, and the dielectric constant, ϵ. These parameters are known to be frequency independent for most lithologies. Depending upon one's preference, resistivity can be used in place of conductivity. The relationship between resistivity and conductivity is

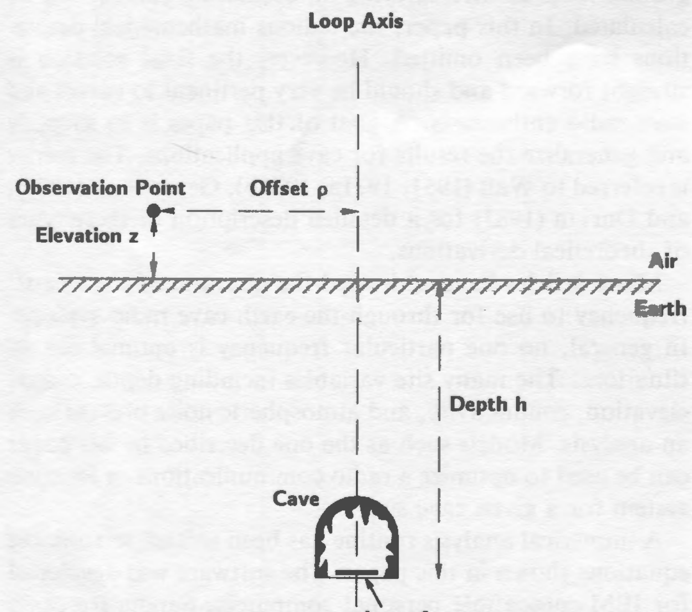


Figure 1. **The model showing a vertical magnetic dipole in a homogeneous half-space.**

$$\varrho = \frac{1}{\sigma}$$

The conductivity (resistivity) is expressed in Siemens/meter (ohm-meter). Typical conductivities for karst geology range from .05 to .0001 S/m. Although the magnetic permeability is also an important electrical property, experience has shown it to be fairly constant for most geological materials. In SI units, the magnetic permeability of free space is 1.257 x 10^{-6} Henry/meter. The free space dielectric constant is 8.854 x 10^{-12} Farads/meter. The dielectric constant of earth materials is typically between one and ten times the free space value. At low frequencies and/or large conductivities, the dielectric constant is not influential and can be omitted from the calculations. This is because the displacement currents are negligible compared to the ohmic currents. This approximation is valid so long as

$$\epsilon\omega \ll \sigma$$

A dimension-less variable, T, is introduced. T is defined as the ratio of the loop depth to the skin depth of the media. Previous derivations by Wait use the symbol H for this variable. To avoid confusion with the symbol, H, that represents the magnetic field terms, T will be used in this paper.

$$T = \frac{\textit{loop depth}}{\textit{skin depth}}$$

or

$$T = h\sqrt{\mu\sigma\omega}$$

where

μ = magnetic permeability
σ = conductivity
ω = frequency (radians/sec) = $2\pi f$ (Hertz)
h = loop depth

The skin-depth is defined as the propagation distance a plane wave travels in a medium to have a total attenuation of 1/e or 8.686 dB. For large skin-depths, the intrinsic attenuation rate of the medium is low. Conversely, a medium with a small skin-depth will rapidly attenuate propagating radio signals. Thus, a large T value describes a poor medium for through-the-earth radio-location or communications.[1] In a conduction-less region or at zero frequency (direct current or DC), T is zero. At 1.0 kHz, typical values of T range from zero to ten.

[1]The model discussed in this paper describes quasi-static induction fields; these are nonpropagating fields. Because skin depth is usually associated with propagating waves it may seem inappropriate in this formulation. However, the mathematical solution to this model is presented as an infinite summation (integral) of plane wave terms. Hence, the T factor is an effective variable for introducing the electrical properties of the medium into the solution.

The magnetic moment of the underground loop is assumed to be entirely vertical, i.e. the plane of the loop is horizontal and parallel to the surface. Furthermore, we are treating the loop as a magnetic dipole. This assumption is valid for loop-to-observer distances that are greater than roughly ten loop diameters (Durkin, 1983).

Geometry

A schematic of the model we are using is shown in Figure 1. Key geometric variables include:

h = loop depth below the surface
z = height of observation point above the surface
ϱ = observation point offset from loop axis

Note that h is the depth of the loop below the surface and *not* the loop-to-observer distance.

Using these values, the following dimensionless ratios can be constructed:

$$D = \frac{\varrho}{h}$$

$$Z = \frac{z}{h}$$

Because of a lack of space, the plots included in this paper will only include the Z = 0 case. This represents observation points located on the surface of the earth. For most caving applications, this is adequate. Other values of Z were important in the Bureau of Mines research program because helicopters were sometimes used to make signal strength measurements.

Field Solutions

The magnetic fields generated by an underground loop are quasi-static and sometimes called induction fields. A propagating field is responsible for energy flow away from a source. However, in an induction field, energy is stored in the field. Induction field losses arise from the currents induced in the surrounding, conducting earth.

Because of symmetry with respect to the loop axis, the magnetic field created by a buried loop has only a vertical and radial component. The azimuthal component is zero at all observation points. This property allows easy radiolocation due to the presence of an azimuthal null.

The vertical and radial magnetic fields can be written as:

$$H_z = \frac{M}{2\pi h^3} Q$$

The magnetic moment of the loop, M, is given by

$$H_\varrho = \frac{M}{2\pi h^3} P$$

$$M = I N A$$

where

I = loop current
N = number of turns in the loop
A = area of one turn of the loop

Inspection of the above field strength expressions shows that the magnetic fields produced by an underground loop are linear with magnetic moment. In other words, if the magnetic moment is doubled, the resulting fields are doubled. Another important point is that the magnetic fields are a function of current flowing in the loop. For a fixed loop configuration, the designer should maximize the current flow in the winding(s) in order to maximize the surface fields.

In the above expressions for the magnetic field, the Q and P factors contain the attenuation, radiation, and geometric correction terms to the DC magnetic field expressions. Explicitly, these two functions are given by Bessel integrals:

$$Q = \int_0^\infty x^3 \frac{e^{-x-\sqrt{x^2+iT^2}} \; e^{x(1-Z)}}{x+\sqrt{x^2+iT^2}} J_0(xD)\, dx$$

$$P = \int_0^\infty x^3 \frac{e^{-x-\sqrt{x^2+iT^2}} \; e^{x(1-Z)}}{x+\sqrt{x^2+iT^2}} J_1(xD)\, dx$$

In these expressions, x is the variable of integration; D, Z, and T are dimensionless variables that have been previously defined. $J_0(xD)$ and $J_1(xD)$ are zeroth and first-order Bessel functions. Q and P are dimensionless, complex numbers with magnitudes that range between zero and one. The expressions for P and Q were derived using Hertz vector potentials and the application of appropriate boundary conditions. Solution of these integrals requires numerical integration on a computer. This can often be difficult due to unforeseen numerical problems.

Examples

Assume an observation point on the loop axis and on the earth's surface (D = 0; Z = 0). The radial component of the magnetic fields is always zero (P = 0) on the loop axis. The behavior of Q as a function of T can be seen in Figure 2. Note that for the DC case or a non-conductor case, T is zero and Q is 1.00. In a similar fashion, the behavior of Q and P are shown for various radial offsets in Figures 3 and 4. As intuition tells us, low frequencies correspond to a small T value, thus the fields are less susceptible to the characteristics of the half-space. However, overall system performance is dependent on the received signal-to-noise ratio SNR. Although lower frequencies are more efficient, the background noise levels are often higher at the lower fre-

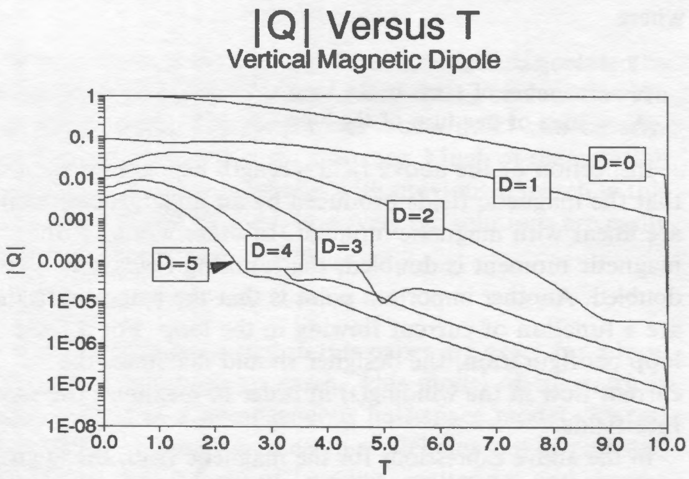


Figure 2. **Magnitude of Q versus the depth/skin depth ratio, T.**

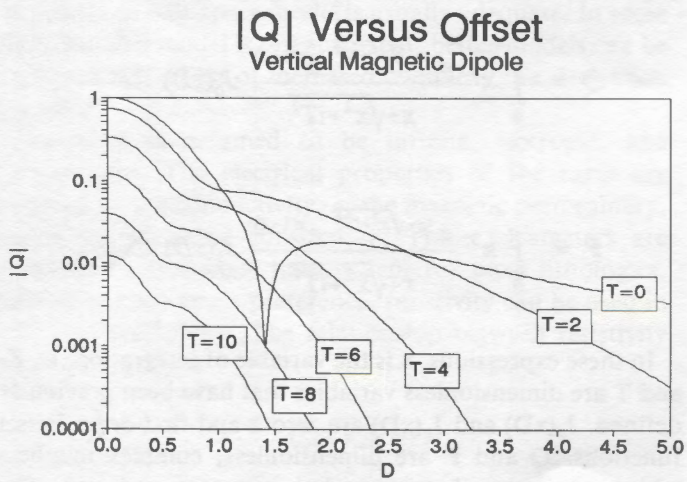


Figure 3. **Magnitude of Q versus the offset ratio, D.**

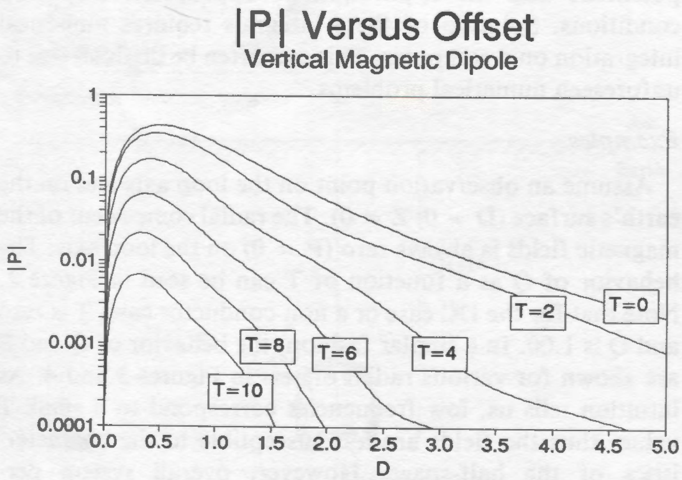


Figure 4. **Magnitude of P versus the offset ratio, D.**

quencies. The optimum frequency to use at a given site is one that maximizes the received SNR. Frequencies that lie midway between the harmonics and sub-haromonics of power lines frequencies are commonly used to minimize noise.

The ratio of the horizontal magnetic field to vertical magnetic field is given by

$$\frac{H_\rho}{H_z} = \frac{P}{Q}$$

This ratio is independent of absolute magnetic field strength as well as the magnetic moment of the underground loop. In Figure 5, the ratio of P/Q is shown as a function of radial offset. T values of 0, 2, 4, 6, 8, and 10 are used. In Figure 6, the P/Q ratio is plotted as a function of the depth/skin depth ratio, T.

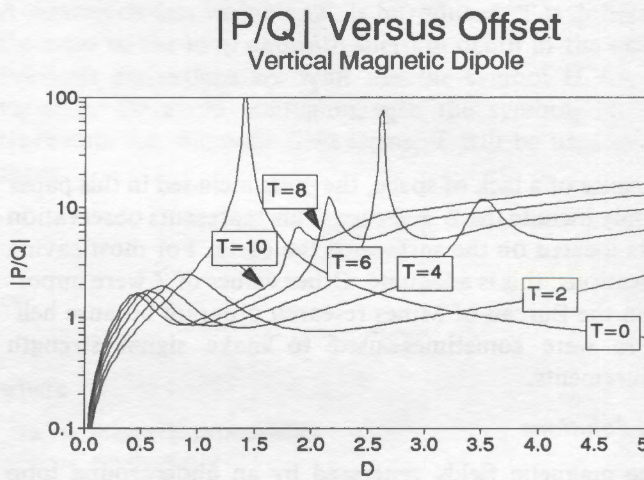


Figure 5. **Magnitude of P/Q versus the offset ratio, D.**

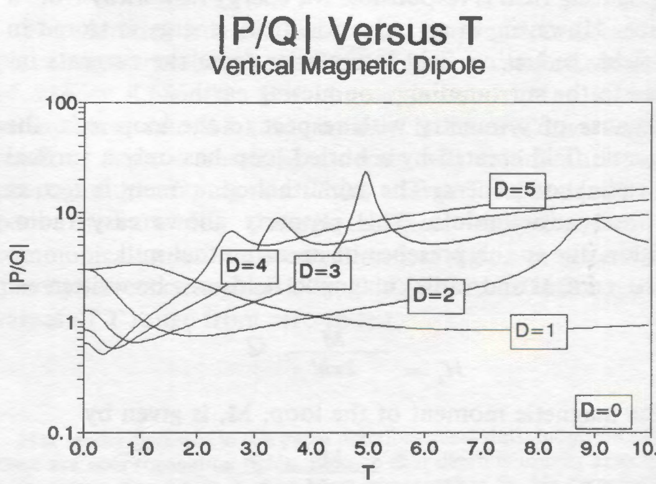


Figure 6. **Magnitude of P/Q versus the depth/skin depth ratio, T.**

Units

Any unit system can be used as long as one is consistent. The integrals for P and Q use dimension-less ratios which makes the integrals completely independent of the unit system. For example, if feet are used for all dimensions including skin depth, the ratios T, D, and Z would be the same as if meters were used instead. However, the magnetic field strength calculations are dependent on the unit system. SI units are suggested.

In the SI unit system, the magnetic field has units of Amperes/meter. These units follow from the magnetic field equations, e.g.

$$H = \frac{I[Amp]\ N[turns]\ A[m^2]}{2\pi h^3[m^3]} \qquad Q = \frac{Amp}{m}$$

Summary

In summary, the procedure for calculating the expected magnetic fields above the earth is:

1) Knowing I, N, and A, calculate the magnetic moment, M, of the underground transmitting loop.
2) Knowing μ, ω, and h, calculate T.
3) For a particular observation point and knowing h, calculate D and Z.
4) For a particular set of T, D, and Z values, obtain P and Q from the graphs or computer program.
5) Use. M, h, P, and Q to calculate the magnetic fields H_ρ and H_z.

LOCATING A BURIED LOOP

This section describes the technique for locating a buried vertical magnetic dipole.

Locating the Loop Axis

The axis of the loop can be found on the surface using conventional radio-location techniques. The radial field forms a vector between the loop axis and an observer. An azimuthal null exists which is orthogonal (perpendicular) to the radial field component. This null can easily be found using a receiver and hand-held loop antenna. If this procedure is repeated at several different surface positions, the common intersection of the observer-to-loop-axis vectors locates the loop axis on the surface. This method will be referred to as the null-vector method.

Experience at low frequencies has shown that the null-vector technique is fairly accurate and reliable. Inaccuracies due to buried conductors, massive resistivity features, and terrain effects, are readily apparent if present. In such cases, the radial field vectors do not intersect at a common point but rather define a polygon-of-uncertainty that encloses the true loop axis. In practice, such problems are rarely encountered when using low frequencies.

However, at higher frequencies (100's of kHz), such problems are common. The higher frequency signals are much more susceptible to localized resistivity anomalies, structural features, and anisotropic resistivities.

Estimating the Loop Depth

Several techniques for determining the depth of a loop have appeared in *Speleonics*. Unless extremely low frequencies are used (i.e., tens of Hertz), any method that uses absolute field strengths to calculate the loop depth (i.e., direct inversion) will usually be inaccurate. Variations in actual sites from the homogeneous half-space model will perturb the measured fields. In addition, calibrated receiving equipment is required.

A better depth-determining technique uses the relationship between the vertical and radial fields. This technique requires no knowledge of the magnetic moment nor does it require the use of calibrated field equipment. As noted in Figure 5, the ratio of P/Q has a distinctive curve for the different T values. However, within an error of +/- 15%, the first P/Q = 1 value occurs at an offset of one-half the loop depth (D = .5). This is valid for a range of all typical T values. In other words, the P/Q = 1 point occurs at a radial offset equal to one-half the loop depth, regardless of the electrical properties of the medium. This fact can be used as a technique for estimating the loop depth.

Once the loop axis is found using conventional techniques, the radial and vertical magnetic fields are compared at successively increasing radial offsets. The distance between the P/Q = 1 point and the loop axis is approximately one-half the loop depth. The attractiveness of this method is that the depth estimate is independent of the half-space conductivity and no calculations are required. Furthermore, the receiving gear need not be calibrated because only relative field strength measurements are made. Using a pair of orthogonal antennas, a receiver could easily be built that indicated when the radial and vertical components are equal.

If the procedure is first conducted at a surveyed location so that the depth of the loop is known, the T value of the half-space can be calculated. This would further improve accuracy when determining unknown loop depths.

CONCLUSIONS

This paper has presented a theoretical model for the magnetic fields generated by an underground loop antenna. Formulas for calculating the vertical and radial magnetic field strengths have been given. These calculations are valuable for designing radio-location and communication systems for particular cave sites. A limitation of these formulas is that they only apply to a homogeneous half-space model of the earth. When actual conditions vary from homogeneous, the model can be in error. For example, a well defined water table located below the loop can actually create surface fields that are larger than expected (Shope, 1982). In general, the homogeneous half-space model is adequate for predicting the surface fields. As expected, lower frequencies are less influenced by the half-space characteristics.

REFERENCES

In addition to these specific references, the reader is referred to *Speleonics* as a source of information about through-the-earth radio systems. *Speleonics* is a periodic publication of the Communications and Electronics Section of the National Speleological Society.

Durkin, J. 1983. Study of through-the-earth communications. Ph.D. dissertation, pp. 9-20. University of Pittsburgh School of Engineering.

Geyer, R. G., G. V. Keller, and T. Ohya. 1974. Research on the transmission of electromagnetic signals between mine workings and the surface. U.S. Bureau of Mines, Open File Report OFR-61-74:37-88. Pittsburgh.

National Academy of Engineers. 1970. Mine rescue and survival. PB191-691:12-50. (Available from NTIS.)

Shope, S. M. 1982. Electromagnetic surface fields due to a magnetic dipole buried in a three-layered earth. U.S. Bureau of Mines publication RI-8702:12-20.

Wait, J. R. 1951. The magnetic dipole over a horizontally stratified earth. *Canadian Journal of Physics* 29:577-92.

Wait, J. R. 1971a. Electromagnetic induction technique for locating a buried source. *IEEE Transactions on Geoscience and Electronics* GE-9:95-98.

Wait, J. R. 1971b. Criteria for locating an oscillating magnetic dipole in the earth. *Proceeding of the IEEE* 59:1033-35.

Appendix

A software program has been developed to solve the magnetic field equations shown in this paper. The software was written for IBM-compatible personal computers. This program allows the user to interactively develop and save specific homogeneous half-space models. The user can switch unit systems from meters to feet for all dimensions in the model. However, the field strengths are always given in SI units. The model variables include:

Frequency
Loop Depth
Loop Magnetic Moment
Receiver Offset
Receiver Elevation
Earth Resistivity or Conductivity
Ambient Vertical Noise
Ambient Horizontal Noise

The program calculates:

T factor
D factor
Z factor

When the model is numerically evaluated, the output includes:

Q Magnitude
Q Phase
Vertical Magnetic Field Strength, H_z
H_z SNR

P Magnitude
P Phase
Horizontal Magnetic Field Strength, H_ρ
H_ρ SNR
|P/Q| Ratio
P/Q Phase Difference

For information about the availability of this software, please contact Sandia Research Associates, Inc. at:

Sandia Research Associates, Inc.
3411 Candelaria, N.E.
Albuquerque, NM 87107

Lewis, Warren C.—Saltpeter Beds: A Review of Nitrate Production in Compost Heaps: *NSS Bulletin* 53: 89-97.

SALTPETER BEDS: A REVIEW OF NITRATE PRODUCTION IN COMPOST HEAPS

WARREN C. LEWIS, M.D.
2225 Oxford Street
Rockford, IL 61103

Saltpeter beds were developed in Europe from the fourteenth through the eighteenth centuries to make saltpeter, the chief ingredient of gunpowder. To increase the supply of niter through five centuries of warfare, powder makers turned to old agricultural techniques. Especially treated compost heaps were developed to augment the supply of nitrates from natural sources. The techniques apparently originated in the Far East and spread westward. Artificial beds were first recorded by European writers in the fifteenth century. As the practice spread over Europe the industry took a variety of forms in different localities. Some, for example, used pits, others beds and some made walls of the mixtures.

In England in the sixteenth century, an elaborate composting plan was put into practice. This process was worked out in detail according to a German formula and apparently could be counted on to give good results. It functioned so well that it made England independent of foreign suppliers. The artificial beds were much used in France during the Napoleonic Wars. The use of the gardens recurred in the mid-nineteenth century in America. As the War of Secession progressed, the Confederacy could no longer depend on the supply of natural saltpeter. Artificial beds were established to help supply the wartime demand. Many Southern cities became involved in furnishing supplies for these beds. The niter piles were well underway at the cessation of hostilities. The primary free-living nitrate bacteria are reviewed.

INTRODUCTION

It is likely that the study of saltpeter originated in the examination of crusts and excrescences which formed on the surface of certain rocks. These incrustations occurred on the foundation walls of buildings, on rock walls, near refuse dumps and on the walls of open drains and sewers. Later saltpeter was extracted from rich dirt around villages, from dry lakes, and from a few European caves. One early use of saltpeter was in the manufacture of fireworks for use during celebrations and church festivals. Gunpowder is reported to have been used at the battle of Mecca in 690.[1] Saltpeter appeared in European literature in about the 10th century. In the 14th and 15th centuries, improvements in iron metallurgy and increased mastery of the art of propulsion led to the widespread manufacture of small arms and cannons. With heightened need for gunpowder, the demand for saltpeter increased greatly.[2]

Although saltpeter was available from India, particularly at Patna, every country in Europe set about to develop its own source of supply.[2] To accomplish this, a type of enriched compost heap was developed which would eventually produce nitrates. The chief product of the artificial niter bed or *nitriére* was calcium nitrate also known as *wall saltpeter* or *cave saltpeter*. This salt was obtained by scraping crusts off the wall of the piles or by leaching the contents. The calcium nitrate, through chemical reaction with potash or wood ashes, was converted into potassium nitrate or *true saltpeter*, to be refined for use in gunpowder. It was also used for pickling meat and in metallurgy.[3]

During the processing, unwanted salts such as carbonates, sulfates and chlorides, as well as soil colloids, were removed. Both calcium and potassium nitrate in common parlance were referred to as saltpeter (saltpetre) or niter (nitre). Crude solutions of saltpeter and their products were graded by the degree of purity as black or red, and by crystal size or by the form of solid blocks. By-products of nitrate refining such as Epsom Salts (magnesium sulfate), Glaubers Salts (sodium sulfate), and magnesium oxide were used in medicine or industry. Other nitrate salts were also found as incrustations on walls: sodium nitrate known as *cubic saltpeter*, ammonium nitrate as *flaming saltpeter*, and magnesium nitrate as *bitter saltpeter*, but these were not known to the ancients.[1]

CHINA AND INDIA

The practice of niter farming is of very ancient origin and probably was first brought to a state of proficiency in China.[4] The rice crop had its own source of nitrates in blue-green algae symbiotic with *Azolla*, a small aquatic fern that thrived in the zone of diminished light in the flooded rice paddies. However, land used for other crops needed renewal of nitrates to sustain production. Animal and human wastes and crop residues traditionally went into the compost heaps on the Chinese farm. Not only farm waste was used but also roadside weeds were harvested and pond plants dredged up for the compost pile. Even today, human waste from cities and villages is returned to the fields. Roadside privies were set up in rural areas with a sign which encouraged the traveler to leave a contribution for the fields.

The mineral and organic content of the compost pile was thus returned to the land but without special handling of the decaying heap, little nitrate was formed. Some ancient farmer observed that by treating the refuse pile with animal products, earth, lime, and urine, and allowing moist decomposition in air, the yield of the crops was increased. From this knowledge came a system which was the base of the artificial production of nitrates. The end product could be leached out of the pile, treated with potash, and crystallized to form an article of commerce. All of the saltpeter of commerce, whether from natural or artificial sources, was extracted by crystallization from solution.

The knowledge of this combination of several ingredients came to Europe by way of India, through the Arabic alchemists. The Arabs recovered saltpeter near Babylon and made gunpowder, possibly from natural sources. Sometimes only parts of the technique were known. It was reported in Egypt that refuse heaps covered with earth along the road between Old and New Cairo, could be lixiviated for saltpeter. Surprisingly, the product was true saltpeter.[5] Early saltpeter was very expensive. The principal trade route was through Venice.[6] For years the Indian trade was in the hands of Dutch shippers who had a monopoly on saltpeter. Later, the British joined the Dutch in this trade.

THE EUROPEAN CONTINENT

Possibly the earliest European reference to nitre pits was in a book on military technology. Kyeser, in 1405, in Germany, suggested that wood ashes be added to the pits as well as lime. Each layer was to be sprinkled with salt water, urine or wine. Afterward another layer of quicklime was to be added with more watering on the above. Layer was to be added upon layer until the hole was full. He also proposed that similar work could be done in large pots.[3]

Moistening the piles with urine became a standard procedure. The use of wine and salt water was less common. The rationale for the use of wine, aside from its water content, is unclear. Decomposition of the sugar and alcohol content could furnish little nutriment for nitrate bacteria. The lees of wine did add potassium. Salt water would also seem to be an unlikely ingredient. Nitrate bacteria do not thrive in saline soil and are unable to grow in normal saline (0.9%). The use of wood ashes in the pile eliminated the need for a separate conversion step to obtain true saltpeter. Potassium, although required in small amounts, in large amounts inhibits the growth of nitrate bacteria.

In 1480, in a German Housebook it was stated that to "draw" saltpeter, a pit was filled in alternate layers of two finger's breadth of quicklime, dried straw and a foot thick of earth. Every day for three weeks urine was to be poured over the mass. Then the earth was extracted with hot water in a large copper pot. One vessel used was 12 feet (3.6 m) in diameter. The solution was to be boiled down, poured into wooden vats and allowed to crystallize. In 1483, saltpeter was exported from Germany to Milan.[6]

Straw, which is principally cellulose, for a long time was thought to facilitate nitrate production. Many of the formulas include straw. It is relatively inert and breaks down slowly in the compost pile and thus may help maintain aeration. Straw used for bedding animals contained manure and urine. The time frame of three weeks in this process appears to be too short for appreciable nitrate production. The large amount of earth seems to be out of proportion to the other ingredients.

In 1556, Agricola, in Germany, advised the saltpeter worker to expose the earth from which the saltpeter had been leached, under the open sky, together with branches of oak or similar trees, and sprinkle with water containing saltpeter. After five or six years, the piles were again to be ready to make into solution.[7]

Since saltpeter, itself, tends to inhibit the growth of *Nitrobacter*, this use would seem to be unwise. Could addition of a solution of saltpeter have been confused with addition of urine? Exposure to the open sky would invite loss of nitrates by leaching during rainfall. In contrast to oak ashes, oak branches would seem to be a poor way to add potassium to the pile even if that were desired. Perhaps the oak branches were to ward off rain. This description of a bed for rejuvination of spent saltpeter earth seems to be quite inadequate and inappropriate. It may have become garbled during transcription from an earlier manuscript.

Agricola is known to have taken much of his information from Biringuccio. Biringuccio's method, published in Italy in 1540, used a primary material, pig-dung, which was to be kept in a dry place for a long time and then mixed with earth. He also used human urine to moisten the niter beds.[8] Ercker, in Hungary in 1574, in a treatise on ores and assaying, recommended use of earth from old sheep pens and stables and mortar from old walls. He extracted the earth with water and poured it into a tub of wood ashes. The pits were to be watered when the moon was waxing.[9] This practice would be equivalent to a 28-day moistening cycle.

It was not long before many sorts of things were being added to the pile. Glauber, who lived in Germany 1604-1670, added horns, hoofs, bones, feathers, bird dung, scraps of leather, bits of cloth, roots of trees, shells, coral and wood ashes to the pits. He attached great importance to the moisturizing of the pits with urine. The human urine that was recommended by him was to come not only from his own house, but also as much as he could get from the houses of his neighbors.[10] It was his ambition to make Germany self-sufficient by producing its own saltpeter.[24]

In the 18th century, the King of Prussia prescribed that every settlement, town or village should have its own bed of broken masonry, compost and vegetables, protected by a shed.[9]

Henshaw, in England in 1665, used earth, pigeon dung, and horse manure along with urine.[6] Boerhaave, in the Netherlands in 1753, urged the use of the urine-soiled plaster of ruined buildings.[11] Building rubble was widely used in beds in the Netherlands and England.

Some niter beds were developed as trench-like pits up to five feet deep. Others were spread out in loose, slightly elevated heaps sometimes called *gardens*. Some beds remained simple affairs, barely thrown together and unprotected from the weather. Others were of more elaborate construction with paved floors, low stone or brick walls, and open sides. Roofs were sometimes constructed in a flimsy way with tree branches or slats. Other beds were built in a permanent manner of stone walls and roofed by an arched stone vault.[9] Sometimes there was a paved trench with a stone wall higher on one side than the other. The higher wall usually faced northwest, the direction from which most storms came.

In the Prussian system, the mass was shaped into a wall with one steep or vertical side. On the other side was a series of hollowed out steps. Water was poured into the gutters on the steps to percolate through the mass and facilitate crust formation along the vertical side. The crusts were scraped off the vertical face from time to time and fresh materials added to the steps. It took about three years for a niter bed to become fit for extraction.[12] Some operators did not add material haphazardly. The ingredients were carefully layered in fixed proportions and the contents turned regularly.

Many medieval cities such as Halle, Germany, used piles of refuse outside the city gates for production of nitrates. In 1545 the town magistrates operated a saltpeter works and powder mill.[1] Often the city refuse was piled in long walls to make collection easier. The citizens hoped that enough saltpeter would be produced so that the officious collectors would not have to scrape the crusts off their basement walls or dig up their cellars. All saltpeter and saltpeter earth, wherever found, belonged to the ruler by regalia, the Right of the King. His collectors could take any material they wished from ruined buildings and even from occupied dwellings. This law was hated almost as much as the hunting regalia that reserved all wild game for the ruler.

It might be noted that manure mixed with water was sometimes used as mortar in building walls. Fortifications such as the 40-foot walls built at Yarmouth, England in 1587 were so constructed. As the mixture dried, the building materials were strongly bonded together. Such walls would provide ready sites for growth of nitrate bacteria.[3]

Urine was a key ingredient to speed up the growth process in the piles. Through hydrolysis, the urea in urine provided a ready supply of ammonia. Many of the putrifying bacteria in the compost heap contained urease, the urea-splitting enzyme. Periodic application of urine gave a repeated stimulus to rapid logarithmic growth of nitrate bacteria. Growth could be sustained through ammonia from destruction of plant and animal tissues as the piles matured. Fermented urine was the classic source of ammonia for the alchemists. However, urine alone, without other ingredients, would not produce nitrates.

The importance of lime in the artificial nitrate process was emphasized by several early writers.[25] The form of lime which was used seems to have depended primarily on that which was available locally and was least expensive. Quick lime, a relatively pure form, seems to have given way to old plaster and mortar, or chalk from the quarries. In practice, any carbonate material could be used to neutralize the strongly acidic nitrate ion. The beds were reported to be ready in about two years and to be exhausted by the end of the third year.[13] By this time the putrifaction of organic material would be nearly complete unless the supply were renewed.

England

In 1561, two English merchants, Phillip Cockeram and John Barnes, obtained a ten-year license from the British Government to make saltpeter. They proposed to use a German method which they obtained from Gerard Honrick(e), a native of West Friesland. For this recipe they paid the princely sum of 300 pounds. The English were forced to pay for the process because the details of the niter-beds on the Continent were a trade secret.[3]

Making of Saltpeter: Honrick's Recipe[17]

The true and perfect art of the making of saltpeter to grow in cellars, barns or in lime or stone quarries.

The nature of saltpeter is to grow in places cold and dry, where neither sun nor rain entereth, nor spring resort, for the drier and colder the place be, the sooner and better do they bring forth saltpeter. And to make the mother of saltpeter these things following be requisite. First *black earth* the blacker the better. The next is *urine,* namely of those persons which drink either wine or strong beers. The *dung* especially of those horses, which be fed with oats and be always kept in the stables. The fourth is *lime* made of Plaster of Paris. The lime which is made of oyster shells is the best, and better than the other if it be kept from rain and water. The lime which is made with other stone is worth nothing for this purpose because it binds too much and has no saltness to it.

And to the intent that those things may be conveniently ordered, first the earth is to be made as dry as dust and the stones are to be sifted out. Then the urine is to be stilled through fresh horse dung and the lye coming thereof must be kept in great fattis or hogsheads wherein must be put a fourth part of unslaked lime and one pound of coarse or refuse saltpeter and the earth must be watered with the lye in like sort, as we water lime or mortar, which we use for building, all which things must be well mingled together.

[The passage of urine through horse manure is unique to this particular formula. The urine thus became enriched by addition of salts and might be seeded with urea-splitting bacteria (see Note 22). It was also buffered in its container by adding lime. The purpose of the addition of saltpeter is unclear. It may have suppressed growth of some putrifactive bacteria since it is mildly bacteriostatic. Possibly it inhibited the reduction of sulfates, thereby reducing the odor.[29]]

And to the aforesaid horse dung which is before steeped, let there be a greater quantity of fresh horse dung added; and after it be so blended, let the same be mixed with the earth for when it is putrified it doth give dryness, and heat to the earth: and because saltpeter proceeds of dryness, and coldness, and those kinds by nature be cold, and dry; that is to say, the earth and urine cold; the dung hot and dry; and the lime salt and dry. Therefore as soon as the lye shall be mingled with the lime, it must soon after grow, so as the same be due in place mete for the purpose.

[Use of these elemental terms shows the inadequacy of alchemic language to define the nature of chemical reactions and the characteristics of chemical substances including saltpeter. However, it was recognized that the process started at once.]

The places mete for this mingling of the lye with the lime, be quarries out of which that kind of stone which is called plaster is dug, so as the same be neither moist nor subject to rain or spring. Barns also standing of that height as there may be five foot depth dug in them. Moreover vaults in the cellars of monasteries and ruined houses of religion where the windows may be shut and the storms [winds crossed out in manuscript] kept out, and be free from rain and moisture: for it is especially to be looked into that the houses be watertight. But it is better to prepare some convenient place wherein such things as are hereunto requisite may be which is to be made as follows.

Take new brick as it comes out of the kiln, which has never received rain or other moisture, and let it be watered with that lye whereof we have spoken, and let it lie soaking till it be thoroughly moistened; and lay your brick with the lime that is tempered with the said lye, and take the said dry earth instead of sand, and so make your wall. . . .

The floor or pavement must be made with the self same brick and mortar that the wall is of. And the lime which is sunk down to the bottom of the kiln is to be taken out and rested upon some floor to dry may be beaten small and mingled with the earth. . . . The pieces of lime may be made as small as the thickness of a man's finger whereunto you may put that rubbish, which cometh of the breaking of said lime.

The earth is to be at least 3 feet deep, worked and turned like a garden and not walked on. At fourteen days end after the said earth shall be first labored, it must also be turned as men do turn wheat, so as the nether part must be turned upward, to the intent that the earth may be made dry. The like must also be done again three weeks after, and then every month until you may perceive that there is a good quantity of saltpeter. The walls and vaults must be swept often, for the saltpeter will hang like snow upon them. . . .

The [spent] earth is to be treated in the same way as the original and can be leached twice after one year. Excess of wood ash can be treated with sea cole [sea cabbage]. The best source of potash is oak leaves. The remnants of the lye must be diligently kept, to water the earth, as often as it is formed, which watering must be in a wrane as is used in the bleaching of linen cloths in the sun. Urine is fit for the making of the lye, albeit it be hard to come by. . . .[17]

Apparently this process was diligently applied and the users achieved great success. By the end of Elizabeth's reign, England was able to produce not only enough saltpeter for her own needs but also enough for export to the Netherlands, Venice and Turkey. One site of production is known. A map dated 1593 shows a "Donghill" on the land of a gunpowder manufacturer, one Hugh Sheale of Ipswich.[3] Undoubtedly there were other sites.

Since the science of microbiology was unknown, nitrate technology was slow to develop. It evolved through much experimentation and guesswork. In this respect it resembled the art of fermentation of grain and fruit and the raising of bread dough. Early descriptions of saltpeter production are often fragmentary. Many sources mention the leaching of nitrous earth but fail to give the source of the earth. Possibly the chemists wished to preserve some degree of secrecy to their methods. Until the end of the 18th century the entire chemical industry was shrouded in secrecy.[10]

SWEDEN

In Sweden, animal carcasses, fish and bones were added to the earth from under farm buildings to make saltpeter. For several centuries the government had regulated saltpeter production in rural Sweden. Swedish farmers, as well as those in territories on the other side of the Baltic, were obliged to provide saltpeter, about 10 pounds per year, to be delivered to the government. The large pans used for extraction were moved by wagon from farm to farm. This developed into big business. In 1827, a column of some 340 horses carried more than 40 tons of niter about 400 miles from Northern Sweden to powder works in Middle Sweden. The journey took several weeks. Farmers living at a great distance from the niter houses asked that a cash payment be substituted for the saltpeter. The conversion to money developed into a burdensome system of rural taxation.[14]

FRANCE

The long wars during the reign of Louis XIV caused a considerable increase in the production of saltpeter in Europe. In France, the consumption of saltpeter tripled between 1690 and 1700. Not until the 18th century, and especially the last third of that century, were artificial niter beds systematically built and maintained. Production again was heightened during the Napoleonic Wars due to the blockade. The beds were covered after it was noted that beds built in the shade produced more than those in the sun.[15] In 1844 the process used in the artificial *nitriéres* was slightly different. Heaps of a mixture of earth, manure and chalk were built inside wooden sheds. They were watered with urine and industrial waste water such as that from the textile works. The water from washing raw wool was a source of potassium carbonate. The heaps were either aerated by pipes or turned by hand from time to time. After about two years the crude saltpeter was extracted from the heaps with hot water.[26]

UNITED SATES OF AMERICA

In 1816, Parker Cleaveland, Brunswick, Maine, issued a handbook for visitors to America. According to him, artificial niter beds were prepared in which were placed earths from the vicinity of inhabited buildings, old plaster, vegetable matter, etc. To these were added blood, urine, etc. After sufficient time, the earth which remained in these beds was lixiviated and an impure niter was obtained.[16]

During the War Between States, there were uncertainties about a continued supply of saltpeter from caves and through importation. The Southern Confederation started saltpeter beds. In the environs of Richmond, Virginia, the capital of the Confederacy, were noted large earthen ricks and heaps. These contained dead horses and other animals, designed for use in the manufacture of niter. The Niter Board adopted the *bed* or *heap* method, rather than the *pit* design widely used in Europe. Near Selma, Alabama, one group of niter beds lay to the north, beyond the Alabama & Mississippi Railroad tracks. Reports indicate that the ground was covered with hundreds of small mounds of petre-dirt in various stages of preparation for leaching.[18]

To facilitate nitrate production in the beds, urine was collected from civilians, as it had been in Europe. The following advertisement was published in the *Selma Sentine:*

> The ladies of Selma are respectively requested to preserve all their chamber lye collected about their premises for the purpose of making nitre. Wagons with barrels will be sent around for it by the subscriber.
>
> John Harolson, Agent, Nitre and Mining Bureau.

Although the purpose of collection was deadly serious, this ad provoked a series of waggish jingles to be written and circulated as far away as Boston.[19]

Niter beds were established not only at Richmond and Selma but also at Columbia, Charleston, Augusta, Savannah, and Mobile. Some 550 men were engaged in working the beds. The Nitre and Mining Bureau by the end of 1864 had more than two million cubic feet of earth in various stages of nitrification, from which it expected to recover an average of 1.5 pounds of nitre per cubic foot.[20] The war ended before the beds became ripe. The end of hostilities and a drop in price brought to a close this wartime activity.[21]

To the agriculturists, for a long time it was a mystery how nitrates, which were consumed by growing plants and also were washed away by the rain, were returned to the soil. Louis Pasteur, pioneer French microbiologist, in 1862 suggested that the production of nitrates in soil was of bacterial origin.[27] Schloessing and Müntz, working with sewage, in 1877 showed by experiment that nitrification was due to living organisms. Warrington, in England, in 1878 demonstrated that it was a two-step process: ammonia to nitrite, and nitrite to nitrate. Winogradsky in 1890 isolated the two responsible organisms, one of which bears his name.[31]

Saltpeter in nature was found in rich soils containing large quantities of organic matter. It was very surprising, when nitrate bacteria were at last isolated, that they turned out to be metabolically independent of organic matter (i.e., autotrophic). These bacteria were unable to metabolize most sugars, organic acids and, in fact, could utilize hardly any organic substances. They could only deal with ammonia or nitrite for energy. Bacterial carbon for growth was obtained, by necessity, from carbon dioxide or carbonates. These limitations may reflect the prokaryocytic origin of the nitrate bacteria which is associated with a limited amount of DNA. They have about 80% of the DNA possessed by other bacteria. Not only could they not metabolize complex compounds but often were unable to grow in their presence. The literature is filled with descriptions of failed cultures.[30] Even agar plates had to be especially prepared by prolonged washing in order to support the growth of these bacteria.[22]

Two soil bacteria, *Nitrosomonas europaea* and *Nitrobacter winogradskyi* are widely distributed over the surface of the earth. These two are by far the most prolific independent producers of nitrates in surface soil. They account for most of the nitrate produced in soils outside of the nodules on roots of plants. They are believed to be the prime nitrifiers in compost piles. They have been found by all other workers who have looked for nitrifying bacteria in soil and they are usually the only bacteria regularly found.[3] The two bacteria, working together, are estimated to produce 300 million tons of nitrates each year worldwide. Unfortunately, they are responsible for some of the destruction of stonework and concrete.[6]

They are not to be confused with the *Rhizobium* species that thrive in nodules on the roots of certain legumes. The *Rhizobia*, which are very important nitrifiers, cannot nitrify outside of plant nodules. *Nitrobacter agilis* is the cave species found by survey to constitute about 80% of the Mammoth Cave population. It posesses motile juvenile forms.[23] *Nitrobacter* is not dependent on exogenous ammonia.

Oxidation of nitrogen compounds is the primary chemical activity of the nitrifiers and is linked to their period of active growth. The oxidation process provides all the energy needed for their growth. These bacteria possess a powerful oxidizing system. Because of this system, *Nitrobacter* has the highest respiration rate of any living creature. Growth, however, is slow by most bacterial standards, with a doubling time of 8 to 42 hours. By way of comparison, the reproduction time for E. coli is 20 minutes.[23]

The two bacteria are often found together in nature, living together in sticky masses called zoogloea, or adhering to carbonate particles. They function symbiotically in a very narrow pH range (pH 6.6-8.0). The pH is restricted to a narrow band close to, or slightly on the alkaline side of the neutral point. This restriction in pH is greater than that found in most metabolic processes but is close to the range of function of blood serum. By occupying sites on carbonate particles, bacteria may find a micro-climate suitable for nitrate development even in unfriendly soil. Juvenile forms, which appear during rapid growth, are free-swimming and by chemotaxis move to sites that are chemically favorable.

Carbonates are the primary buffers in natural and artificial beds. Neutralization of acid allows the bacteria to produce the strongly acidic nitrate ion without acid inhibition. Under aerobic conditions, nitrate synthesis, although slow, will outstrip nitrate decomposition. In compacted or flooded soil, growth is slow because of reduced oxygen. Oxygen diffuses 10,000 times faster in air than in water. Nevertheless, nitrate production continues on the surface of soaked soils. These bacteria prefer to live in the dark in moist, airy soil. *Nitrobacter* can only grow in the dark. The energy system of this bacterium is inactivated by light due to photo-oxidation of cytochrome C.[28]

In neglected saltpeter beds and in poor soils, ammonia is in short supply. When nitrite ion is low, *Nitrobacter* will synthesize ammonia from the air. By use of its enzymes, nitrogenase and hydrogenase, and a powerful respiratory system, it "fixes" nitrogen. Even though the process is enzymatic, it requires a great deal of bacterial energy. In deficient environments as much as 80% of the bacterial energy may be devoted to nitrogen fixation. The energy for fixation is derived from oxidation of nitrites. This means that *Nitrosomonas* must be present and growing for the oxidation to proceed. Each bacterium depends upon the other. With a deficiency of ammonia, the rate of growth of each one is retarded. Saltpeter formation in nitrate beds slows down to a low level when composting is complete.

ACKNOWLEDGEMENT

The assistance of the Rockford Public Library, The Northern Illinois Library System; Rockford College Library; Bill Torode and the NSS Library; Nancy Dale and St. Anthony Hospital Library; University of Chicago Press; Kentucky Library; Department of Library Special Collections, Manuscripts, Western Kentucky University, Bowling Green, Kentucky; Marion O. Smith; Angelo I. George; Carol A. Hill; and anonymous reviewers is gratefully acknowledged.

NOTES

1. Beckmann, John, 1846, A History of Inventions, Discoveries, and Origins, Henry G. Bohn, London, p. 485.

   Some Indian saltpeter came from the soil around houses and near the village water supply. However, much was extracted during the dry season from the soil of dried up cattle ponds which had been inundated during the rainy season. It was reported to form at times a white crust on the ground. Trenches were dug across these fields, water was admitted and the mud mixed by trampling. The heat of the sun was used for evaporation and drying. Crude saltpeter in later years was relatively inexpensive and was carried like ballast in the holds of ships returning to Europe.

2. Daumas, Maurice, 1969, *A History of Technology and Invention*, Vol. 2, Crown Publishers, Inc., New York, p. 174.

   Konrad Kyeser was born in 1366 at Eichstadt, a small city in Bavarian Franconia, halfway between Munich and Nuremburg. He was forced into exile in the mountains of Bohemia in 1396. There he composed his work, *Bellifortis,* which was dedicated in 1405 to Emperor Ruprecht of the Palatinate. He was primarily a military engineer. He is credited with the first description of "tanks" and machine guns. He briefly outlined saltpeter beds and also described in rather vague Latin a method of making saltpeter in pots.

3. Williams, A. R., 1975, The Production of Saltpetre in the Middle Ages, *Ambix,* Vol. 22, Part 2, July, pp. 125, 133.

   This historian explored the early purchasing of saltpeter in England and found a number of obscure documents relative to its use. By experiment, he showed that manure and earth alone or manure and earth mixed with lime did not produce nitrates. Urine alone did not produce nitrates. He also found that nitrification started at the top of the pile and worked downward.

4. Fowler, Gilbert J., 1928, Studies in intensive bacterial oxidation of ammonia to nitric acid, *Journal of the Indian Institute of Science,* Vol. 10A, p. 97.

   In India, there was experimental production in large vats of liquid waste. The industrial process needed heavy seeding with bacteria, replenishment of material and constant buffering for successful operation. Too much ammonia at the start was harmful to the process. The upper limit of concentration of saltpeter was 7.5%. In cave soil the concentration is rarely over 1.0% and the greatest concentration is about 2.0%. Dialysis may be a useful technique for continuous production.

5. Allen, L. A., 1949, The effect of nitro-compounds and some other substances on the production of hydrogen sulfide by sulfate-reducing bacteria in sewage. *Proceedings of the Society of Applied Bacteriology,* p. 26.

6. Partington, J. R., 1960, *A History of Greek Fire and Gunpowder,* W. Heffer and Sons, Ltd., Cambridge, p. 315. Also see his *Origin and Development of Applied Chemistry,* 1935, on nitre, pp. 149, 298.

   Some Indian saltpeter came from the soil around houses and near the village water supply. However, much was extracted during the dry season from the soil of dried up cattle ponds which had been inundated during the rainy season. It was reported to form at times a white crust on the ground. Trenches were dug across these fields, water was admitted and the mud mixed by trampling. The heat of the sun was used for evaporation and drying. Crude saltpeter in later years was relatively inexpensive and was carried like ballast in the holds of ships returning to Europe.

Mittelalterliche Hausbuch, c. 1480, probably was written in South Germany as a workbook of practical procedures.

Henshaw, Thomas, 1667, The History of the Making of Saltpetre, and 1665, *Phil. Trans.* i, 33, No. 3, p. 314.

Here are found many practical remarks on saltpeter which were subsequently repeated by others.

7. Agricola, Georgius, 1556, *De re metallica,* libre XII, English translation by (President) Hoover, H. C. and Hoover, L. H., 1912, London, reprinted 1950, p. 564.

   Agricola was a prolific German who, despite the implications of his Latinized surname, collected and summarized the current knowledge of metallurgy and mining. He described the production and use of saltpeter in the purification of precious metals. His works were beautifully illustrated with woodcuts and were used as textbooks through the following century.

8. Biringuccio, Vannuccio, 1540, *De la Pirotechnia,* Venice.

   He traveled extensively in Italy and Germany and wrote an Italian work that is one of the early classics in metallurgy. It describes casting, glassmaking, smelting, ores and minerals, assaying, and chemical processes. In Book X he gives what is said to be the earliest detailed account of extracting and refining saltpeter.

9. Ercker, Lazarus, 1574, *Treatise on Ores and Assaying,* translated by A. G. Sisco and C. S. Smith, The University of Chicago Press, Chicago, 1951, Book 5, Saltpeter, p. 127.

   He served as a superintendent of the mines of Hungary, Transylvania and Tyrol for the Emperor Rudolph II, and wrote this important work in German.

   [In Book 4, 1574, he noted the usefulness of the lodestone, a natural magnet, in stroking the needle of the compass used by miners in the pits in the magnificent and praiseworthy art of surveying.]

10. Glauber, Johann Rudolph, 1604-1670, Teutschlands Wohlfahrt, 1660, *Various Cheap and Easy Ways of Making Salt-petre.*

    This German author of many works on chemistry, medicine and metallurgy is sometimes called the first real chemist. At the age of 21 he discovered the medicinal value of sodium sulfate which has been known since as Glauber's salt. He described and illustrated the preparation of saltpeter and improved the methods of extraction. His death followed a lingering illness possibly brought on by exposure to poisonous chemicals.

11. Boerhaave, Hermann, 1724, *Elementa Chemiae,* translated by Peter Shaw, London: T. & T. Longman.

    This Dutch physician, botanist and chemist, whose fame was worldwide, taught a generation of chemists from all parts of Europe. He was an outspoken advocate for peace.

12. Craig, B. F., Report on Nitrification, *Smithsonian Institute Annual Report for the Board of Regents,* 1861, pp. 305-331.

13. Attfield, Professor, *Chemistry: General, Medical and Pharmaceutical,* cited in William Eggert, Jr., 1935, *The Fountain of Youth, Health and Rejuvenation,* 62 Kingston Avenue, Brooklyn, NY.

    Extraordinary medical powers were attributed to saltpeter by Mr. Eggert to cleanse tainted blood.

14 Ahslund, Bengt, 1975, A rural war industry: The impact of saltpetre production in Sweden, *Acta,* International Commission of Military History, p. 63.

15. Boussingault, J. B., 1844, Economie rurale, Paris: Déchet Jeune.

    He showed that plants could decompose water, releasing oxygen and fixing hydrogen. This allowed the plants to make fats and oils high in hydrogen.

16. Cleaveland, Parker, 1816, *An elementary treatise on Mineralogy and Geology,* published by Cummings and Hilliard, No. 1, Cornhill, Boston, MA. Printed by University Press, Cambridge, England, p. 110.

    This treatise by a professor at Bowdoin College was for use of pupils and travelers in the United States of America. In noting that saltpeter invests the sides of caverns and fissures in calcarious rock, which it often corrodes, he was ahead of his time. The site at which saltpeter gardens were constructed was not specified.

17. Honrick, Gerard, 1561, Making of Saltpeter, *Calendar of Patent Rolls* (Elizabeth I, 1560-1563, II, 98, 104, and *Calendar of State Papers,* Domestic (Charles I), 1641, 75, 487 (B). The report has been shortened and punctuation revised.

18. Miles, Dr. Wynkham D., 1961, The Civil War, *Chemical and Engineering News,* April 3, pp. 108-123.

    This informative report is written in colorful journalistic style on Civil War chemistry and chemists.

19. Jackson, Walter M., 1982, *Women, Nitre and Verse,* York Grotto Newsletter, Vol. 19, No. 2, March, pp. 36-39, from Jackson, Walter M., 1954, *The Story of Selma,* pp. 199-201; from the Burton Faust Collection.

    Material is by courtesy of the Kentucky Library, Department of Library Special Collections, Manuscripts, Western Kentucky University, Bowling Green, KY.

20. Powers, John, 1981, Confederate Niter Production, *NSS Bulletin,* Vol. 43, No. 4, pp. 94-97.

    Many details of Southern nitrate production can be found here.

21. Mallet, J. W., 1909, Work of the Ordnance Bureau of the War Department of the Confederate States, 1861-1865: *Southern Historical Society Papers,* 37:9.

22. Alexander, M., 1977, *Introduction to Soil Microbiology,* John Wiley and Sons, NY, pp. 238, 313.

    He has much to say about the role of bacteria in soil. Several chapters are devoted to the complex role of nitrate bacteria in natural surface soils. The bacterial formation and degredation of nitrates is discussed.

23. Fliermans, C. B. and E. L. Schmidt, 1977, Nitrobacter in Mammoth Cave, *International Journal of Speleology,* pp. 1-19.

    Numerous samples of cave soil were tested for *Nitrobacter.* He found an average of 62,000 of these bacteria per gram in many samples of Mammoth Cave soil. They were also found in other saltpeter caves in the surrounding area.

24. Weeks, M. E., 1960, *Dictionary of the Elements,* Mack Printing Co., Easton, PA, p. 190.

    An engaging history of the elements and their compounds is presented here.

25. Faust, Burton, 1949, The Formation of Saltpeter in Caves. *NSS Bulletin,* No. 11, November, pp. 17-23.

    This work is the result of much study of the process of nitrification in nature. His collected material is preserved in the University of Kentucky Library, Department of Library Special Collections, Manuscripts, Bowling Green, KY.

26. Meiklejohn, Jane, 1953, The nitrifying bacteria: A revue, *Journal of Soil Science,* Vol. 4, No. 1, p. 59.

    This work is from the Rothamsted Experimental Station in England which is the site of early and continuing studies of nitrate bacteria in soil.

27. Pasteur, Louis, 1862, Etudes sur les mycodermes. Role de ces plantes dans la fermentation acétique, Compt. Rend. Acad. Sci., Paris: 54:265-270.

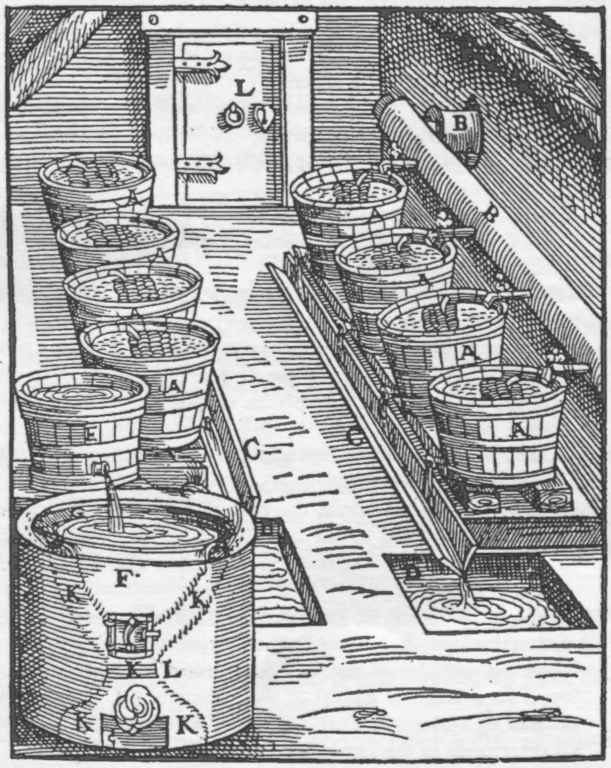
This French microbiologist was a pioneer investigator of numerous important diseases caused by minute organisms. He discovered the essential nature of fermentation. He was the first person to successfully treat rabies and gave his name to a process for control of bacteria in milk by moderate heating. He demonstrated that vinegar was formed by a biological oxidation. Apparently this led him to suggest that nitrates might be formed in soil by a similar process.

28. Hill, Carol A., 1981, Origin of Cave Saltpeter, *NSS Bulletin*, Vol. 43, No. 4, pp. 110-126.
Much data has been gathered with the help of Cave Research Foundation teams on the presence and location of saltpeter in caves. Guano caves, with an obvious source of ammonia, in some ways resemble artificial beds. The controversial theories of the source of nitrates are examined in light of the evidence from several types of caves.

29. Postgate, J. R., 1960, The economic activities of sulfate-reducing bacteria, *Progress in Industrial Microbiology*, Vol. 2, p. 49.

30. Mishustin, E. N., and V. K. Shil'nikova, 1972, Biological Fixation of Atmospheric Nitrogen, Pennsylvania State University Press, University Park, PA.
This publication reviewed information from several hundred papers which were mainly of Russian origin. It illustrated the confusion that permeated the entire field of nitrate bacteriology. Extreme variation is noted between various reports. Experimental results often proved to be difficult to duplicate. Much of this was due to the problem of obtaining and maintaining pure cultures. Some of these difficulties have persisted to the present time.

31. Lewis, Warren C., 1989, Some historical speculations on the origin of saltpeter, *NSS Bulletin*, Vol. 51, No. 1, June, pp. 66-70.



[FIGURE 39.—LEACHING VATS AND THE BOILER IN A SALTPETER WORKS]

A—The eight vats with earth, in which the earth is leached. *B*—The pipes through which the water runs into the vats. *C*—The gutters in which the liquor runs into the sumps. *D*—The sumps in which the liquor is collected. *E*—The little vat from which the liquor runs into the boiler. *F*—The furnace. *G*—The boiler. *H**—The little iron door through which wood is pushed under the boiler. *I*—The draft hole down in the furnace. *K*—The shape of the furnace inside. *L*—An iron grate on which the wood rests.

* Note that there is no *H* in the figure and that there are two *L's*, one on a door, but not the firebox door.

[130] [FIGURE 40.—PANS AND TUBS FOR CRYSTALLIZING SALTPETER]

A—The tall, slender vat in which the concentrated liquor cools. *B*—The furnace containing the boiler. *C*—The master who prepares the concentrated liquor and, removing the salt with a ladle, puts it in a little basket resting over the boiler on rails so that the strong liquor that was left on the salt can drain back into the boiler. *D*—The little basket on rails. *E*—The small vat from which strong liquor runs into the boiler. *F*—The pans in which the crude saltpeter crystallizes. *G*—The four tubs sunk in the ground, in which the crude saltpeter crystallizes. *H*—A strong vat into which the liquor is poured that remains after crystallization.

This woodcut appeared in the 1580 edition of Lazarus Ercker's *Treatise on Ores and Assaying*. It was reproduced in a translation by A. C. Sisco and Cyril Stanley Smith, published by the University of Chicago Press in 1951. Permission to use this material was gladly granted by Perry Cartwright, Permissions Editor, The University of Chicago Press. Cyril Stanley Smith was of the opinion that the copyright expired about 350 years ago which would place it in the public domain. Mr. Smith graciously referred the author to additional material.

[FIGURE 41.—A SALTPETER WORKS, WITH BEDS AND BOILING-HOUSE]

A—The front part of the saltpeter works, which houses the leaching vats. *B*—The back part, which houses the boiler, and where the boiling takes place. *C*—The old beds from which saltpetery earth is scraped. *D*—Wood for the boiler. *E*—The workman who scrapes the earth from the old beds.

Griffith, David M.—The Effects of Substrate Moisture on Survival of Adult Cave Beetles and Cave Cricket Eggs in a Sandy Deep Cave Site: *NSS Bulletin* 53: 98-103.

THE EFFECTS OF SUBSTRATE MOISTURE ON SURVIVAL OF ADULT CAVE BEETLES (*NEAPHAENOPS TELLKAMPFI*) AND CAVE CRICKET EGGS (*HADENOECUS SUBTERRANEUS*) IN A SANDY DEEP CAVE SITE

DAVID M. GRIFFITH*
University of Illinois at Chicago
Department of Biological Sciences (M/C 066)
Box 4348, Chicago, IL 60680

The effect of slight fluctuations in substrate moisture potential on the distribution and abundance of adult carabid cave beetles, adult and nymphal cave crickets, and cave cricket eggs was investigated in a sandy, deep cave site in Great Onyx Cave, Mammoth Cave National Park, Kentucky. The distribution and abundance of adult cave beetles and cave cricket eggs were correlated with field assays of substrate moisture potential on three different spatial scales, and field enclosure experiments demonstrated the strong effects of substrate moisture on the survival of cricket eggs and adult beetles. These results suggest that abiotic variations may be more important than implied under the "constant cave environment" paradigm.

INTRODUCTION

Abiotic factors have long been recognized as important in determining the distribution of carabid beetles (Thiele, 1977). Recently, biotic factors such as competition have received increasing attention in the literature (Brunsting and Heesen, 1984; Lenski, 1984). Research on carabid cave beetles has had a different emphasis, with abiotic factors receiving little attention (e.g., Kane and Poulson, 1976; Mitchell, 1968; see Juberthie, 1969, for an exception), partly because the cave environment is relatively more constant than the surface environment (Poulson and White, 1969). Variations in abiotic factors such as temperature and relative humidity of the air are so slight that these fluctuations are thought to be unimportant. Consequently, research on carabid cave beetles has focused on biotic interactions such as predation, coevolution, and heterogeneity of prey (Kane et al., 1975; Norton et al., 1975; Kane and Poulson, 1976; Griffith, 1990a).

The cave beetle *Neaphaenops tellkampfi* (Coleoptera: Carabidae) has been the primary object of most of the studies cited above. It is widely distributed among caves of the Pennyroyal Plateau and adjacent uplands in west-central Kentucky. There are four recognized subspecies (Barr, 1979). The nominate *tellkampfi* subspecies is the most abundant and ubiquitous organism found in terrestrial environments in the caves of Mammoth Cave National Park. *N. t. tellkampfi* is a predator on the eggs and of the cave cricket *Hadenoecus subterraneus* (Orthoptera: Rhaphidophoridae), removing a high proportion (> 93%) of the eggs laid in a sandy deep cave environment (Kane and Poulson, 1976; see Hubbell and Norton, 1978, for details on the life history of *Hadenoecus*).

This paper documents the importance of slight gradients of an abiotic factor, substrate moisture, on the distributions and abundances of both beetles and crickets within a deep cave environment. I suggest that adult cave beetles and cave cricket eggs are more limited in their distribution and abundance on finer scales of substrate moisture than previously suspected. I present results from field surveys and field enclosure experiments to support my hypotheses.

METHODS AND MATERIALS

A. *Description of study site*

My study site is the same area used by Kane and Poulson (1976) in their study of beetle foraging in Great Onyx Cave

*Current address: Governors State University, College of Arts and Sciences, Division of Science, University Park, IL 60466, U.S.A.

within Mammoth Cave National Park, Kentucky. The beginning of the study site is located 1.6 km from the only entrance to the cave accessible to humans. This Great Onyx site is 340 m long and averages 10 m wide, encompassing about 3,400 m² of floor area. There are at least three separate vertical shaft complexes within the study site, and two of these certainly provide exits/entrances (approximately 20-30 m vertical distance and 10-20 m horizontal distance to surface openings) for the trogloxenic cave crickets. The floor of the study site is covered with sand containing varying amounts of gypsum and calcite. Temperature is nearly constant at 13.5°C year-round, and the relative humidity of the air is always 92-96% (Poulson et al., 1985).

Kane and Poulson (1976) divided the study site into two areas they called the Front and Back. I divided the site into four numbered locations (I, II, III, IV; Fig. 1), to sample a wider range of moisture conditions in which cave beetles and cave crickets were found. Each location was approximately 24 m in length (see Table II for band census stations encompassed by locations), and had approximately equal amounts of sand and rocks. Locations II and III correspond to Kane and Poulson's Front and Back, respectively.

TABLE I
CORRELATIONS OF ADULT BEETLES AND CRICKETS FROM THE BAND CENSUSES[a]

DATE	Hs/m²	Nt/m²	r	p
AUG '85	0.06	0.08	.151	> .05
DEC '85	0.25	0.26	.466	< .005
JAN '86	0.20	0.11	.509	< .005
MAR '86	0.21	0.24	.519	< .005
JUL '86	0.12	0.27	.060	> .10
DEC '86	0.07	0.11	.240	< .05
MAR '87	0.22	0.18	.750	< .005
JUL '87	0.08	0.10	.400	< .05

[a]The correlation coefficients were generally significant at all times of the year except for summers, when population densities were low.

TABLE II
RESULTS OF THE 0.7 m² QUADRAT SAMPLING[a]

LOCATION[b]	EGGS/m²[c]	BEETLES/m²[d]	MOISTURE POTENTIAL[e]
I.	0.3 (0.0, 0.9)	0.3 (0.0, 0.7)[a]	−15.0 (−20.0, −10.0)
II.	0.9 (0.3, 1.4)	1.0 (0.0, 2.1)[a]	−12.1 (−18.0, −8.0)
III.	0.9 (0.0, 1.8)	5.6 (2.7, 8.4)[b]	−3.1 (−3.8, −1.9)
IV.	0.0	5.4 (2.4, 8.5)[b]	−0.9 (−0.95, −0.8)

[a]Mean values are given, with 95% confidence intervals in parentheses.
[b]Locations: I. = band census stations 4-6 (at edge of "Desert").
II. = band census stations 9-11 (Front).
III. = band census stations 27-29 (Back).
IV. = band census stations 31-32 (Far Back).
[c]$n = 10$.
[d]$n = 10$, letters indicate significant differences at the .05 level by multiple comparisons.
[e]$n = 8$.

TABLE III
BEETLE DENSITY AND SUBSTRATE MOISTURE POTENTIALS ALONG A TRANSECT IN THE BACK AREA[a]

−BARS	NUMBER OF BEETLES/m²
10.1	0.0
9.1	0.5
12.0	0.0
4.2	1.3
9.1	0.0
6.5	1.3
5.3	2.0
3.0	3.0
3.1	4.5
2.9	4.3

[a]Beetle density and moisture potential are positively correlated ($r = 0.88$, $p << .01$).

B. *Distribution and abundance of adult crickets, cricket eggs, and adult beetles in relation to substrate moisture gradients*

A series of 32 "band" census stations were set up along a 300 m transect in order to quantify the distribution and abundance of adult crickets and beetles. Each band was 2 m wide and encircled the entire passage for a total area of approximately 37 m². The center of each band was separated from the center of the next band by approximately 11 m. All adult beetles and crickets and cricket nymphs were censused within each band on nine separate dates over a two-year period (June 1985-August 1987).

Substrate moisture potential in Great Onyx Cave was measured by the filter paper technique of Fawcett and Collis-George (1967). Substrate moisture potential measures

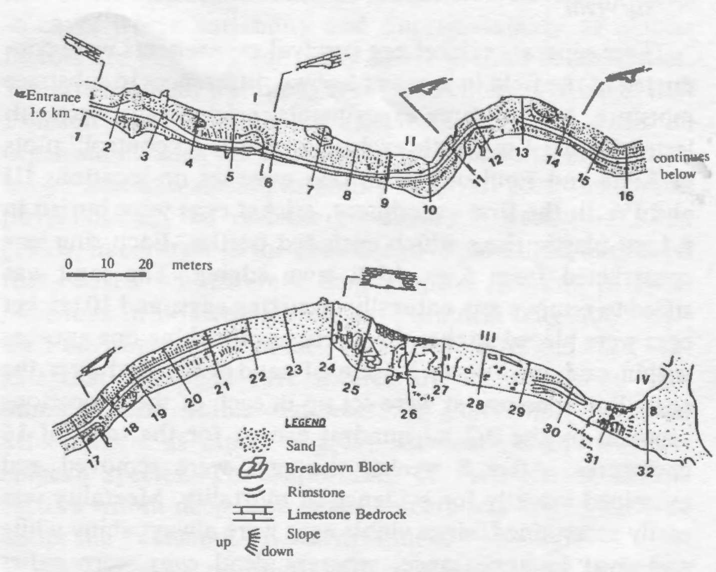


***Figure 1.* Map of the Great Onyx Cave study site, showing band census positions and locations of study areas I, II, III, and IV (the map was drafted by the Cave Research Foundation, with additions by the author).**

the pressure needed to remove water molecules from interparticle spaces.

Substrate moisture was sampled at three different spatial scales. At the largest scale, 11 band census stations were chosen at 10-70 m intervals apart to determine variations throughout the entire Great Onyx site. All samples were taken at the center of the band in loose substrate near the center of the passage.

After this initial survey, four locations were chosen for the second more detailed scale of study within each location. These locations represented the extremes of moisture potential found in the study site and were designated as locations I, II, III, and IV (see Fig. 1 for locations). A plastic 0.7 m^2 quadrat was haphazardly thrown at an angle towards the wall 10 times to the left or right (5 times in each direction) from the center of the passage at 5 m intervals in each location. Adult beetles within the quadrat were counted and the sand was sifted to a depth of 5 cm with 1/16 inch fiberglass screening for cricket eggs. A substrate sample was taken from the first eight quadrats within each location, and 95% confidence intervals were calculated for the means of substrate moisture potential, beetle density, and egg density for each area.

Finally, at the smallest scale, substrate moisture potentials were measured along a gradient of moisture and beetle densities in the Back area. A sample was taken from the middle of a series of 10 quadrats at 4 m intervals within the Back area starting with band 26 and ending near band 30 (Fig. 1). Each quadrat was 4 m^2 in area, and all beetles were counted within each quadrat.

C. *Effects of substrate moisture on cricket egg and beetle survival*

Three separate cricket egg survival experiments were conducted in the field in areas of known differences in substrate moisture. For all three experiments, cricket eggs were collected from 0.1 m^2 beetle exclusion plots (= "control" plots of Kane and Poulson, 1976) that were set up locations III and IV. In the first experiment, cricket eggs were buried in 0.1 m^2 plastic rings which excluded beetles. Each ring was constructed from 5 cm high lawn edging. The sand was sifted to remove any naturally occurring eggs, and 10 cricket eggs were placed so that they were not touching one another within each enclosure; 1.5 cm of sand was sifted over the eggs. Four enclosures were set up in each of the 4 locations sampled by the 0.7 m^2 quadrat census for the total of 16 enclosures. After 8 weeks, the eggs were removed and examined visually for evidence of mortality. Mortality was easily ascertained, since viable eggs were always shiny white and oval in appearance, whereas dead eggs were either shriveled and/or black in color. The number of dead eggs per enclosure was recorded. Moisture potentials were measured at the beginning of the experiment and again at the end of the two experiments described below. A Kruskal-Wallis test for location effects was performed on the data.

In the second experiment, ten enclosures were set up in each of two locations (III and IV) for a total of 20 enclosures. These locations were chosen on the basis of the results of the preceding experiment, which suggested that eggs in location IV may experience higher mortality than location III. As before, ten eggs were buried in each enclosure. This time eggs were given sufficient time to hatch (91 days), and the number of surviving first instar crickets was counted and analyzed with a Wilcoxon two-sample rank test.

In the third experiment, five enclosures were set up in each of two areas within the Back area. This experiment was designed to test for survivorship in an area intermediate in moisture content between locations II and III. One of the locations was identical to location III above, and the other was located 15 m from location III (between areas II and III). Each enclosure had 10 buried cricket eggs, and the experiment was run for 62 days, which was sufficient time for the eggs to hatch. Substrate moisture samples were taken within each enclosure.

Adult beetle survivorship was determined by enclosing ten beetles within four 0.1 m^2 enclosures in the same four locations described above. All beetles were collected from location III. After 30 days the number of surviving beetles was counted, and the percent mortality for each location was graphed along with the cricket data for comparative purposes. This experiment was run during the month immediately following the first experiment, and the results were analyzed separately with a Kruskal-Wallis test.

A second adult beetle survivorship experiment with ten beetles per enclosure was run in two areas: 1) location III, and 2) and area of intermediate moisture potentials located near band 27. Three replicates were done in each location.

RESULTS

A. *Distribution and abundance of adult crickets, cricket eggs, and adult beetles in relation to substrate moisture gradients*

There was a significant positive correlation between numbers of adult crickets and adult beetles on six out of eight dates (Table I). Summer months, when numbers of crickets and beetles were low, had non-significant correlations. On two dates when moisture data were available (March and July, 1987), partial correlation analyses (Sokal and Rohlf, 1981) were performed of adult crickets and beetles holding substrate moisture potential constant for ten different band stations, but none of the coefficients was significant for adult crickets and beetles. The partial coefficient between nymphal crickets and adult beetles, holding moisture constant, was significantly positive in March 1987 ($r = 0.9330, p < .01$), and nonsignificant in July 1987 ($r = -0.1956; p > .05$). Assuming that nymphal crickets tend to

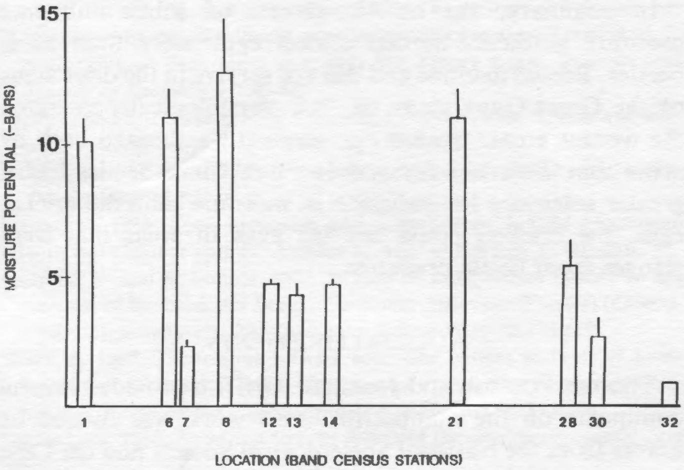


Figure 2. **Mean substrate moisture potentials (-bars) at eleven band census stations at three dates in Great Onyx Cave. Temporal variation at a site is indicated by standard deviations represented by the vertical lines.**

be found in areas where lots of cricket eggs are laid, these results suggest that beetles may be "tracking" crickets to oviposition sites during periods of peak cricket ovipositing activity (see Griffith, 1990b, and Kane et al., 1975, for cricket egg input patterns into the study site; in general, cricket egg input was highest in winter). When the partial correlation analysis was done holding beetles or crickets constant, none of the coefficients was significant.

Spatial variation in substrate moisture potentials (-bars) for 11 locations in the study site is shown in Figure 2. Increasing negativity for substrate moisture potential indicates dry locations; low negativity indicates moist locations. Band 1 is at the beginning of the study site at the edge of an arid part of the cave (i.e., the "desert" of Poulson et al., 1985). The results of the 0.7 m^2 quadrat census (Table II) show that low moisture levels are correlated with low densities of animals. There was a significant positive correlation (r = .57, $p < .01$) between substrate moisture potential and the number of beetles per quadrat. The standing crop density of cricket eggs was too low ($< 1/m^2$) to do a statistical analysis.

Since the data for numbers of beetles per quadrat were not homogeneous, and transformations did not result in homogeneity, a nonparametric Kruskal-Wallis test was used to test the null hypothesis of no difference in numbers of beetles per quadrat across the four locations. The results were highly significant (H_{adj} = 53.46, $p << .001$). A nonparametric multiple comparisons test (Conover, 1981) showed that at the .05 level, areas I and II were significantly different from areas III and IV (Table II).

Beetle density was also positively correlated with moisture potentials along a fine scale transect in the Back area (Table III). However, it is possible that the short distances between the samples (4 m) may violate the assumption of independence, so the correlation should be viewed with caution.

B. *Effects of substrate moisture on cricket egg and beetle survival*

In the first experiment, higher mortality of buried cricket eggs occurred in drier areas of the study site (Fig. 3). Since beetles were excluded from the enclosures, and eggs were obviously desiccated in areas I and II, the difference in mortality between the locations may be attributed to substrate moisture potential differences. A nonparametric one-way analysis of variance showed a significant difference among the locations (Kruskal-Wallis test, H_{adj} = 13.57, $p <$ .01). I attribute this difference to substrate moisture effects. However, a nonparametric unplanned multiple comparisons test (Conover, 1981) showed that areas I and II, and areas III and IV, were not significantly different. All other comparisons were significantly different at the .05 level. The results of a second experiment (Fig. 3) showed a significant difference between locations III and IV in the number of surviving cricket nymphs after 91 days (Wilcoxon two-sample rank test, U = 81, p = .01). When the sand was sifted to examine the condition of dead eggs, the eggs were always blackened in locations III and IV. When beetles are enclosed in areas of different substrate moisture content, it may be seen that beetles cannot survive in the dry areas of the study site (Fig. 3). In the wetter areas, no differences in beetle mortality were observed.

DISCUSSION

Poulson and White (1969) and Culver (1982) have argued that biotic interactions such as predation are easier to study in caves where variability and unpredictability of abiotic factors are less than for many above ground communities. The environment was thought to be so constant in caves that Poulson and White hypothesized that ". . . when an organism invades the stable cave environment, selection no longer acts to maintain its ability to adjust ecologically and physiologically to variable conditions." Kane and Ryan (1983), in contrast to the constant cave paradigm, suggested that, based on different demographic patterns of *Neaphaenops* in different caves, cave animals may not "see" their environment as stable. To extend this argument I suggest that terrestrial cave species are so adapted to high humidity and stable temperatures that slight variation affects them as much as great seasonal variation affects epigean species. The importance of variation of abiotic factors within deep cave environments was largely ignored under the "constant cave environment" paradigm.

Both moderately high and moderately low substrate moisture potentials were associated with low survival of cricket eggs in my Great Onyx Cave study site but these results are difficult to compare with other studies of arthropod egg survivorship (e.g., Tanaka, 1986). Doane (1967)

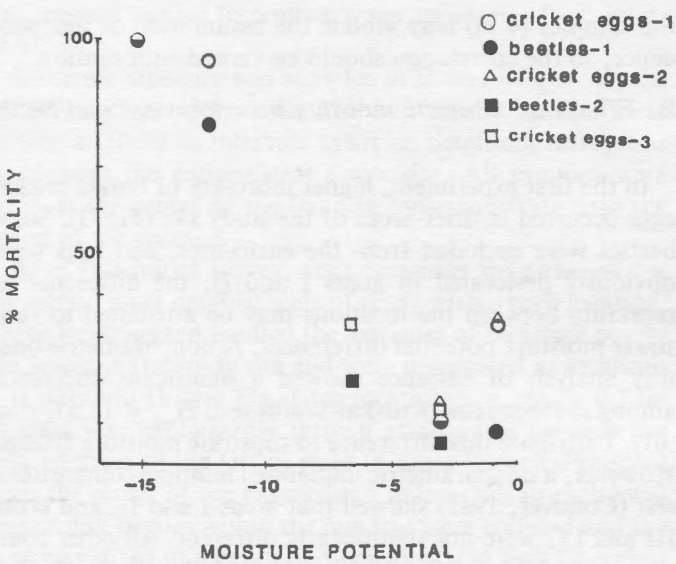


Figure 3. **Mortality of beetles and of cricket eggs as a function of substrate moisture (–bars). $n = 4$ and 2 for the first and second beetle experiments, respectively. $n = 4$ for the first cricket egg experiment at each location. For the second cricket egg experiment, $n = 10$ for each location. The third cricket egg experiment had $n = 3$ at each site. Half-filled circles represent identical values from both the first cricket egg and the first beetle experiments. See text for analyses.**

found that the prairie grain wireworm preferred to lay eggs in areas of intermediate moisture, but since he reported moisture potential as "percentage of the dry weight of soil" (p. 276), my results are not directly comparable. I did find that cricket eggs experienced higher survivorship in locations with intermediate substrate moisture potentials, and that crickets in the field lay more eggs in these same locations (Griffith, 1990b). It is possible that the higher mortality associated with moist conditions is due to parasitic fungi (Hinton, 1981), although problems with oxygen uptake also can occur if a layer of water surrounds the egg (Marrone and Stinner, 1983). Meats (1967) found that the eggs of *Tipula oleracea* and *T. paludosa* died when exposed to pFs of greater than 4.2 (–15 bars). Lower potentials increased developmental times, but were not associated with greater mortality. My results showed that all cricket eggs became desiccated at potentials of –15 bars.

Survival of cave beetles was also compromised by dry conditions, with 100 percent mortality occurring at moisture potentials of –15 bars (Fig. 3). However, in contrast to the cricket eggs, I did not see evidence that high mortality of cave beetles occurred in moist areas of the study site. In even moister areas outside my study site, beetles are regularly seen at the edges of stream banks walking on water-soaked mud banks, indicating that excess moisture is not a problem for adult beetles.

In summary, the abiotic effects of subtle substrate moisture gradients limited cricket eggs more than adult beetles. Beetles avoided and did not survive in the drier areas of the Great Onyx study site but physiologically tolerated the wettest areas. Cricket egg survival was limited both by areas that were too dry and too wet. Since beetles had a greater tolerance for variation in moisture than did cricket eggs, the crickets could not lay eggs in areas that were refuges from beetle predation.

ACKNOWLEDGEMENTS

Thomas Poulson and Jeannette Griffith provided helpful comments on the manuscript. This work was funded by grants from the National Speleological Society and the Cave Research Foundation. I thank George Gregory and the National Park Service for providing access to the cave. The Cave Research Foundation (especially Mick Sutton) prepared the map of Great Onyx Cave. Special thanks are due to many persons, too numerous to list here, who helped me in the field. This paper is part of a dissertation submitted to the University of Illinois at Chicago in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

REFERENCES

Barr, T. C. 1979. The taxonomy, distribution, and affinities of *Neaphaenops,* with notes on associated species of *Pseudanophthalmus* (Coleoptera, Carabidae). *American Museum Novitates,* No. 2682, pp. 1-20.

Brunsting, A. and Heesen, H. 1984. Density regulation in the carabid beetle *Pterostichus oblongopunctatus. Journal of Animal Ecology* 53:751-760.

Conover, W. 1981. *Practical nonparametric statistics, 2nd ed.* Wiley, New York, NY.

Culver, D. C. 1982. *Cave life: Evolution and ecology.* Harvard University Press, Cambridge, MA.

Doane, J. 1967. The influence of soil moisture and some soil physical factors on the ovipositional behavior of the prairie grain wireworm *Ctenicera destructor. Entomologia Experimentales et applicata* 10: 275-286.

Fawcett, R. and N. Collis-George. 1967. A filter-paper method for determining the moisture characteristics of soil. *Australian Journal of Experimental Agriculture and Animal Husbandry* 7:162-167.

Griffith, D. 1990a. Laboratory studies of predatory behavior in two subspecies of the carabid cave beetle *Neaphaenops tellkampfi. International Journal of Speleology* 19:8-17.

Griffith, D. 1990b. Ecology and evolution of specialized predatory behavior in the carabid cave beetle *Neaphaenops tellkampfi.* Ph.D. dissertation, University of Illinois at Chicago, IL.

Hinton, H. 1981. *Biology of insect eggs, Vol. 1.* Pergammon Press, New York, NY.

Hubbell, T. and R. Norton. 1978. The systematics and biology of the cave crickets of the North American tribe Hadenoecini (Orthoptera: Saltatoria: Ensifera: Rhaphoridae: Dolichopodinae). *Miscellaneous publications of the Museum of Zoology, University of Michigan,* No. 156, pp. 1-80.

Juberthie, C. 1969. Relations entre le climat, le microclimat et les *Aphaenops cerberus* dans la grotte de Sainte-Catherine (Ariege). *Annales de Speleologie,* 24:75-104.

Kane, T., R. Norton, and T. Poulson. 1975. The ecology of a predaceous troglobitic beetle, *Neaphaenops tellkampfi* (Coleoptera: Carabidae). I. Seasonality of food input and early life history stages. *International Journal of Speleology* 7:45-54.

Kane, T. and T. Poulson. 1976. Foraging by cave beetles: Spatial and temporal heterogeneity of prey. *Ecology* 57:793-800.

Kane, T. and T. Ryan. 1983. Population ecology of carabid cave beetles. *Oecologia* 60:46-55.

Lenski, R. 1984. Food limitation and competition: A field experiment with two *Carabus* species. *Journal of Animal Ecology* 53:203-216.

Marrone, P. and R. Stinner. 1983. Effects of soil physical factors on egg survival of the bean leaf beetle, *Cerotoma trifurcata* (Forster) (Coleoptera: Chrysomelidae). *Environmental Entomology* 12:673-679.

Meats, A. 1967. The relation between soil water tension and rate of development of the eggs of *Tipula oleracea* and *T. paludosa* (Diptera, Nematocera). *Entomologia Experimentales et Applicata* 10:394-400.

Mitchell, W. 1968. Food and feeding habits of the troglobitic carabid cave beetle *Rhadine subterranea*. *International Journal of Speleology* 3:249-270.

Norton, R., T. Kane, and T. Poulson. 1975. The ecology of a predaceous troglobitic beetle, *Neaphaenops tellkampfi* (Coleoptera: Carabidae: Trechinae). II. Adult seasonality, feeding, and recruitment. *International Journal of Speleology* 7:55-64.

Poulson, T., K. Lavoie, and J. Keith. 1985. Biological deserts under the caprock. *Cave Research Foundation Annual Report* 14:22-25.

Poulson, T., and W. White. 1969. The cave environment. *Science* 165:971-981.

Sokal, R. and F. Rohlf. 1981. *Biometry, 2nd ed.* W. H. Freeman and Company, New York.

Thiele, U. 1977. *Carabid beetles and their environments.* Springer-Verlag, Heidelberg.

Tanaka, S. 1986. Uptake and loss of water in diapause and non-diapause eggs of crickets. *Physiological Entomology* 11:343-351.

Volz, Paul A. and Ji Ping Yao—Micro-Fungi of the Hendrie River Water Cave, Mackinac County, Michigan: *NSS Bulletin* 53: 104-106.

MICRO-FUNGI OF THE HENDRIE RIVER WATER CAVE, MACKINAC COUNTY, MICHIGAN

PAUL A. VOLZ AND JI PING YAO
Mycology Laboratory, Biology
M. Jefferson Building
Eastern Michigan University
Ypsilanti, MI 48197

Soil samples collected in the beech-maple forest surrounding the Hendrie River Water Cave and from within the cave of the Fiborn Karst Preserve in the Upper Peninsula of Michigan were examined for micro-fungal populations. Variation was noted in fungal species found within the cave and those found in areas out of the cave. The micro-fungal isolates were in greater abundance in soil outside the cave; however, suitable conditions existed within the cave that permitted limited micro-fungal survival and growth.

INTRODUCTION

Samples of sediment from the Hendrie River Water Cave and soil samples from nearby surface sites were collected in July 1990. Sediments were deposited over an extended time period along the sides of the cave river. Material was examined for micro-fungal populations present inside the cave in comparison to surface areas surrounding the cave. During spring thaws or during heavy rains the cave water level rises, leaving behind additions to the accumulated sediments. The cave is Michigan's largest at 0.645 km in length, located within the 1.538 km² private Karst Preserve in Mackinac County of Michigan's Upper Peninsula (Meyerson and Kenyon, 1989). Karst landscapes are characterized by caves, steep valleys, sinkholes, and underground drainage that form the hidden passages. The Michigan Preserve is the largest privately held karst preserve in the United States. Surface features include Fiborn Pond, a limestone quarry, Hendrie River South Branch, Nelson Creek, and forest (Fig. 1). The preserve is open for visits by permission except when scientific studies or special needs, such as bat hibernation periods, require limited visitation. In addition to bats, the cave is also inhabited by frogs, leeches, crayfish, and small sculpin fish.

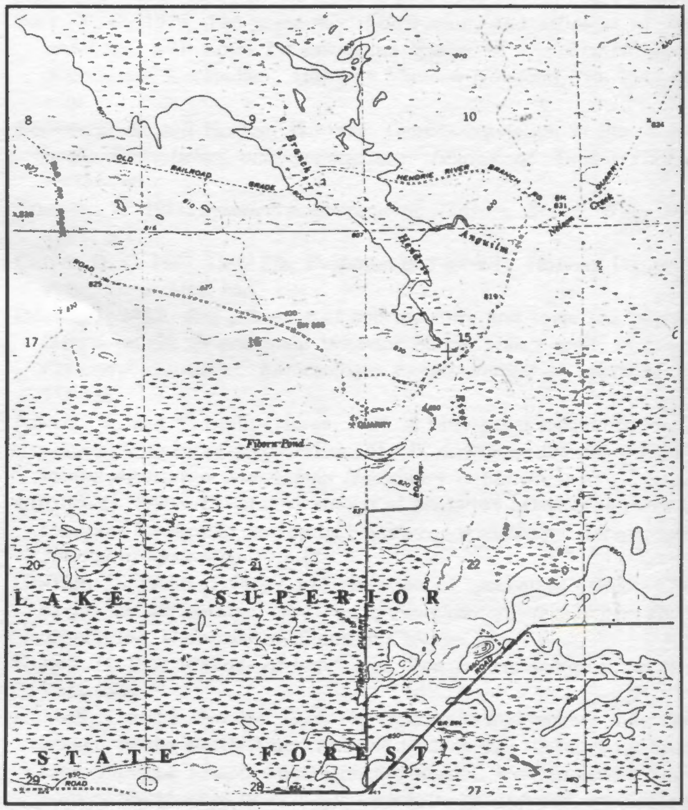


Figure 1. **Fiborn Karst Preserve surface features of the Hendrie River Water Cave area in the Upper Peninsula of Michigan (USGS 1964).**

Karst regions throughout the world are features formed by underground drainage. Karst landscapes provide unique habitats for plants and animals, but problems in water supply, waste disposal, construction, and other land uses occur. Many karst features have been victim to landfills in the past and their unique habitats have been greatly altered or destroyed. Michigan karst areas include the gypsum karst in Kent County, surface drainage areas in Monroe County that reappear as blue holes in Lake Erie, sinkholes and earth cracks in Alpena and Presque Isle counties, and a broad band of outcrops of the Niagara Escarpment in the Upper Peninsula that includes karst sinks, springs, and caves in Mackinac County. The micro-fungal populations of the Hendrie River Water Cave were identified and compared to the populations of soil borne isolates in areas adjacent to the cave. Species identification and frequency of isolation revealed differences in micro-fungal populations inside and outside the cave.

MATERIALS AND METHODS

A total of 100 soil samples was collected during July 1990 throughout the Fiborn Karst Preserve mixed beech-maple forest. In addition, 25 sediment samples also were collected throughout the underground passageways within the Hendrie River Water Cave. The cave is the largest cave in the state and is part of the Fiborn Karst Preserve natural protected area under supervision of the Preserve Committee. The survey of micro-fungi was made during baited surface soil and cave sediment, and soil and sediment placed on selected agar media.

Soil and sediment samples were collected in sterile plastic zip lock bags and immediately transported to the laboratory for further study. Samples of the collected soil were placed in sterile disposable plastic Petri dishes and moistened with sterile distilled water. Small sections of sterile hair from one human subject and sterile horse tail hair from one horse were generously added to the surface of the soil cultures. After 2-3 weeks incubation at 24°C, hair segments directly supporting fungal colony growth were transferred to microscope slides and mounted with lactophenol cotton blue for viewing. Systematic hair degradation readily occurs by the sporulating keratinophilic fungi that easily aid in species identification (Hsu and Volz, 1975).

Surface soil and cave sediment from each collection site were placed by serial dilution on selected agar media to isolate for nonkeratinophilic micro-fungal species. Selected agar media used for micro-fungal isolation and growth included Sabouraud dextrose agar, corn meal agar, Czapek solution agar, brain heart infusion agar, and Littman oxgall agar (Difco, Inc., 1985; Oxoid, Ltd., 1971). The agars were selected due to their growth support for a broad spectrum of micro-fungal species. Pure cultures of the micro-fungal isolates were maintained on Sabouraud dextrose agar for transfer to microscope slides and mounting in lactophenol cotton blue for species determination.

RESULTS

The hair bait technique for the study of soil micro-fungi permits growth of keratinophilic species. Accumulated sediment inside the cave yielded *Chrysosporium pannorum* (Lind) Hughes (Soderstrom, 1975) and *Trichophyton terrestre* Durie *et* Frey (Barkerspigel, 1974), each at 9.1% frequency of isolation. Both species are considered nonpathogens. Surface soil collected around the cave contained *Chrysosporium indicum* (Randhawa *et* Sandhu) Garg (Carmichael, 1962) and *Helicosporium lumbricoides* Saccardo (Moore, 1955) at 20.0% and 11.1% frequency of isolation, respectively. *H. lumbricoides* grew saprophytically and not as a keratinophilic isolate.

Additional species of soil micro-fungi were isolated using serial dilutions on selected agar media. Isolates found inside the cave and their frequency of isolation included *Trichoderma harzianum* Rifai, 50.0% (Rifai, 1969); *Humicola fuscoatra* Traeen, 45.5% (Soderstrom, 1975); *Mucor racemosus* Fresenius (Gilman, 1957) and *Scopulariopsis brumptii* Salvanet-Duval (Morton and Smith, 1963) both at 25.0%; and *Aspergillus niger* van Tieghem (Thom and Raper, 1945) and *Epicoccum nigrum* Link (Fletcher and Kwong, 1983) at 10.0% each. Surface soil collections surrounding the cave produced *Mucor racemosus,* 80.0%; *Humicola fuscoatra,* 60.0%; *Aureobasidium pullulans* (deBary) Arnaud (Cooke, 1959), 30.0%; *Fusarium oxysporum* Schlechtendahl (Booth, 1971), 20.0%; and *Epicoccum nigrum, Penicillium purpurogenum* Stoll (Raper and Thom, 1968), *Scopulariopsis brumptii,* and *Trichoderma harzianum* each at 10.0% frequency of isolation. *Aspergillus niger* was recovered inside the cave in low densities and not from soil samples collected outside the cave, while *Aureobasidium pullulans* and *Penicillium purpurogenum* were isolated from outside soil and not within the Hendrie River Water Cave.

DISCUSSION

Although different keratinophilic micro-fungal species were found in soils inside and outside Michigan's largest cave, keratinophilic fungi were more commonly isolated from sediment collected within the cave than from surface soil surrounding the cave. Two keratinophilic species of *Chrysosporium* were recovered; *C. pannorum* was inside the cave while *C. indicum* was located outside. Likewise, *Trichophyton terrestre* was found within, and *Helicosporium lumbricoides* was collected outside the cave. Even though hair supported the growth of these isolates, none of the four is capable of producing primary infection in man (Volz et al., 1991). Hair deterioration is systematically accomplished by several keratinophilic species and phenotypes. An abundance of conidia is also produced along the hair shaft by these organisms (Veselenak and Volz, 1977). Soil readily supports growth of causal agents of dermatophytoses (Otcenasek et al., 1967; Volz, 1971).

Soil dilution agar plate isolates found both inside and outside the Hendrie River Water Cave included *Mucor racemosus, Humicola fuscoatra, Fusarium oxysporum,* and *Scopulariopsis brumptii.* Various soil types and collection sites provide diverse habitats for high populations of micro-fungi (Volz et al., 1991). Isolates were more abundant in surface soil instead of cave sediment except for *Scopulariopsis brumptii* at 25.0% frequency of isolation inside the cave and 10.0% outside. *Epicoccum nigrum* was at equal frequency levels within and out of the cave.

On a few occasions, *Fusarium oxysporum* (Anderson and Chick, 1963; Gutman and Chou, 1975), *Aspergillus niger* (Mahvi et al., 1968), and *Aureobasidium pullulans* (Vermeil and Gordeff, 1971) have been identified as causal agents of mycoses in humans; however, most isolates recovered are considered nonpathogens except for patients with debilitating illnesses on long-term therapy. Most soil borne micro-fungi are nonpathogenic and isolates primarily exist saprophytically on organic material in soil when suitable moisture and temperatures are provided (Volz et al., 1975).

ACKNOWLEDGEMENTS

Appreciation is extended to Dr. Rane L. Curl from the University of Michigan, Science Subcommittee chair, and the Fiborn Karst Preserve Committee for permission and assistance in acquiring the soil and cave sediment samples for the mycology studies.

REFERENCES

Anderson, B. and E. W. Chick. 1963. Mycokeratitis: Treatment of Fungal Corneal Ulcers with Amphotericin B and Mechanical Debridement. *South Medical Journal* 56:270-275.

Barkerspigel, A. 1974. The Keratinophilic Fungi of Ontario, Canada. *Mycopathologia* 53:1-12.

Booth, C. 1971. The Genus *Fusarium*. Commonwealth Mycological Institute, Kew, Surrey, England.

Carmichael, J. W. 1962. *Chrysosporium* and Some Other Aleuriosporic Hyphomycetes. *Canadian Journal of Botany* 40:1137-1173.

Cooke, W. B. 1959. An Ecological Life History of *Aureobasidium pullulans* (deBarry) Arnaud. *Mycopathologia* 12:1-45.

Difco, Inc. 1984. Difco Manual, 10th Ed. Difco Laboratories, Detroit, MI.

Fletcher, H. J. and Y. S. Kwong. 1983. Pigment Production by an Isolate of *Epicoccum nigrum*. *Bulletin of the British Mycological Society* 17:145-147.

Gilman, J. C. 1957. A Manual of Soil Fungi, 2nd Ed. Iowa State University, Ames, IA.

Gutman, L. and S. M. Chou. 1975. Fusariosis, Myastenic Syndrome and Aplastic Anemia. *Neurology* 25:922-926.

Hsu, Y. C. and P. A. Volz. 1975. Penetration of *Trichophyton terrestre* in human hair. *Mycopathologia* 55:179-183.

Mahvi, T. A., H. M. Webb, C. D. Dixon, and J. A. Boone. 1968. Systemic Aspergillosis Caused by *Aspergillus niger* After Open Heart Surgery. *Journal of the American Medical Association* 203:520-524.

Meyerson, H. and D. Kenyon. 1989. Michigan's Longest Cave. *Michigan Natural Resources* Sept.-Oct.:4-9.

Moore, R. T. 1955. Index to the Helicosporae. *Mycologia* 47:90-103.

Morton, F. J. and G. Smith. 1963. The Genera *Scopulariopsis* Bainier, *Microascus* Zukal and *Doratomyces* Corda. *Mycological Papers, C.M.I.* 86:1-96.

Otcenasek, M., J. Dvorak, and J. Kunert. 1967. Geographic Distribution of the Geophilic Dermatophytes in the Soil. *Mycopathologia* 31: 151-162.

Oxoid, Ltd. 1971. The Oxoid Manual of Culture Media, Ingredients, and Other Laboratory Services. Oxiod Ltd., London.

Raper, K. B. and C. Thom. 1968. A Manual of the Penicillia. Hafner Publishing Co., New York, NY.

Rifai, M. A. 1969. A Revision of the Genus *Trichoderma*. *Mycological Papers, C.M.I.* 116:1-56.

Soderstrom, B. E. 1975. Vertical Distribution of Micro-fungi in a Spruce Forest Soil in the South of Sweden. *Transactions of the British Mycological Society* 65:419-425.

Thom, C. and K. B. Raper. 1945. A Manual of the Aspergilli. Williams and Wilkins Co., Baltimore, MD.

United States Geological Survey, 1964. Rexton Quadrangle Michigan, 7.5 Minute Series (Topographic). Reston, WV.

Vermeil, C. and A. Gordeff, 1971. Blastomycose cheloidienne a *Aureobasidium pullulans*. *Mycopathologia* 43:35-39.

Veselenak, J. M. and P. A. Volz. 1977. Utilization of Keratinophilic Material by Selected *Trichophyton terrestre* Space Flight Phenotypes. *Mycopathologia* 60:87-97.

Volz, P. A. 1971. A Preliminary Study of Keratinophilic Fungi from Abaco Island, The Bahamas. *Mycopathologia* 43:337-339.

Volz, P. A., Y. C. Hsu, C. H. Liu, S. M. Ho, and Z. C. Chen. 1975. The Keratinophilic Fungi of Taiwan. *Taiwania* 20:23-31.

Volz, P. A., M. J. Wlosinki, and S. P. Wasser. 1991. Sparce Diversity of Potential Pathogenic Soil Micro-fungi in the Ukraine. *Microbios* 65:187-193.

PROCEEDINGS OF THE NATIONAL SPELEOGICAL SOCIETY
ANNUAL MEETING, JULY 1 - JULY 5, 1991
COBLESKILL, NEW YORK
NORMA DEE PEACOCK, EDITOR

AMERICAN CAVING

CAVES AND THE GAIA THEORY

Moore, George W. -Department of Geosciences, Oregon State University, Corvallis, OR 97331

In 1972, after having successfully used infrared telescopic analysis of the atmosphere of Mars to predict the absence of life there in advance of instrumental landings,James Lovelock proposed the GaiaTheory. Based on knowledge that organisms are responsible for the Earth's oxygenated atmosphere,the Gaia Theory further states that the Earth and its life together constitute a super-organism in which the crust, oceans,atmosphere, and climate are all regulated by living things to be comfortable for life. Caves may be used as natural reaction chambers to study Gaia's processes in effect, as gigantic pores in the regolith. Some Gaian processes occur at high temperature, such as the hypothetical growth of continental crust by the delivery of life-modulated products to subduction zones, but most occur at the moderate temperature preferred by life and characteristic of caves. Reaction rates are slow at moderate temperature, thus making long- lived caves splendid sites for studying sluggish mineral reactions. Many cave processes owe their origin to the microbial production of carbon dioxide in the roof of the cave, so we may say that an ordinary calcite stalactite, formed by the release of that gas far from its point of production, is ultimately a biologic product. Other cave minerals, such as those containing manganese, have an even closer relationship to microorganisms. And the chain of cave life itself is folded back onto the cave mineral matter. Cave silt, as the recycling station for the system, is the ultimate center of the cave food web. Within the silt, clay minerals and bacteria constitute Gaia's most intimate symbiosis.

AMERICAN SPELEAN HISTORY

MYTHS AND TRADITIONS OF WYANDOTT CAVE

George, Angelo I. - 1869 Trevilian Way, Louisville, KY

Wyandotte Cave of southern Indiana has been known since 1798. Since that time period the true history of the cave has been shrouded in myths and traditions. Myths on the discovery, exploration, and commercial development found a niche when historic fact failed to be preserved. Central to this study is an analysis of the discovery of the cave by F.I. Bentley and the wounded Indian story. Benjamin Adams, M.D., owned the cave during the War of 1812, and mined epsom salt and saltpeter for the war. An account will be made of the 1850 New Cave discovery and the people involved, and the pervasive story of the counterfeiters in the cave will be examined.

Many of these questions were resolved by placing the traditions in context with a known chronology of historic events. This was achieved through the collecting, cataloging, and evaluation of over 870 published and unpublished references spanning 1810 to the present. Much remains to be collected.

This study shows actual benchmark historic events occurring several years earlier than previously known to spelean historians.

A HISTORY OF THE EXCAVATIONS AT CUMBERLAND CAVE, MARYLAND

Grady, Fred - 1201 S. Scott St. #123, Arlington, VA 22204

A cave containing fossil bones was discovered near Cumberland, Maryland during excavations for the Western Maryland Railroad in 1912. Raymond Armbruster informed the Smithsonian Institution of the discoveries and assisted J.W. Gidley of the Smithsonian in collecting several hundred specimens over a period of 3 years. In 1950, Brother Nicholas Sullivan discovered additional fossil bones in a portion of the cave on the opposite side of the tracks from where the Smithsonian parties worked. Brother Nick's excavations continued through the early part of 1953 and resulted in the destruction of much of what was left of the cave. In 1968 a Carnegie Museum of Natural History party led by Allen McCrady and Harold Hamilton collected a considerable amount of material at Cumberland Cave, much of it from the Smithsonian dump piles. Finally in the late 1980s a few additional specimens from Cumberland Cave were donated to the Smithsonian Institution by Trent Spielman. An investigation of the site determined there was still more fossil material in what is left of Cumberland Cave.

THE LOST PARK RESERVOIR PROJECT, PARK COUNTY, COLORADO: AN ILL-FATED, TURN-OF-THE-CENTURY ATTEMPT TO USE A GRANITE CAVE AS A "NATURAL DAM"

Hose, Louise D. - Department of Geology, University of Colorado, Colorado Springs, CO 80933

One hundred years ago, on January 1, 1891, Stephen R. Pratt and William A. Powers staked a claim and began working on an attempt to plug a natural granite cave, now called Goose Creek Cave, and form a reservoir in the alpine valley through which Lost Creek flows. The project continued for approximately 24 years and more than $75,000 was spent in building roads and cabins, opening a 180 foot shaft to the middle part of the cave, lining the shaft, clearing timber from the proposed reservoir site, excavating the bedrock stream bed, installing a foundation for the dam, and installing two valves weighing 3000 pounds each. Despite these efforts, stream flow was never blocked.

Lost Creek flows into the approximately 3900 foot long cave under a ridge up to about 180 feet high. The ridge through which the stream flows is so distinct that the stream is called Goose Creek below the resurgence. The subterranean dam is about 1200 feet from the insurgence. The dam is 25 feet thick at its base, 20 feet thick at the top, and 80 feet high. It spans cave passage that is 50 feet wide at the base and 75 feet wide at its top. The flow of the stream seasonally varies but is approximately 25 cubic feet per second in mid-summer. The dam and some support structures remain today.

EARLY VISITORS TO WOLF CAVE, ALABAMA

Lundquist, Charles A.- Associate Vice President for Research The University of Alabama in Huntsville, Huntsville, AL 35899

Wolf Cave in the Newsome Sinks of Morgan County, is one of the historic caves of Alabama. It is a large cave with an impressive entrance, and it has long been popular with casual visitors. The cave walls have inscriptions of names and dates that reach back to the early 1800s. The earliest notations typically are scratched in cursive script. Several visitors who made pre-Civil War inscriptions have been identified in census records, land transactions and other documents. The earliest clearly associated name and date are Wm. Moore, July 18, 1835. Signatures by S. Newsom and R.W. Newsom dated November 10, 1839, are of interest because these individuals presumably are members of the Newsom(e) family for whom the Newsome Sinks are named. Richard W. Newsom in 1841 received title from the U.S. Government for land in S31 Township 6S Range 1E, which is just northeast of Newsome Sinks. In 1843 he obtained title to land in the Oleander community nearby. Sowell Newsom, a candidate for the S. Newsom inscription, got land in Oleander in 1846. In 1831 William Newsom was the first recorded land owner within Newsome sinks valley, although his name was not found in Wolf Cave. The use of cursive script by early visitors sometimes allows a comparison of cave signatures with those on preserved documents. For example, Richard J. Rivers left two cave signatures in the 1850s that are remarkably like the signature on his marriage record in Morgan County. Success in associating cave inscriptions with individuals in historical records shows that the pre- Civil War visitors to Wolf Cave typically were local settlers of the area. The first recorded visits were contemporary with the earliest land acquisitions.

THE DISCOVERY AND EARLY HISTORY OF CRYSTAL CAVE, PENNSYLVANIA

Snyder, Dean H. - 3079 Main Street, Neffs, PA 18065

While quarrying for limestone, William Merkel and John Gehret discovered a large cave on November 12, 1871. One of its early explorers was Samuel D.F. Kohler, a local farmer whobecame so captivated by his adventures that he purchased the property for $5,000 the next year. He made improvements and opened Crystal Cave for tourists with a Grand Illumination on May 25, 1872. This attraction became so popular that Kohler discontinued farming and built a hotel near the entrance. Kohler encouraged writers and scientific parties to tour the cave, and their flowing reports were used in advertising materials for many years.

After S.D.F. Kohler's death in 1908, his son David managed the property. He made many improvements, including the installation of a generator so the cave could be electrically lighted. David Kohler sold Crystal Cave in 1923, but established the "Kohler Museum" where he exhibited memorabilia and speleothems from the cave. Since his death in 1949, his family has preserved the museum exactly as he left it. Due to the efforts of S.D.F. and David Kohler, more than a million visitors have been able to view the under-ground wonders of Crystal Cave, Pennsylvania.

MCFAIL'S HOLE: HISTORY OF EXPLORATION, PURCHASE, AND EARLY NSS OWNERSHIP

Stone, Fred D. - Hawaii Community College, University of Hawaii, Hilo, HI

McFail's Hole, the longest cave in the Northeast, is also the first cave owned by the NSS. This talk is a personal account of the exploration and purchase of McFail's based on detailed files I kept during the 1960s. I will cover the following topics: 1) Discovery and exploration of McFail's major extension by Cornell Outing Club cavers in the early 1960s. 2) Events leading to the purchase of McFail's Hole on August 2, 1965. 3) Acceptance of McFail's ownership by the NSS Board of Governors at the 1965 Indiana Convention, setting the precedent for subsequent NSS cave ownership. 4) Origin of the McFail's Cave Management Committee, and how it successfully dealt with problems of visitation and liability.

BIOLOGY

THE EFFECTS OF CAVE VISITATATION ON TERRESTRIAL CAVE ARTHROPODS

Carlson, Kent R. - 1640 Besley Road, Vienna, VA 22182

The effects of human traffic on arthropods present in the terrestrial cave environment was investigated. Five cave entrances (2 heavy traffic and 3 light traffic) of the Organ Cave System were sampled 30 times each using two methods, bait trapping and mouth aspiration. Samples were taken from three designated zones: 1) the surface zone (0-20 meters outside the cave entrance), 2) the entrance zone (0-20 meters inside the cave environment), and 3) the deep cave zone (60- 80 meters inside the cave). Preliminary results indicate decreasing species number and diversity associated with increasing depth into the cave. Differences in species diversity or number, between entrances, are variable for each major arthropod group, and are not strongly associated with human traffic.

ORIGINS OF KARST WINDOW POPULATIONS OF GAMMARUS MINUS

Fong, Daniel W. - Department of Biology, The American University, Washington, DC 20016

Populations of the amphipod Gammarus minus can be found in cave streams, karst windows, and groundwater resurgences within the same underground drainage basin. Karst window populations exhibit eye size which is intermediate between that of cave populations with small eyes, and resurgence populations with large eyes. Formation of karst windows generally necessitate pre-existing cave passages. Extant karst window populations of Gammarus minus may thus have descended from resurgence populations which colonized the karst after its formation, or may have descended from pre-existing cave populations. The origin of karst window populations thus have significant implications on the mechanism of eye size evolution in cave Gammarus. I present preliminary results from an analysis of the origin of karst window populations using the random amplification polymorphic DNA (RAPD) marker technique, which suggests that karst window popu- lations descended from preexisting cave populations.

BIOGEOGRAPHIC AND PHYLOGENETIC IMPLICATIONS OF A NEW SPECIES OF THE SUBTERRANEAN AMPHIPOD CRUSTACEAN STERNOPHYSINX FROM A CAVE IN SOUTH AFRICA

Holsinger, John R. - Department of Biological Sciences
Old Dominion University, Norfolk, VA 23529

A new species of the subterranean amphipod genus Sternophysinx is being described on the basis of specimens collected from Matlapitse Cave in the Transvaal province of South Africa by Drs. Stewart and Jarmila Peck. Recognition of this species raises the number of species in Sternophysinx to five, all recorded from caves and springs of northeastern South Africa. Sternophysinx is currently classified in the superfamily Crangonyctoidea. Other members of this superfamily include the families Neoniphargidae, Paramelitidae and Perthiidae from the southern hemisphere, and the families Crangonyctidae and Pseudocrangonyctidae from the northern hemisphere. Certain morphological similarities shared by members of the superfamily and the fact that all are restricted to inland fresh-water habitats, largely groundwater in nature, suggest this to be a very old amphipod group that might have originated on Pangaea in the Triassic.

Perhaps the most remarkable character of the new species is the presence of small, paddle-shaped "sensory" structures, called calceoli, on antenna 2 in both males and females, marking the first noted occurrence of this rather curious "organ" in the genus. Because of its widespread occurrence among gammaridean amphipods, combined with recognition that it can occur in nine different character states, the calceolus may be a useful indication of phylogenetic relationship. For example, the calcelous found in Sternophysinx appears to be the same type as that of several other crangonyctoidean genera in both the northern and southern hemispheres, and thus is viewed as additional support for the hypothesized phylogenetic affinity between the freshwater amphipod faunas of the Holarctic region and parts of Gondwana.

GENETIC STRUCTURE OF CAVE AND SPRING POPULATIONS OF THE AMPHIPOD GAMMARUS MINUS

Kane, Thomas, C. - Department of Biological Sciences
University of Cincinnati, Cincinnati, OH 45221
Culver, D. - Department of Biology, The American University, Washington D.C. 20016

Gammarus minus (Amphipoda: Gammaridae) is widespread in springs, spring runs and caves throughout much of the eastern United States. In a large karst area in West Virginia, individuals from cave populations are highly modified, with elongated appendages and with eyes less than 10% the size of spring-dwelling individuals. This pattern is repeated in at least six closely adjoining karst basins, all containing cave and spring populations.

An electrophoretic study of 19 enzymatic loci on 24 cave and spring populations in these six drainage basins yields FST of 0.49, indicating substantial differentiation among populations. Genetic differentiation occurs primarily between the spring and upstream cave populations within a drainage and between cave populations of different drainages. These data indicate that: (1) G. minus has invaded caves independently in each drainage; (2) there is gene flow among spring populations connected by surface streams; and, (3) there is little gene flow between cave and spring populations within drainages.

EXISTENCE OF CRYSTALIN AND OPSIN GENES IN REDUCED EYES OF THE CAVE FISH ASTYANAX FASCIATUS CUVIER 1819

Langecker, T. G., Schmale, H., and Wilkens, H
Zoologisches Institut und Zoologisches Museum, Universitat Hamburg, Germany

The Mexican blind fish Astyanax fasciatus has come to play a central role in the research of cavernicolous evolution. Due to a complete interfertility of the blind cave-dwelling populations with their eyed epigean ancestor, it was possible to analyze the genetics of character displacement in the cave fish by classical means.

The most thoroughly examined character of A. fasciatus, that has become a subject to regressive evolution, is the eye. Based on detailed studies on the genetics, ontogeny and microscopical anatomy of the eye of epigean and cave-dwelling A. fasciatus, it was suggested that regression is primarily caused by mutations of genes controlling the developmental expression of structural genes. A first step in testing this hypothesis at the level of molecular genetics was to examine whether cave fish still express genes encoding for such eye-specific structures which are regressed in the adult stage. The "Pachon" cave fish exhibits a complete regression of the lens and the retinal photoreceptor cells. The lens of vertebrates consists of fiber cells producing structural proteins, the crystallins. They are subdivided in different classes. One of them, the crystallins, are encoded by genes which are expressed at both early and late developmental stages. A specific protein of the photoreceptor cells is opsin, the visual pigment. Rhodopsin and two types of color visual pigments are known to occur in many fish species. The results of in situ hybridization experiments detecting the expression of crystallin and two visual pigment genes in the eyes of adult epigean and cave-dwelling A. fasciatus will be reported.

THREATS TO THE SUBTERRANEAN AQUATIC ECOSYSTEM OF THE BALCONES FAULT ZONE, EDWARDS AQUIFER IN TEXAS

Longley, Glenn - Edwards Aquifer Research & Data Center, Southwest Texas State University,
San Marcos, TX 78666-4616

The Balcones Fault Zone Edwards Aquifer supports a very diverse (>40 species) assemblage of aquatic forms, that are highly adapted to the conditions found there. This unique community is in danger of being impacted severely by the activities of man. The primary impacts are from overpumping that will cause dewatering of some of the system and also lead to water quality degradation due to encroachment of highly saline water into areas now having only high quality water. Recent investigations have yielded new insight into the potential for changed water quality.

The average recharge (1934-1989) to the San Antonio portion of this aquifer is 628,000 acre feet annually. Pumpage in recent years has approached 540,000 acre feet in a single year. Levels of the aquifer now regularly drop at the rate of one foot each day during the late spring and early summer. A short term drought in the region has shown how shorter duration and less intense droughts can cause much greater changes than were experienced during the drought of record (1947-1956). There is a problem with controlling mans impact on the aquifer since Texas allows surface owners to pump as much as they want under Texas' outmoded "Right of Capture" provision in the groundwater statutes. Solutions are being sought for the problem, with little progress made at this time.

If overpumping is allowed, the impact is certain for those species that exist in this aquifer. There is a need for concerned biologists in different disciplines to make their concern known to the governmental agencies that now have some responsibility in matters concerning this aquifer.

PREDATION AND BODY SIZE VARIATION BETWEEN SPRING-DWELLING POPULATIONS OF GAMMARUS MINUS

Man, Zhijun, and Fong, Daniel W .- Department of Biology, The American University, Washington, DC 20016

Variations in body size were examined for eight spring-dwelling populations of the amphipod Gammarus minus in West Virginia. Populations from Jefferson County, located in the northeastern part of the state, are significantly larger in body size than are populations from Greenbrier County, located further south. Within each county, populations subjected to predation by sculpins are significantly smaller in body size than are populations that have not been colonized by sculpins. Within each population, adult individuals in precopulatory amplexus are generally larger than unpaired individuals. Body size in Gammarus minus populations thus seem to represent a balance between size-selective predation, which decreases body size. A model is presented to incorporate predation and sexual selection into the determinants ofcommunity structure in karst springs.

BIOENERGETICS OF CAMEL CRICKETS FOR CARLSBAD CAVERN NATIONAL PARK

Northup, Diana E., 1601 Rita Dr. NE, Albuquerque, NM 87106-1127
Lavoie Kathleen H., and Studier, Eugene H., Biology Department, University of Michigan-Flint, Flint, MI 48502-2186

To study differences in bioenergetics individuals of three species of camel crickets (Ceuthophilus longipes, C. carlsbadensis, and C. conicaudus) were caged and starved for approximately four days. Weight loss with time shows a steady decrease for all three cricket species based on their metabolic rate. The slope of the line is the steepest for C. carlsbadensis, the least cave-adapted species, and the most shallow for C. longipes, the more cave specialized species. Differences in metabolic rate and foraging intervals are discussed. Results from this study are compared to those from studies by Studier and Lavoie of other cave and camel cricket species.

SEASONAL PATTERNS OF SPECIES DIVERSITY AND NUMBERS OF MITES INHABITING BAT GUANO IN CARLSBAD CAVERN

Northup, Diana E. - University of New Mexico, Albuquerque, NM
Welbourn, W. Calvin - Acarology Lab, Ohio State University, Columbus, OH 43223

A study of the mite fauna inhabiting the bat guano of Carlsbad Cavern was undertaken in 1990. Samples of guano were taken every 28 days (February 1990 - January 1991) from three randomly chosen sites under the old bat roost and current bat nursery, for a total of six samples each period. Samples were sorted by type of invertebrate, with mites being sorted to family. Number of each type were counted. Preliminary results of analysis of species diversity and composition of representative samples from each season are discussed.

THE BEHAVIORAL ECOLOGY IN CAVE-LIVING FISH

Parzefall, J. - Zoologisches Institut und Zoologisches Museum, Universitat Hamburg, Germany

The ecological conditions in caves are characterized by two main factors: nearly all caves have complete darkness and more or less constant temperature. Besides species such as bats, which enter caves regularly to rest during the day and in winter, also many species live permanently in the complete darkness.

In the teleostean fish, members of 14 families have colonized caves successfully. Mainly three of these families have been studied for behavioral adaptations to the cave habitat.

Potential cave-dwellers seem to need preadaptation for cave life in their sexual behavior which is mainly based on chemical communication. The most striking phenomenon is reduction of different behavioral traits ranging from circadian locomotory activity, fright reaction, dorsal light reaction, phototaxis, schooling and aggressive behavior to parts of the feeding behavior.

These behavioral differences between cave-dwellers and their epigean relatives allow the use of these animals for studies on evolutionary genetics in behavior because of fertile cross-breeding. On the basis of the present data it is very likely in cave animals that, with some important exceptions, such as aggressive behavior, selection may play a minor role compared with the accumulation of neutral mutations. For these reasons field and laboratory studies on cave-dwelling fish seem to hold great promise.

BIOLOGICAL INVESTIGATIONS IN A THERMOMINERAL SULFUROUS CAVE

Sarbu, Sherban - Department of Biological Sciences, University of Cincinnati, Cincinnati, OH 45221-0006

Southern Dobrogea, Romania led to the discovery of Movile Cave, a "window" to a unique subterranean environment. The cave consists of a network of fissures and small passages partially flooded by hydrogen sulfide rich thermomineral waters. Microbial mats cover the water surface and limestone walls of the cave. Preliminary studies indicate that these consist of chemoautotrophic organisms which use hydrogen sulfide as an energy source. The aquatic and terrestrial communities of Movile Cave support high densities of species and large biomass. Of the 25 terrestrial arthropod taxa collected to date in Movile Cave, 19 are previously undescribed species. Among the new taxa are two new species of pseudoscorpions, five new species of spiders, four new species of isopods, two new species of collembola and six new species of other insects The aquatic community is less well sampled but has already yielded a new species of leech, a new aquatic snail species and a new species of amphipod. All of the species inhabiting the cave are characterized by an advanced degree of troglomorphy indicating a long history of cave isolation. The current hypothesis is that the ancestors of the terrestrial fauna invaded the subterranean environment at the end of the Miocene (5.5 to 5.2 million years ago) when Southern Dobrogea was transformed into a semi-desert. Some of the surface fauna presumably sought refuge in the underground network of fissures and cave passages and survived by feeding upon the rich chemoautotrophic microbial community.

"NO TROPICAL TROGLOBITES" AND THE GLACIAL RELICT THEORY OF TROGLOBITE EVOLUTION: RISE AND DEMISE OF A PARADIGM?

Stone, Fred D. - Hawaii Community College, University of Hawaii, Hilo, HI

The development of theories to explain the evolution of highly cave adapted species (troglobites) have been strongly influenced by the idea that troglobites are "relictual" species. An apparent lack of troglobites from tropical caves led to formulation of the "glacial relict" theory by biospeleologists. Independent discovery of troglobites in the Galapagos by Leleup in the 1960s and in Hawaii by Howarth in 1971, followed by similar discoveries in other tropical regions, requires a reassessment of the glacial relict theory, and of relictual theories in general. This talk will explore the historical development of relictual theories of troglobite evolution, and examine possible reasons that biologists had missed finding the abundant tropical troblobite fauna in the past. In fact, tropical troglobites had been known for over a century, but had been either ignored or rejected as being part of a soil fauna. Attachment to relictual ideas may well have influenced the way in which biologists searched for and reacted to tropical cave species. Current research in Hawaii, Australia, and Thailand indicates that tropical troglobites are highly adapted to specific underground environments shared by deep caves and medium sized voids (mesocaverns). Occurrence of surface-dwelling relatives of the cave species indicates that the troglobites are often non-relictual species. New models are needed to explain the abundant and diverse tropical troglobite faunae. An alternative currently being examined is the "adaptive shift" model, in which population preadapted species expand into the subterranean environments to take advantage of energy resources, and adapt to the extreme conditions (darkness, saturated humidity, high carbon dioxide, low oxygen), enabling them to more efficiently utilize the resources.

TROPICAL CAVE CRICKETS AND COCKROACHES: STATUS OF CURRENT AND RESEARCH IN HAWAII, SOUTHEAST ASIA, AND AUSTRALIA

Stone, Fred D. - Hawaii Community College, University of Hawaii, Hilo HI

Research is currently underway in Hawaii on cave crickets of the genus Caconemobius (Gryllidae) and their surface relatives (Hawaii Bishop Foundation grant). In Southeast Asia and Australia, we are studying cave adapted cockroaches in the genera Nocticola and Speleoblatta (Nocticolidae), and in Australia Nocticola and Paratemnopteryx (Blattellidae) with travel and field support from the Explorers Club. In Hawaii, evidence from ecology, behavior, morphology, and karyotype indicates that several species of Caconemobius evolved from sea-coast dwelling ancestors to take advantage of inland bare-rock habitats including underground anchialine habitats, recent lava flows, and the deep root zone (mesocaverns and lava tubes). The more cave adapted species (C. sp. A.) shows the least morphological variation over its range, while the less cave adapted species morphologically and behaviorally (C. various) shows a clinal morphological variation from cave to cave. In Thailand, Malaysia, Indonesia and Philippines, numerous species of Nocticola show varying degrees of cave adaptation. The most geographically comprehensive surveys have been done in northern Thailand. There, degree of troglomorphy apparently correlates with range (the most widespread species are least cave adapted) and cave environment (greatest troglomorphy correlates with high humidity and high carbon dioxide levels). Australian species of Nocticola and Paratemnopteryx occur in caves, lava tubes, and surface environments (rainforest, rotting logs). In the limestone towers of the Chillagoe area of northern Queensland, both Nocticola and Paratemnopteryx show clinal variation among limestone towers, with greater troglomorphy toward the north. In the lava tubes at Undarra, Queensland, the most highly cave adapted species of both genera occur in the saturated humidity and high carbon dioxide of the deepest cave zone. Troglophilic species of Paratemnopteryx occur in less humid areas and in association with bat colonies in both Undarra lava tubes and Chillagoe caves.

FEMORAL ATTENUATION AND ANNUAL FEMUR LENGTH: MASS RELATIONSHIPS IN CAVERNICOLOUS CRICKETS (INSECTA: ORTHOPTERA:RAPHIDOPHORIDAE AND GRYLLIDAE)

Studier, E.H. and Lavoie, Kathy H. - Biology Department, University of Michigan-Flint, Flint, MI 48502-2186

Curvilinear relationships exist between hind femur length (HFL) and crop-empty live weight (CELW) for the cave cricket (Hadenoecus subterraneus) and the camel cricket (Ceuthophilus stygius). These relationships differ significantly between species and also by gender in both species and by season for cave crickets. In C. stygius, females of small HFL are slightly lighter, and of large HFL, slightly heavier, than males. In H. subterraneus, females have progressively greater CELW than males as HFL increases. In adult H. subterraneus of identical HFLs, CELW is greatest in fall and least in spring, i.e., individuals are most robust in the fall in these long-lived crickets, probably due to seasonal constraints on food resources.An attenuation index of CELW/HFL^3 yields a ratio which ranks the degree of adaptation to cave life in these two and eight other species of rhaphidophorids and gryllid cave and epigean "crickets". Lower values (i.e. relatively longer femurs) of the attenuation index indicate greater adaptation to cavernicolous existence.

GEOLOGIC CONSTRAINTS ON THE DISTRIBUTION AND MANAGEMENT OF FEDERALLY LISTED ENDANGERED SPECIES IN TEXAS CAVES

Veni, George - George Veni & Associates, 11304 Candle Park, San Antonio, TX 78249

Seven invertebrate and one salamander species located in the vicinity of Austin, Texas, have received federal endangered status. Regional management efforts to preserve the species' habitats included the geologic study of preferential lithologic zones, defining and delimiting the interstitial zone, and examining local geologic karst evolution with regard to the development of migration barriers which promote speciation. Eleven karst areas were defined based on the geologic migration barriers. The distribution of 38 troglobites restricted to the Austin region provided measures for the effectiveness of those barriers and was summarized through the development of a speciation index. The speciation index also suggests species which should be reconsidered for addition to or removal from the federal endangered species list. The final phase of the project was the drafting of endangered species distribution maps, indicating on 7.5" topographic quadrangle, the areas known to contain endangered species, which are likely to contain endangered species, or which have a low probability for endangered species. These maps are being used by federal, state and local authorities in land acquisition, permitting and planning.

COMPARATIVE STUDY AND PHYLOGENTIC AGE OF EPIGEAN AND CAVE FORMS OF THE GENUS RHAMDIA (PIMELODIDAE, TELEOSTEI)

Wilkens, H. - Zoologisches Institut und Zoologisches Museum Universitat Hamburg, Germany

The pimelodid catfish Rhamdia laticauda is found in torrents of the Sierra Madre Oriental (Mexico), which are characterized by cooler water temperatures. R. laticauda is the ancestor of the cave fish R. reddelli and several other cave-dwelling populations of R. laticauda, which occur in the Sierra de Zongolica (Veracruz). One of the latter, the Ostoc-cave form, and R. reddelli are very recent cave invaders. Under daylight conditions both still develop half as much melanophores as the epigean form. As the melanin content is the same, the cave forms appear darkish.

The eye of adult specimens of the cave fish shows a high inter-and intraindividual variability. Its mean size is intermediate between epigean and cave forms. The negative phototactic behavior, too, is subjected to reduction. Whereas the epigean form is extremely negative phototactic, this reaction is much weaker in the cave fish, although they are very well able to perceive light.

The barbels show a constructive evolution. They have increased their size by about 50%. Furthermore the fat storage ability is improved as an adaptation to the limited food supply in caves.

Contrary to another Mexican catfish, R guatemalensis, R. laticauda produces eggs which contain twice as much yolk. As the yolk content in both cave derivatives has not been enhanced, one can characterize this feature besides others as a very important prerequisite of R. laticauda for cave colonization.

The cavernicolous evolution of the R. laticauda derivatives cannot have started before the end of the Pleistocene. At this time, the torrents of the Sierra Madre Ori ental became slightly warmer and could be invaded by a cool-resistent spectrum of fish species, which even today is poorer than in the lowlands. R. reddelli which occurs within an isolated mountain ridge in the lowland could probably start cave evolution a little earlier, because this region warmed up earlier. This is confirmed by a higher degree of eye reduction and the negative phototactic behavior.

THE BIOLOGY OF THE CRUSTACEAN CLASS REMIPEDIA, WITH EMPHASIS ON INTERNAL ANATOMY

Yager, Jill - Biology Department, Antioch College

A general overview of the internal anatomy of remipedes is presented. Remipedes are an unusual group of troglobitic crustaceans that live exclusively in anchialine caves. They inhabit marine water of very low dissolved oxygen content. Large hemocyanin crystals are scattered throughout the tissue of the head and swimming appendages. Remipedes are simultaneous hermaphrodites and have flagellated sperm packed into distinctly shaped spermatophores. Large secretory glands are associated with the first maxilla of several species. Although direct feeding observations have not been made, it is hypothesized that prey items are injected with the secretory product.

CAVE RESCUE

WORKING WITH THE MEDIA

Bannerman, Bruce - Box 257, Culloden, WV 25510

The media is often a source of some aggravation to rescue personnel. As conflicting goals collide conflicts occur. Research on the problem and interviews with rescue managers and media personnel have allowed the formulation of new media practices for rescue leaders. This paper will discuss research done in this area and suggest methods of limiting media problems.

THE WILDERNESS EMT AND HIS/ HER ROLE IN CAVE RESCUE

Conover, Keith - 36 Robin Hood Road, Pittsburgh, PA 15220-3014

The cave rescue situation requires medical personnel to work independently of a hospital environment. Often long term care is provided during a delayed extrication period lasting many hours.

The role of the modern caver EMT may require care that is beyond his/her current legal authority. This paper describes a program of training and certification cur rently available that may allow cave rescue medics to better meet the needs of wilderness patients. Also the role of the EMT-W is explained in detail at other wilderness incidents.

LANDMARKING YOUR PATIENT

Dodds, Arthur W., Jr. - 11472 Laurelwalk Dr., Laurel, MD 20708

The wilderness environment creates demands for long term patient care not found in the swoop and scoop training received by the urban rescue squads. The urban Emergency Medical System's "Golden Hour" saves lives by its proximity to transportation systems and hospitals. Minor patient discomforts, blood covered skin, and the need to void are taken care of at the hospital. The wilderness and cave rescue experience demands that the medical provider not only consider the urgent medical needs of their patient but the long term comfort and sanitation needs as well. Landmarking your patient's critical care areas before packaging and transportation begins, will save time, increase the patient's comfort and their confidence in you. These care areas include: injury sites, head, nose, mouth, neck, back, arms, genitals, legs, knees, bones close to the surface of the skin, and any monitoring equipment to be used. Hovering and planning over your patient tends to reduce patient confidence in you and your team's ability to perform. Many situations in packaging and transport can be acted out, using volunteers of the same size and duplicates of equipment, before exposing your patient to an unsuccessful attempt.

The litter packaging, nursing, and transportation techniques you use for your patient's physical and psychological comforts may do as much for your patient as the medical treatment you administer.

CAVE RESCUE INCIDENTS OVER 40 YEARS, WHERE ARE WE GOING AND WHAT DOES IT MEAN

Hempel, John C. - RD 1 Box 371, Dilliner, PA 15327

This paper describes cave rescue missions over the last 40 years and looks at the type, number and growth rate of rescue missions in the United States over that period. Graphs and charts illustrate mission statistics and caver population growth during each decade.

From the data presented several conclusions as to what we should be doing to train our people to meet cave rescue challenges in the 21st century are drawn.

"MISSION REPORT" ONESQUETHAW CAVE
DECEMBER 1, 1990

Mobley, Emily Davis - Box 10, Schoharie, NY 12157
Engle, Thom - 7D West St., Voorheesville, NY 12186
Rubin, Paul - RD1, Box159, Feura Bush, NY 12067

On a sunny afternoon in December 1990, five students from Syracuse University entered Onesquethaw Cave. They became trapped several hours later by an unexpected flash flood.

The intelligent actions of the party, the positive relationship between cavers and local authorities and the support of local businesses combined with the quick response of the cave rescue network helped to make this another successful mission.

The cause of this clear day flood, the actions of cavers, the effects of running a media circus and benefits of a good relationship with local authorities will be discussed in this paper.

RESCUE IN KING BLAIR CAVE - A MANAGEMENT PERSPECTIVE

Paquette, Don - 835 Hickory Dr., Bloomington, IN 47401

During March of 1990 in Monroe Co., Indana caver Aaron Howell fell while exploring King Blair Cave. The site of the accident was 1500 feet from the entrance beyond a difficult water crawl passage. Major injuries complicated the rescue which involved 128 people. At any given time 68 people were underground moving the patient.

This paper details the nature of the accident, the patient condition and the management decisions that allowed this to be another successful mission.

COMMUNICATION AND ELECTRONICS

THE RIGHT TEST EQUIPMENT

Cole, Ray - 3410 Austin Court., Alexandria, VA 22310

The newcomer to caving-related electronics may be a little frustrated without the right type of electronic test-equipment. The basic tool needed is a method of measuring voltage, current, and resistance. This is called a volt-ohm-milliammeter (VOM). Usable models can be found at electronics parts stores including Radio Shack. More sophisticated equipment including signal generators and oscilloscopes is needed for building your own cave radios. A good place to find electronic test equipment is at amateur-radio fleamarkets called Hamfests. Other useful items include electronic breadboards, and capacitance and resistance substitution boxes.

BATTERIES FOR CAVING

Heller, Chuck - 27 Lakeshore Drive, Lake Hiawatha, NJ 07034

A survey of different types of batteries and lighting systems for dry caving includes building a simple charging system which one can use from AC or car battery.

Costs, advantages and disadvantages of standard D,C,A and AA cells, nickel-cadmium dry and wet cells, gel cells, lithium batteries and mercury batteries will be covered.The Care and feeding of gel-cells and nickel-cadmium batteries, along with memory-restoration and depletion of nicads will bediscussed. Shelf-lives of all the above batteries will be covered.

An inexpensive charging system which is easy to build and can charge all types of batteries will be demonstrated, along with examples of different types of batteries and lights.

AN EXPERIMENTAL SYNCHRONOUS CAVE-RADIO

Pease, Brian - 567 Fire Street, Oakdale, CT 06370

A synchronous cave-radio operating at 3496 Hz has been developed and tested in several different applications. It was originally built as the simplest device that could provide a steady meter-readout of received relative magnetic-field strength from an in-cave beacon to determine depth of field strength for survey applications. The zero-centered meter provides left-right or up-down indications for homing in on "ground zero". The phase-sensitive detector provides deep nulls by rejecting out-of-phase secondary signals generated in the rock. A simple method of measuring ground conductivity without probes, using these secondary signals, has been tested. This conductivity technique shows promise as a way to do "cave hunting" from the surface with the same survey gear. Maximum horizontal range is the usual 1500 feet (457 meters) or so, in quiet conditions.

CAVE RADIOS AND THE LAW

Pease, Brian - 567 Fire Street, Oakdale, CT 06370

Federal Communications Commission regulations currently allow homebuilt cave-radios employing loop antennas to be legally operated in the USA without license or approval of any kind. The weak electric fields actually generated by loops at low frequencies allow cave radios to legally operate at much higher power levels (and higher frequencies) than commonly used. In particular, this will allow the development of high power two-way voice cave-radios in the optimum 15-30 kHz range. Units offered for sale in quantity are supposed to pass a certification test and would carry warning stickers saying that they must not cause harmful interference, etc., such as those found on cordless telephones.

CONSERVATION AND MANAGEMENT

THE POLLUTION OF THOMPSON CEDAR CAVE, VIRGINIA: PAST, PRESENT AND FUTURE EFFECTS

Holsinger, John R., Department of Biological Sciences,Old Dominion University, Norfolk, VA 23529

Culver, David C. - Department of Biology, American University, Washington, DC 20016

Thompson Cedar Cave, located in Lee Co., Virginia, is a 250-meter-long stream cave in a prominent karst area called the Cedars. Prior to pollution the cave had an especially rich and abundant aquatic fauna, including the troglobitic isopod crustacean Lirceus usdagalun, known from only two cave systems in Lee County. This cave fauna had been the subject of ecological studies that resulted in several publications. In the spring of 1987, the sinkhole entrance to the cave was filled with sawdust, cedar bark, and other waste from a sawmill located adjacent to the cave mouth. The result of this action, plus additional sawdust accumulations that severely altered recharge in other parts of the drainage basin, was the massive organic pollution of the cave stream ecosystem and the extirpation of its cavernicolous fauna. Although sawmill personnel removed the sawdust and cedar bark from the entrance sinkhole in winter 1988, there had been no recovery of the fauna by summer of 1990. Only tubificid worms, chironomid flies, and occsional salamanders were present. Through actions of the Virginia Cave Board, Virginia Natural Heritage Program, and the Virginia Department of Waste Management, the Russell Lumber Company signed an agreement in January, 1991 to begin remediation of water and solid waste pollution. While considerable progress has been made with the cleanup to date, we suspect that it will take years for the cave stream ecosystem to recover, if ever. We will continue to monitor the cave, its fauna, and land use in the surrounding area.

HISTORY, CONSERVATION, AND SCIENCE OF GARDNER CAVE, WASHINGTON

Martin, Kyle - NOAA/National Weather Service, Northwest River Forecast Center, 220 N.W. 8th Ave., Room 121, Portland, OR 97209

Gardner Cave has undergone tremendous change since its discovery around 1903. Limited exploration and public visitation during the 1920's were followed by scientific surveying by Dr. William Halliday in the 1950s and vandalism during the 1950s and 1960s. Intervention by the Washington State Park Commission halted vandalism, upgraded pathways in the cave, and guided tours began in 1977. Another scientific study (isotope geochemistry and paleomagnetism) was conducted in the mid-1980s, including a more detailed inventory of New Cave - a nearby companion cave loaded with pristine speleothems. Gardner Cave contains a rich diversity of speleothems for a cold-climate limestone cave, despite the scars of vandalism which have been left to heal naturally.

THE SPELEOLOGICAL INTEREST, EXPERIENCE AND DEMOGRAPHIC STUDY OF THE NSS MEMBERSHIP

Stitt, Robert R., - 1417 9th Ave. W, Seattle, WA 98119
Wilson, John M. - 7901 Dalmain Drive, Richmond, VA

Preliminary results of the Social Science Section study commissioned by the Board of Governors will be presented. This study will provide a wide range of information about the caving activity, affiliations, interests, education, profession, and demographics of NSS members. By obtaining information that is compatible with some of the cave register questions, the survey data can be applied to more research problems and thus, improve the usefulness of the survey. It will also provide additional reliability measures by comparing the two data bases. A random sample of 600 members was surveyed to provide a reliable base for many options for future data use. The data has been entered into an electronic data base and is available for other researchers.

THE HAWAII CAVE CONSERVATION TASK FORCE: PROGRESS REPORT

Stone, Fred D. - Hawaii Community College, Hilo, HI
Howarth, Francis G. - B.P. Bishop Museum, Honolulu, HI

The Hawaii Cave Conservation Task Force was established following the 1982 NSS Convention in Bend, Oregon. It grew out of work toward protection of Hawaiian caves by Howarth dating from his discovery of their unique fauna in 1971. Ongoing work includes: (1) Work with the Hawaii Volcanoes National Park to develop and implement a cave management plan with a strong protection component; (2) Work with Hawaii State agencies to inventory and survey caves and develop management plans for caves in state Natural Area Reserves; (3) Work with the Hawaii Department of Agriculture to survey a 2 mile long lava tube on State Ag. lands, and lease it to the University of Hawaii as a cave laboratory/reserve; (4) Work with the State Historic Preservation Office and the Hawaiian Burial Committees to survey caves with Hawaiian burials and archaeological deposits, and to propose mitigation measures where these caves are threatened by proposed development. One successful project involved the survey and protection of major lava tubes in the geothermal subzone (5) Work and survey caves in current preserves; (6) A strong public education program on important values of caves, including talks and cave tours to National Park interpreters, school groups, university groups, and the general public; and (7) Regular clean-up trips into Kaumana Cave involving school and university students.

THE EFFECTS OF THE CHANGE IN THE NSS REWARD TO DETER CAVE VANDALISM

Wilson, John M. - 7901 Dalmain Drive, Richmond, VA 23228

The NSS has paid one reward under the new flexible reward with a minimum of $250 and a maximum of $1000. The reward will be given to the person or persons providing information that leads to a conviction for cave vandalism. This reward replaced the $500 reward that had been in effect since 1982. The changeover date was 1 June 1990. New fund raising options have resulted in more money being raised for the reward since the mid 1980s. The Commission continues to recall all of its previous posters, replacing them with the new version. These notices will be posted at show caves, managed caves, and other places in cave areas.

CONDUCTING A CAVE REGISTER PROGRAM

Wilson, John M. - 7901 Dalmain Drive, Richmond, VA 23228

Version 5.0 cave registers have been in use for approximately three years. A few results have been returned to the Study Group to date, and preliminary results will be shared at this session. The revised format cave register is intended to provide more information of value to cave managers, conservationists, and cave organization leadership, and early results indicate that the new format will be more beneficial than the old format cave registers. The CCUS software is now being shipped to over 20 of the 45 cave register programs in North America.

This talk will include a short "how to" presentation on operating a register program. A small supply of registers and containers will be available to any NSS member planning to conduct a register program. Order forms requesting supplies from the study project can also be obtained at this session.

DIGGING

ON THE IMPORTANCE OF SAVING CAVE CONNECTIVITY DATA

Curl, Rane L. - Department of Chemical Engineering, University of Michigan, Dow Bldg., Ann Arbor, MI 48109

Digging is finding new caves and connecting or extending old caves. These alterations are changing data about the number and lengths of caves, from which useful information can be obtained. For example, it is possible to deduce the number and lengths of proper entranceless caves, as well estimate the number and vol-umes of caves that can be explored by organisms larger or smaller than humans, if accurate data are available for the natural state of caves.

The definition of a cave will be discussed, and prior results from length data will be interpreted, to illustrate present and possible future applications for accurate data.

THE BIG MANHOLE CAVE DIG PROJECT

Peerman, Steve, - 1757 Defiance Road, Las Cruces, NM 88001
Lory, Jeff - 840 Holly Dr., Sp B-11, Las Cruces, NM 88005-1010

The Big Manhole Cave Dig Project was begun in March, 1988 by cavers from the Lechuguilla Cave Project, in the interest of finding a "back door" to nearby Lechuguilla Cave. After a short period of time the Big Manhole project took a life of its own. This presentation will discuss the management of the dig on both an administrative and logistical level. Specifics will include techniques developed and utilized to enhance digging efficiency and productivity. The accompanying slide program will illustrate all facets of the dig's progression. Also included in that discussion will be how restoration of the cave became an integral aspect of the dig. Closing comments will provide the present status of the Big Manhole Cave Dig Project.

DIGGING IN THE GLACIATED KARST OF SCHOHARIE COUNTY, NEW YORK

Kiparski, Wolfram - 512 Washington Ave. #2, Albany, NY 12203

The karst of Schoharie County, New York lies mostly buried under glacial sediments. Glaciation during the Pleistocene epoch buried many surface karst features and altered the subsurface drainage pattern of the limestone. During deglaciation, a high sediment load was supplied to streams entering the cave systems and many cave passages became choked with glacially derived sediments. Insurgences and resurgences plugged and were abandoned. Subsequent erosion has either partially restored preglacial drainage patterns or established new drainage routes. Because of the effects of glaciation, the currently explorable extent of known caves represents only segments of larger, integrated cave systems. Large segments of cave passages may exist behind plugs of glacial sediment. The recognition and understanding of this situation is the most important source of motivation for digging efforts in the area.

BLASTING FOR CONSERVATION: THE ETHICS OF BLASTING AND DIGGING IN CAVES

Wilson, John M. - 7901 Dalmain Drive,Richmond, VA 23228

Ethical dilemmas are resolved by determining how the results of a given course of action such as cave digging and blasting in a cave are compatible with and help to achieve one's highest value. One of the most efficient ways to do this is to apply the tools of ethical consideration: rules, agreements, and comparisons. The strongest case against digging and blasting is made by people using naturalism, a value system that prefers to leave things as they naturally occur. Naturalists often use legalism as the method of justification. An alternative to naturalism as a highest value is Agape. It may be defined as: care about and respect for each person, while understanding the necessity of civilization and the environment that provides the needed support for each person to have a life that is appropriate for fulfillment as a human being.

The justification for modifying a cave using objective comparison (consequencialist) methods requires that all of the consequences of blasting and digging be weighed against not blasting and digging. The results are then compared in terms of which course of action contributes to attaining one's highest value.

Naturalism as a highest value is shown to be inadequate in providing a rational for human concerns. It provides little in the way of a system to guide cave explorers, speleologists, and cave managers in establishing acceptable caving impact standards, cave management plans, and criteria for obtaining speleological knowledge. Blasting and digging in caves are tools that can be used to help us gain the knowledge necessary to make good decisions in managing cave and karst areas and other natural assets for which we as humans have assumed responsibility. The cumulative knowledge and power that Mankind has obtained requires active management. This is the only realistic option for cave and karst resources to remain a positive asset for our species and the others with whom we share this planet. By doing so we affirm the need for and recognize the mutual benefits of respecting a shared environment.

A case history using Perkins Cave as an example will be presented. Some role plays or group discussion may be used to demonstrate various alternatives.

GEOLOGY AND GEOGRAPHY

SUBMARINE KARST ON THE FLORIDA- HATTERAS SLOPE?

am Ende, Barbara Anne, and Paull, Charles K. - University of North Carolina, Chapel Hill, NC 27599-3315

The Florida-Hatteras Slope off the southeastern United States has numerous features that suggest they have formed by karst processes. The bathymetery of the inner Blake Plateau shows numerous closed depressions that resemble sinkholes. No other known marine process is likely to produce these morphologies. We also suggest that coral-coated pinnacles up to 150 m high, which have been interpreted as deep water coral build-ups, instead may be karren.

We propose that the Eocene strata are discharging fresh water to the ocean at depths of 250-850 m on the Florida-Hatteras Slope where these karst-like features are located. Continentally-derived groundwater is known to flow through aquifers underneath the continental shelf. A JOIDES well drilled on the continental shelf approximately 50 km from the Georgia-Florida state line produced an artesian flow of fresh water with a hydraulic head of at least 18m. Previous studies have suggested that coastal caves in areas such as the Yucatan and Bahamas are forming where fresh water mixes with seawater. Any mixture of fresh and salt water experiences a decrease in its saturation state and may become corrosive to carbonate rocks.

Dissolution associated with fresh and salt water mixing, at the edge of the continental aquifers, may have generated these karst-like features.

STRUCTURAL, GLACIAL, AND HYDROLOGIC FACTORS IN THE DEVELOPMENT OF THE JOROLEMANS-HANNACROIX COMPLEX, ALBANY CO., NY

Engel, Thom - 7D West Street, Voorheesville, NY 12186

Five unconnected caves (Jorolemans, Jorolemans Back Door, Skips Sewer, Merritts, and Hannacroix Maze) in southern Albany Co., NY can be viewed as a single feature in how they relate to past and present surface drainage. Factors affecting cave development and surface drainage include Arcadian deformation, faulting, the Wisconsinan Glaciation, and the local hydrologic base level. The two longest caves, Merritts Cave and Hannacroix Maze (about 900 and 2000 feet long respectively), are developed along the axis of a single syncline in relatively flat lying rock. Several thrust faults have been identified in and near Hannacroix Maze and Merritts Cave. These thrust faults may prevent downward development of these two caves. Jorolemans Cave and Jorolemans Back Door are paleo-caves developed on the limb of this same syncline. They carried a significant stream at one time, but have become partially filled with sediment. Their passage morphology may be controlled by a thrust fault zone. Preliminary paleontological excavations have been done in Jorolemans Cave.

BASELINE TRACE ELEMENT CHEMISTRY OF KARST SPRINGS IN SCHOHARIE AND ALBANY COUNTIES, NY

Garbellano, Linda, and Shaw, George H. Geology Department, Union College, Schenectady, NY 12308

Plasma source mass spectrometry is a rapid method for determining trace element concentrations in dilute natural waters. The high sensitivity allows routine measurement of many ions at the parts-per-billion level, using sample volumes as small as 10 ml. Provided that background levels of suitable elements are sufficiently low, there is the possibility of using some trace elements as water tracers, especially in quantitative studies of subsurface flow. As a preliminary to water tracing tests we are determining natural background levels of a variety of ions in karst springs in Schoharie and Albany counties.

Starting in October 1990, and continuing to the present, water has been sampled at fifteen springs. Samples were taken every 2-4 weeks, and after acidification and addition of internal standards the samples were analyzed for a suite of elements using a plasma source mass spectrometer, employing blank subtraction procedures. Among the elements determined were: Mg, Ca, Sr, Ba, Na, K, Rb, Pb, Th, U, Cu, Zn, and Br. Calcium, sodium, magnesium, and potassium are typically present at levels of 1-100 ppm, with concentrations generally decreasing in the order given. Calcium concentrations are usually about 8-10 times those for magnesium, and sodium is generally about three times magnesium. Potassium is about 1/10 the concentration of sodium.

Barium concentrations are mostly in the 50-100 ppb range, with strontium 4-6 times as high. Rubidium is usually present at about the 1 ppb level. Lead and thorium occur at concentrations below 0.1 ppb. Lead in many samples is below the detection limit of 10 parts-per-trillion. Uranium is usually present at around 0.3-0.5 ppb.

The most interesting elements for potential use in water tracing are copper, zinc, and bromine. Backgrounds for copper and zinc are around 1 ppb and bromine 5-10 ppb. Allowable concentrations in drinking water are orders of magnitude higher than background levels, providing a significant range for artificially increasing concentrations in natural flows while maintaining a significant safety factor for preservation of water quality.

SIMULATION MODELING OF EARLY KARST DEVELOPMENT

Groves, Christopher G. - Department of Geography and Geology, Western Kentucky University, Bowling Green, KY 42101
Howard, Alan D. - Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22903

Much of the work that has been done in order to understand the nature of karst has been concerned with the large scale, explorable segments of these systems. For a more complete understanding, however, we must also consider events that occur at scales that preclude direct observation. A new simulation model that couples dissolution kinetics with hydrodynamics of flow through small limestone conduits is currently under development. The program features subroutines which calculate rates of calcite dissolution assuming both surface reaction rate control and diffusion control, so that the limiting rate can be chosen under varying chemical and flow conditions as the passages enlarge. A third kinetic model, assuming control by CO_2 hydration, is being added. Simulations of published laboratory dissolution experiments are quite encouraging. For typical karst waters, upon reaching turbulent flow conditions, the model predicts that diffusion gives over control to surface reaction rate, and dissolution rates increase by about an order of magnitude. Continuing work includes investigation of mixing of chemically distinct waters, and effects of conduit constrictions.

KARST TERRAIN: THE BOWLING GREEN EVALUATION OF GROUNDWATER CONTAMINATION POTENTIAL IN A SOUTH QUADRANGLE OF KENTUCKY AS AN EXAMPLE

Howcroft, William D. - Center for Cave and Karst Studies, Department of Geography and Geology, Western Kentucky University, Bowling Green KY 42101

The Bowling Green South topographic quadrangle was evaluated in terms of its groundwater contamination potential through application of a modified DRASTIC methodology on a Geographic Information System. Arc/Info was utilized to create five coverages representing sinkhole and non-sinkhole areas, bedrock type, soil cover, slope, and agricultural land use. Integration of the five coverages into a single DRASTIC map yielded a series of polygonal areas with distinct characteristics represented numerically and stored in Info files. The characteristics were summed in each polygon yielding a DRASTIC Index which represents the groundwater contamination vulnerability for that particular area. Analysis of the final DRASTIC map suggests that the alluvium areas along Drakes Creek and the Sinkhole Plain Margin near Three Springs represent the regions of least groundwater contamination vulnerability. Distribution of the areas evaluated to be most vulnerable is more complex and is dependant on various hydrogeologic variables.

CAVE RESOURCE INVENTORY OF ROCKINGHAM COUNTY, VIRGINIA

Hubbard, David A. - 40 Woodlake Drive, Charlottesville, VA 22901
Berdeaux, Gary C. - Endless Caverns, P.O. Box 859, New Market, VA 22844
Spina, Thomas A. - 3209 Sherry Court, Virginia Beach, VA 23464
Holsinger, John R. - Old Dominion University, Biology Department, Norfolk, VA 23529

A survey of the caves in Rockingham County, Virginia is generating some interesting data. The survey was initiated in 1990; ultimately, the inventory will include all of the approximately 100 known caves as well as some previously unreported caves. As in other contemporary cave surveys, mapping efforts are culminating in new detailed maps and the replacement of outdated maps. Geologic setting is determined during the mapping of most of the caves and includes the geologic mapping unit, attitude, and significant features. Two of the eight caves inventoried, as of February 1991, are associated with cave onyx and saltpetre mining. An interesting facet of the inventory is related to the cave biota. New occurrences of aquatic crustaceans have been recorded in four caves; two or three of the occurrences are biogeographically significant. The habitats of these crustaceans are being classified as phreatic, vadose stream, or vadose dripping. The range of the species is generating interesting data about groundwater basins and perhaps paleobasins. Habitat mapping combined with water tracer studies will help supplement existing regional karst studies. The characterization of groundwater basins is important for the understanding and protection of the groundwater resources of Rockingham County as well as other karst areas within the Valley and Ridge physiographic province.

RECOGNITION OF MICROCLIMATE ZONES THROUGH RADON MAPPING, LECHUGUILLA CAVE, CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

LaRock, E.J., and Cunningham, K.I. - U.S.Geological Survey, MS 905, Box 25046, Denver Federal Center, Denver, CO 80225-0046

Radon levels throughout Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico support a model in which outside air temperature and barometric pressure control radon concentrations only in the entrance passages and areas immediately adjacent to these passages. The majority of the cave is developed in 3 geographic branches beneath the entrance passages and maintain radon levels independent of surface effects. These deeper, more isolated areas are subject to convective ventilation driven by temperature differences along the 477 m vertical extent of the cave. Radon is used to delineate 6 microclimate zones (air circulation cells) throughout the cave in conjunction with observed airflow data. Suspected surface connections contribute fresh air to remote cave areas demonstrated by anomalous radon lows surrounded by higher values, the presence of mammalian skeletal remains, CO_2 concentrations and temperatures lower than the cave mean, and associated surficial karst features.

SOLUTIONALLY ENLARGED GLACIAL STRIATIONS ON A DOLOMITE KARST TERRANE

Medville, Douglas M. - 11762 Indian Ridge Rd., Reston, VA
Goggin, Keith - Department of Geology, George Mason University, Fairfax, VA

Structural surfaces on west-dipping carbonate rocks are found in several locations on the west slope of the Teton Range, Wyoming. One such surface, found on the Ordovician Bighorn Dolomite in upper Darby Canyon, has an aerial extent of about 10 square km. In addition to classic karren features: e.g. kluftkarren, spitzkarren, maanderkarren, trittkarren; an additional and possibly unique feature, has been observed and will be discussed. This karren form consists of "furrows" parallel to each other and also to the dip of the dolomite. The furrows are 20-40 cm. deep, are spaced 30 cm to 50 cm apart, and have linear extents in the order of hundreds of meters. They are observed on several exposed dolomite beds in conjunction with other standard karren features. The furrows are interpreted as being solutionally enlarged striations resulting from Pleistocene valley glaciation. The origin and potential age of the furrows will be discussed.

CAVE FORMATION ON NEW PROVIDENCE ISLAND AND LONG ISLAND, BAHAMAS: EVIDENCE OF FLANK MARGIN DEVELOPMENT

Mylroie, John E. - Department of Geology and Geography, Mississippi State University, Mississippi State, MS 39762
Carew, James L. - Department of Geology, The College of Charleston, Charleston, SC 29424
Sealey, Neil E. - Social Sciences Division, The College of the Bahamas, Nassau, Bahamas
Mylroie, Joan R. - 617 Sherwood Road, Starkville, MS 39759

Cave development in coastal and island limestones is often geochemically driven by mixing of marine and fresh groundwaters at the margin of the land mass. In Quaternary limestones of limited areal exposure, as exist in The Bahamas, large caves have formed despite severe limitations on time and catchment area. The caves are testimony to the power of mixed-water dissolution, and they also illustrate the unusual passage morphologies produced by that genesis mechanism. The flank margin model explains cave development in such environments.

Each of six caves from New Providence Island and an additional six caves on Long Island, Bahamas, exhibit classic flank margin features such as: vertically restricted large, globular rooms, maze-like side passages, tubular conduits that lead inland and end abruptly, and thin wall partitions that separate chambers and passages. There are two distinct flank margin morphologies seen among Bahamian caves: caves developed around an elongate central chamber; and caves developed as large tubular passages that parallel the ridge containing them. The flank margin morphologies are found at the scale of caves only a few meters across, up to caves over 100 m across. Some of the larger caves contain individual chambers in excess of 14,000 m^3. Based on the age of the limestone, and the duration of the high sea level events of the Late Pleistocene, the total aggregate time available for dissolution of these caves cannot have exceeded 30,000 years.

HYDROSTRATIGRAPHIC ANALYSIS OF DYE TRACE RESULTS FOR INTERPRETING GROUND WATER MOVEMENT FROM CLASS V INJECTION WELLS

Ogden, Albert E., Redman, Ronald K., Perrett, Bret D., and Mason, John C., Center for the Management, Utilization, and Protection of Water Resources, Box 5033, Tennessee Technological University, Cookeville, TN 38505

Around Cookeville, Tennessee, much of the stormwater runoff has been diverted to man-modified sinkholes that are considered Class V injection wells by the U.S. EPA classification scheme. To ascertain the impact of these sinking streams on spring water quality and the ground water flow directions, a dye tracing program was initiated. The results from ten dye traces performed for this project and twenty previous traces show that differences in the hydraulic conductivity (k) of beds within the Mississippian-aged Monteagle, St. Louis, and Warsaw Limestones control the elevation of springs, caves, and sinkholes. Caves form above the beds having low k values supporting a "perched water table" origin of caves versus base level control.

Drainage off the Hartselle Sandstone bench moves under near vertical hydraulic gradient until sandy, thin-bedded limestone perching units within the upper Warsaw are encountered. The quality of the springs located at this contact zone is good since recharge to sinkholes is from predominantly forested areas with some agricultural activities. Within the city limits of Cookeville, urban drainage is perched above chert layers within the lower St. Louis that have low k values. Upon reaching more permeable layers at the surface, streams sink in the middle Warsaw or upper

St. Louis and move under low hydraulic gradient. These springs show chemical and biological evidence of the water quality degradation. The lower Warsaw is a calcareous siltstone and shale and perches ground water commonly 10 to 30 ft. above base level streams. Long, horizontal caves have developed at this contact. Contaminant movement from Class V injection well sinkholes is perched above these beds. Since springs form a major component of flow to the surface streams, Class V injection wells are therefore, posing a threat to surface drinking water sources.

WATER QUALITY, QUANTITY AND LAND DEGRADATION IN THE KARST OF BATUAN, BOHOL, THE PHILIPPINES

Reeder, Philip P. - Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI 53201

Located in the southern portion of the Philippine Archipeligo 500 kilometers southeast of Manila is the island of Bohol. In the Central Plateau Region of Bohol, in the municipality of Batuan, springs issuing from the Pleistocene aged Maribojoc Limestone are the sole source of irrigation water during dry periods. Rice cultivation sometimes occurs in terraced fields which are irrigated by a spring-fed communal irrigation system. Other fields are exclusively irrigated with meteoric water and crop yields during dry periods are diminished. The soil resource is also severely degraded because population pressure has decreased fallow times in the shifting agricultural system and has forced landless people to cultivate marginal land in the hinterlands. Slash and burn agriculture in the hinterlands has greatly diminished aquifer recharge rates and has increased soil erosion.

The lack of a consistently reliable water supply and land degradation have greatly inhibited agricultural development and have imparted a negative impact on the local economy. In March 1989 a pilot program was implemented to develop methodology to increase irrigable land in Batuan. In cooperation with the Philippine Department of Agriculture, the water resources of Camaro Spring were assessed. This entailed a detailed survey of the subsurface reservoir that recharged Camaro Spring. Subsequently an engineering and management plan was developed that consisted of the construction of a dam in Camaro Cave to regulate the discharge of Camaro Spring. By regulating spring discharge, potential irrigation water could be stockpiled in the cave for use during dry periods thus reducing water loses due to evapotranspiration and spring discharge during high flow when meteoric water is sufficient to irrigate fields.

GROUNDWATER CONTAMINATION IN BOWLING GREEN, KENTUCKY

Reeder, Philip P. - Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI 53201

Bowling Green, Kentucky is built upon a sinkhole plain and is almost entirely located within the Lost River Karst Groundwater Basin. Recharge of the aquifer predominantly occurs via sinkholes, sinking or losing streams, caves and storm water drainage wells. The existence of an urban center in this karst setting and the ease with which potential contaminants entered the aquifer led to concerns about groundwater contamination in Bowling Green.

It was theorized that drainage wells were major avenues through which urban-based contaminants entered the subsurface drainage network. Research was conducted which focussed upon drainage well function and efficiency. Also, sixteen contaminant levels and related parameters were monitored for fourteen months at four sites in and around Bowling Green. This investigation revealed the groundwater contamination is a more serious problem in the rural area south of Bowling Green (the upstream portion of the basin) and in the urban area near downtown Bowling Green. It was concluded that the Bowling Green area has nonpoint source groundwater contamination problems at some specific locations. However, when the overall picture is viewed, contamination of the Lost River under Bowling Green is not that substantial, primarily because of the dilution of contaminants by water from the entire groundwater basin.

EVOLUTION OF THE STOCKTON PLATEAU KARST, WEST TEXAS

Veni, George - George Veni & Associates, 11304 Candle Park, San Antonio, TX 78249

The Stockton Plateau is the semi-arid to arid westward extension of the Edwards Plateau and is comprised of largely undeformed Cretaceous carbonate and clastic units, with the Fredericksburg Group limestones being the dominant outcrop. Earliest karst development occurred circa the Oligocene to Miocene when groundwater circulation was promoted by water loss from the ancestral Rio Conchos flowing downgradient to discharge at the more deeply incised ancestral Pecos River. This flow system created a network of large phreatic passages which bear no relationship to modern drainage or cave development but are expressed as linear subsidence sinkholes up to 5 km in length. The second and more recent major stage of karstification began in the early Pleistocene as deep phreatic and perched phreatic conduits began to drain local uplands to the incised river valleys to develop the deepest and some of the longest caves in Texas. Continued stream down-cutting and a descending water table created many relict caves. Surface karst on the Plateau is poorly developed due to the arid climate and the relatively recent (late Pleistocene) exposure of much of the limestone.

FIFTY YEARS OF CAVE GEOLOGY IN THE UNITED STATES: THE ROLE OF THE NSS

White, William B. - Department of Geosciences and Materials Research Laboratory, The Pennsylvania State Univesity, University Park, PA 16802

When the NSS was founded in 1941, the "classic" period of cave geology was coming to a close with the publication of

J. Harlan Bretz's "Vadose and Phreatic Features of Limestone Caverns" in 1942. As interest in caves by the professional geological community stagnated, the founders of the NSS installed cave science as one of the principal objectives for the new organization. The early work of the NSS was primarily cave exploration, survey, and inventory. It is significant that Ralph W. Stone and William E. Davies, both of whom were individually involved in cave inventory work later co-opted the NSS in their work and both served as NSS presidents. The contributions of the NSS to cave geology are many but perhaps can be grouped into four categories: (1) The continued emphasis on cave exploration, preparation of high quality cave maps and descriptions and their publication has insured a comprehensive data base to be drawn upon by the cave geologist. (2) The NSS has provided a forum, in its annual conventions and internal organizations for efficient communication between cave geologists. (3) The NSS Bulletin has played a critical role as a publication outlet for cave geology, particularly from the mid 1950s to mid 1970s when publication of cave and karst-related papers in the mainstream journals was extremely difficult. (4) The NSS has been a hot-bed for nurturing of new cave geologists.

LASER-EXCITED LUMINESCENCE FROM CAVE CALCITE SPELEOTHEMS

White, William B. - Department of Geosciences and Materials Research Laboratory, The Pennsylvania State University, University Park, PA 16802

Secondary calcite in caves - stalactites, stalagmites, and flowstone - gives a broad-band bluish to greenish white phosphorscence when excited by strobe lamps and ultraviolet lamps. It has been established that the luminescence arises from humic and fulvic acids which has been carried into the cave from overlying soils and deposited along with the calcite. Speleothem luminescence can also be excited by the blue and green lines of an argon laser. By using a microfocus Raman spectrometer in which the laser is focused onto a microscope stage with a spatial resolution of 1-2 micrometers, it is possible to map the luminescence emission for individual growth bands in sections of stalactite and stalagmite. The brightest luminescence is associated with the lighter colors, mainly from the fulvic acid component. Darker colors, indicating more humic component, give a weaker luminescence which is also shifted to longer wavelengths.

CHEMICAL EVOLUTION OF ACID-MINE DRAINAGE STREAM IN KARST TERRAIN

Wicks, Carol M. - Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22903
Groves, Chris G. - Department of Geology and Geography, Western Kentucky University, Bowling Green, KY 42101

This field study quantitatively defines chemical changes occurring in Camp's Gulf Branch, an acid-mine drainage contaminated stream in Van Buren County, Tennessee. As the stream flows over and through the carbonate rocks of the Cumberland Plateau Escarpment, rapid chemical changes take place as the waters are buffered from a pH value of 3.0 up to 7.2 along the study reach. Observed chemical compositions of the water along the flow path are used with the geochemical model WATEQF to calculate aqueous speciation, saturation indices, and CO_2 partial pressures. Mass balance calculations, using potassium as a conservative constituent, were performed to obtain mass transfers of CO_2 and calcite. The stream is originally an iron- and sulfate-rich system that rapidly changes to a calcium-sulfate-bicarbonate system, with stream chemistry controlled by calcite dissolution, CO_2 outgassing, $Fe(OH)_3$(am) formation and Mn oxide precipitation. Physical evidence of the geochemical change is apparent as the abundant "yellow boy" coating at the upstream locations and rapid decrease of this coating in the downstream direction. Additional work will involve calculation of calcite dissolution rates along this stream as a means of validating laboratory-derived rate laws.

STRUCTURAL AND HYDRAULIC FACTORS IN CONDUIT INITIATION

Worthington, S.R.H. - Department of Geography, McMaster University, Hamilton, Ontario, L8S 4K1, Canada

The geometric characteristics of a large number of conduit flow paths were studied to gain insight on the controlling factors in conduit initiation. These characteristics included conduit sinuosity, flow path width/length and depth/length ratios, and the ratio of the depth of loop crest to loop bases. It was found that bedding planes were the principal fractures guiding flow paths, and that >90% of the variance in conduit flow depth was explained by catchment length and stratal dip. Thus the 300m+ flow depths proven at Vaucluse (France) and Mante (Mexico) reflect very long flow paths, while the shallow flow paths typically found in the Appalachians reflect low stratal dips and/or short catchment lengths.

An active conduit acts as base level for the developing flow field below it, often for a period of >100,000 years. The initiation of the next tier of cave conduits may be modeled using the Hagen - Poiseuille equation, with the inclusion of the temperature-dependent viscosity and density terms, and of exponential hydraulic gradients. The surprising result is that the inputs furthest from the spring may be the first to achieve breakthrough.

These findings support a new model of conduit initiation. The model explains why loop crest depth/loop base depth ratios are >0.5, why the flow paths of most principal conduits in karst are phreatic, why distributary and vauclusian springs are common, why cave tiers form, and where thermal karst springs occur.

INTERNATIONAL EXPLORATION

THE 1990 AND 1991 SPELEOLOGICAL EXPEDITIONS TO THE NORTHERN VACA PLATEAU, BELIZE, CENTRAL AMERICA

Reeder, Philip P. - Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI 53201

Between March 8th and March 25th 1991 and February 23 and March 4, 1991 cave related research was conducted on the northern Vaca Plateau, Cayo District, Belize, Central America. The goal of this research was an initial reconnaisance of the karst resources in the vicinity of Spanish Water Hole in western Belize approximately 10 kilometers east of the border between Belize and Guatemala. The proposed plan of study consisted of surface reconnaissance of the karst landscape, the discovery, exploration, and mapping of caves and the mapping of surface and subsurface Mayan artifacts. The research team consisted of three graduate students from the Geography department at the University of Wisconsin-Milwaukee, two hydrogeologists from the Atlanta office of the Environmental Protection Agency, a geographer specializing in settlement geography and four Belizians.

During the 1990 expedition over thirty cave entrances were located, three caves were surveyed and numerous small caves were explored. The 1991 expedition located, explored and surveyed caves in a rugged area, which was located during the 1990 expedition, two kilometers east of the Guatemalan border. Twenty cave entrances were located and six caves were surveyed. The presentation will briefly discuss observations and collected data, but paramount will be a discussion of the cave exploration aspect of the study.

PALEONTOLOGY, ANTHROPOLOGY, & ARCHEOLOGY

FOSSIL CHIROPTERA FROM TWO WEST VIRGINIA CAVES

Grady, Fred - 1201 S. Scott St. #123, Arlington, VA 22204

Large numbers of fossil chiropteran bones have been found in Hamilton and New Trout Caves, Pendleton County, West Virginia. The main Hamilton Fauna is Late Irvingtonian in age about 800,000 years before present while the main site at New Trout is Rancholabrean age ranging from before 30,000 to about 17,000 years before present. The fossil bats in the Hamilton Fauna include Eptesicus fuscus, Pipistrellus subflavus, Plecotus sp., Lasiurus borealis, Tadarida cf. brasiliensis, and several species of Myotis. The New Trout Fauna includes Eptesicus fuscus, Pipistrellus subflavus, Plecotus sp., Lasiurus borealis, Desmodus sp., and several species of Myotis. Some of the Myotis mandibles from both caves are probably Myotis grisescens based on their large size. Myotis grisescens does not presently inhabit West Virginia, its northern occurrence being southwest Virginia. Tadarida is a southern genus and the fragments of vampire bat, Desmodus sp. from New Trout are from a large unidentifiable extinct species. Detailed studies of these chiropteran remains will hopefully shed light on past bat faunas of the area.

SKELETAL REMAINS AND FOOTPRINTS OF THE FISHER, MARTES PENNANTI, FROM BOBCAT CAVE, BATH COUNY, VIRGINIA

Grady, Fred - 1201 S. Scott St. #123, Arlington, VA 22204

Teeth from a skeleton found deep inside Bobcat Cave, Bath County, Virginia have been identified as belonging to a fisher, Martins pennanti. The skeleton is some 1500 feet horizontally and 475 feet vertically below the known entrances. Several hundred footprints of fishers have been found elsewhere in the cave, suggesting that fishers had access to the cave sometime in the past. There are no confirmed historic records of fishers in Virginia, though anecdotal evidence suggests they were present and became extinct when the spruce forests they inhabited were logged in the 19th century. There are 4 other fossil records of Martins pennanti from Virginia and all including that from Bobcat Cave are probably Late Pleistocene in age.

PROJECTO CUEVA SAN JOSECITO: A PLEISTOCENE LOCALITY IN MEXICO

Ralph, Ronald W. - Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, TX 78744
Arroyo-Cabrales, Joaquin
Johnson, Eileen - Museum of Texas Tech., Lubbock, TX 79409

The San Josecito Cave Project involves the reappraisal of a Pleistocene fauna locality located in the south of Nuevo Leon, Mexico. The cave, first excavated by the California Institute of Technology in the late 1930s, early 1940s, has produced a large faunal assemblage including mammals (45 species), birds (43 species), snakes (2 species), and two species of iquanid lizard. About 30 species are extinct. This is the type locality for 12 species including Desmodus stockii the three foot wingspan Pleistocene vampire bat.

Based on previous excavations, a joint project involving Mexican and American researchers was funded by the National Speleological Society and others to study the San Josecito Cave and its bearing on Late Pleistocene ecosystems. The results of our 1990 excavations were presented previously. The initial results of the laboratory analysis and preliminary radiocarbon dating will be presented here.

PHOTOGRAPHY

PREPARING BLACK AND WHITE PRINTS FROM SLIDES

Frantz, Bill - 16345 Englewood Ave., Los Gatos, CA 95032

The cave photographer is frequently asked to make black and white prints from slides for publication in various caving publications. The author will discuss some techniques for making black and white negatives from slides. He will also discuss the problems of contrast control, and offer specific techniques to control negative contrast in black and white photography in general and in making negatives from slides in particular.

CAMERAS AND CAVING

Heller, Chuck - 27 Lakeshore Drive, Lake Hiawatha, NJ 07034

Cameras and caving will cover 35mm, video, and medium format under dry conditions but with some information about underwater use. Lighting. Lenses. Super slides.

Filming the underground, I have gleaned almost 30 years experience in both dry and underwater caving. I will cover: cameras I have used and their malfunctions, how to choose a good cave camera and how to carry it in various ways, how different lenses can be used for different shots, also comparing the lighting needed for lenses, strobes vs bulbs, strobe units, flash units, malfunctions, etc.

I will also cover medium format camera types and advantages, what is medium format, and cropping medium format to make super 35mm slides. Inexpensive cameras for good medium format photos one can get at camera shows will also be covered. Video and lighting will be briefly covered.

DOCUMENTARY CAVE PHOTOGRAPHY

McClurg, David - 1610 Live Oak Place, Carlsbad, NM 88220

Documenting a cave photographically involves taking a planned series of pictures to show the exact nature of the cave and its main characteristics. Shots will normally include the entrance, typical passages and rooms, breakdown, streams and lakes, important speleothems, and typical activities by cavers. This presentation will show examples of each of these shots and suggest how to study the cave to plan a sequence of documentary shots.

A NEW METHOD FOR PHOTOGRAPHY OF LUMINESCENCE AND ITS APPLICATIONS IN SPELEOLOGY

Shopov, Y. Y. - Geology Dept.,McMaster University, Hamilton, Ontario, L8S 4K1 Canada

A new method for photography of luminescence (fluorescence and phosphorescence independently or both together) with impulse sources is elaborate. Its application for research of speleothems allows previous diagnostic of minerals, registration of color and zonality of fluorescence and phosphorescence of minerals and its spectra, UV-photography, extraction of single mineral samples, registration of changes of the chemistry behavior of the mineral forming solution, climate and solar activity variations during the Quaternary. Apparata for its application are elaborated. They are very useful in caves and allow registration of up to 40 frames of spectra per hour.

Impulse photography of phosphorescence can be used by every caver. Slides obtained by using this method can be developed by CSS method for preparation of spectra of phosphorescence.

This method is one of the bases of the International Programme for research of "Luminescence of Cave Minerals" of the Commission of Physical Chemistry and Hydrogeology of U. I. S. It allows easy non-destructive determination of objective information for mineral composition and luminescence of speleothems and easy collection of information for cave minerals and conditions of its formation in caves around the world from non-skilled cavers and central development of the information with standardized technics.

An instruction for preparation of slides of Speleothem Phosphorscence is presented.

JUDGING THE SLIDE PORTION OF THE CAVE PHOTO SALON: RECOMMENDATIONS TO PHOTOGRAPHERS AND NSS PHOTO SALON AUTHORITIES

Wilson, John M. - 7901 Dalmain Drive, Richmond, VA 23228

A review of the procedures for judging the slide portion of the salon is followed by several suggestions about clarifying the criteria. For example, one criterion is that all salon photographs depict or express an idea about some aspect of speleology or caving or express an idea about caves or karst.

Specific types of photographic techniques are listed in the order of frequency in which salon judges report deficiencies:

A. Lighting
B. Composition
  1. Main interest
  2. Components are well integrated
  3. Dynamic symmetry
  4. Keeping supporting lines and shapes in a balanced arrangement
  5. Simplicity
  6. Main interest at the dynamic center
C. Artistic merit
D. Focus
E. Simplicity of purpose
F. Relevance
G. Processing and development defects

The present standards are simplistic and have limitations in flexibility and clarity of intent. Often, to achieve an artistic photograph with impact and caver appeal, one may sacrifice a rule or principle to achieve a more important goal. At present, the salon has no mission or highest value statement. This lack of mission or value statement is particularly difficult in an organization such as the NSS which has competing and sometimes conflicting purposes that have not been unified by the development and acceptance of a common highest value statement.

One criterion for a salon mission statement and clarification of purpose should be a unifying statement about the role of cave related photography. It should bring together cave explorer and recreational caver; the cave conservationist and cave user; the cave scientist and the lay person. It should recognize the existence of rules of photography but provide a basis for disregarding photographic rules to achieve a more important goal. It should recognize that the rationale for disregarding a photographic rule can be done on three levels.

SURVEYING AND CARTOGRAPHY

USE OF A LASER POINTER FOR ACCURATE SURVEYS

Crowell, Hubert C. - 3105 Mary Dr. N.E., Marietta, GA 30066

One large source of survey errors comes from the vertical angles taken during cave surveys. The use of a laser pointer can reduce this error as well as improve the accuracy of compass sightings. Plans for a clinometer and compass mount for use with a laser pointer will be presented.

By using two small tripods and a laser pointer, a beam can be projected from the forward station to align a compass and clinometer located on the rear station tripod. The laser pointer can also be used to locate points on the walls and roof and the angles to these points used to calculate the dimesions of large passages. The possibility of solo surveys without a tape measure is also raised using an offset mirror on the forward station and reflecting the beam between the two stations.

LOCATING CAVE MAP SIDES WITH MINIMUM SURVEY DATA

Crowell, Hubert C - 3105 Mary Dr. N.E., Marietta, GA 30066

Drawing cave maps from minimum survey data can be a challenge for mappers or a computer program. Simple curving passages can be drawn easily from a survey line and side measurements. However when passages turn sharply or branch out and the mapper has only the left and right measurements to the sides, the map is open for wild guesses.

A procedure for locating the map sides will be offered when only the survey line and side measurements are known. Logical assumptions are made about extending the sides around sharp corners and locating inside corners for sharp turns and side passages. Connecting side passages can present a problem in locating the corners. This may not appear to be a problem for someone familiar with drawing cave maps, but what about a computer program that cannot make judgments?

CGIS - A CAVE ORIENTED GEOGRAPHIC INFORMATION SYSTEM

Dotson, Douglas P. - Department of Computer Science, Frostburg State University, Frostburg, Maryland 21532-1099

As more data is gathered about caves and their resources, it is becoming increasingly difficult to represent and manipulate this data to produce information. Geographic Information Systems have made vast progress towards solving these problems for above ground resources but fall short when applied to the unique problems related to caves and their resources. For the past year, a specialized Geographic Information System has been under development in cooperation with the National Park Service at Mammoth Cave National Park. This presentation will discuss the features and applications of the developed GIS and the applications for which the system is useful.

DETERMINING CAVE LENGTH AND QUALITY - A DISCUSSION

Engel, Thom - 7D West St., Voorheesville, NY 12186

How is cave length best defined? Is Total Horizontal Length (THL) the most appropriate method or is it merely an artifact of how we draft maps? Is a method that more closely measures the distance a caver travels through a cave the best method? If so, just what would that method be?

Further, once an acceptable algorithm for defining cave length has been found and accepted can we say that it is the best way for describing a cave from a recreational perspective? Is some kind of objective cave quality index needed to tell the caver how much of a cave he or she will really see short of pushing every little lead? Is the idea of penetration (distance from entrance to furthest point in cave) an appropriate measure in describing cave quality and does it really provide useful information? Is there a better method or is the idea of measuring cave quality so subjective that no reproducible method can be developed?

PASSAGE WALLS CONSTRUCTION FOR STAGE-4 CAVE MAPS

Wefer, Fred L. - 4600 Duke St. #1310, Alexandria, VA 22304

A computer program called Interactive Cave Map (ICM) is being used by the author to explore the application of interactive computer graphics to the generation and display of State-4 cave maps, i.e., cave maps designed to be viewed on the computer graphics screen. ICM displays four basic types of information: traverse lines information, passage walls information, symbols information, and auxiliary information.

This paper concentrates on passage walls information. Previous attempts at showing passage walls on 3D computer generated maps are first reviewed. Some requirements for the effective display of passage walls information are then presented. A set of design elements which satisfy the requirements is next developed. Finally, the ICM implementation of these design elements is discussed, including the techniques used to input, store, generate, and display both cross sections and passage walls.

Key to the success of the ICM implementation is the use of only information normally available from traditional cave surveys, i.e., no special surveying instruments or techniques are necessary. Hardcopies of the State-4 cave maps of Corkscrew Cave (an artificial cave used for testing the computer program) and also of Cueva Catanamatias (a real cave in the Dominican Republic) are used to illustrate the techniques.

UNITED STATES EXPLORATION

CAVING IN THE WEST: AN ALTERNATIVE AND SUCCESSFUL MODEL FOR CAVE EXPLORATION

Hose, Louise D. - Department of Geology, University of Colorado, Colorado Springs, CO 80933

The famous Western explorer, John Wesley Powell, recognized the unique geography of the western United states and suggested that land use and water policy west of the 100th meridian must be different from eastern standards. Almost any Westerner can tell horror stories about towns ruined when Easterners, insensitive to the differences, were allowed control of community development. Many cavers have also followed different policies in cave exploration west of the 100th meridian. These policies, first verbalized by Art Lange in the 1950s and commonly called "secrecy", have been remarkably successful.

Although " secrecy" cavers have produced impressive scientific results and have forsaken self-glorification while trying to preserve the West's finite and often extremely delicate cave resources, they are often chastised by outsiders as "selfish". Comparisons between western caves that have been managed by a policy of "secrecy" for the last three decades and caves that have been promoted within the cavers' literature show that "secrecy" is the most effective, democratic, and palatable management tool for some caves.

The heroes of western caving should not be the media stars of Sports Illustrated, Smithsonian, and videos. The real heroes are Art Lange, Ray deSaussure, George Mowat, Tom Aley, Jerry Hassemer, Donald G. Davis, Tom Strong, and other many low-visibility practitioners of "secrecy" who have explored hard, contributed heavily to the scientific literature, and left many of their discoveries pristine and flagging tape-free. A future generation of cavers will undoubtedly be grateful for their thoughtfulness.

FIFTY MILES PLUS - WHEN WILL IT END? LECHUGUILLA CAVE

Kambesis, Pat - 1026 South Candler St.,Decatur, GA 30030-4464

In August of 1990, the survey of Lechuguilla Cave broke fifty miles. Though no major extensions have been made in the past year, the cave continues to grow in two to three mile increments per expedition. The boundaries of the mazes continue to expand and, even in areas that have seen much attention, new discoveries continue to be made.

GLACIER GROTTO'S P.O.W.I.E. IV.

Klinger, David M. - P.O. Box 537, Leavenworth, WA 98826

Cavers affiliated with Glacier Grotto of Alaska continue to discover new caves on Prince of Wales Island in southeast Alaska. Some of these caves still have to be completely explored and surveyed. Additionally there are many leads to be checked out throughout the area.

The presentation will include discussion of the weather and terrain, how to get there, facilities expected to beavailable, logistical support, personal clothing and equipment needed, conditions of working with the U.S. Forest Service and the program for 1991 P.O.W.I.E. V. There will be slides of several major caves and maps of various areas of interest.

While it would be nice if attendees are proficient in vertical caving techniques, there is plenty of caving available for horizontal cavers. P.O.W.I.E. V is scheduled for 15 July to 15 August, 1991.

EXPLORATION OF THE PORTAL, GREENBRIER COUNTY, WEST VIRGINIA

Simmons, Ron - P.O. Box 7351, Charlottesville, VA
Medville, Doug - 11762 Indian Ridge Road, Reston, VA

Between mid-1988 and late 1990, six miles of passage have been surveyed in The Portal, a cave in northern Greenbrier County, West Virginia. Found and partially surveyed in the early 1980s, the cave was revisited in July 1988 when a serious effort at exploration and mapping began. The cave contains a substantial trunk passage in two segments and several long upper level paleo-drainage routes. Directional orientation of the cave is partially controlled by strike-oriented faulting. The total depth is about 300 feet with the cave ending in sumps 80 vertical feet lower than the nearby bed of Spring Creek.

Index to Volume 53 of the National Speleological Society Bulletin

Ira D. Sasowsky
Nittany Geoscience, Inc.
120 Radnor Road
State College, PA 16802

and

Keith D. Wheeland
Wheeland/SoftCorp, Inc.
2191 Mountainview Road
State College, PA 16801

This index contains references to all articles and abstracts published in volume 53 parts 1 and 2. Abstracts for the 1988, 1989, 1990, and 1991 NSS Annual Meetings are contained in this volume.

The index consists of three sections. The first of these is a **keyword index** which starts on **page 127.** Keywords include: unique words from the article title, cave names, geographic names, and descriptive terms. The second section is a **biologic names index** on **page 141.** These terms are Latin names of organisms discussed in articles. The third section is an alphabetical **author index** starting on **page 142.** Articles with multiple authors are indexed under each author.

Citations include only the name of the authors, followed by the page numbers of the article. Within an index group, such as "Archaeology", the earliest article is cited first, followed by consecutive articles.

Index data was input on an IBM-PC using the SDI-Soft front-end program designed by Keith Wheeland. The index was prepared on an IBM 4341 computer running a VM/CMS operating system. Indexing was performed by the IBM KWIC/KWOC program as modified by William H. Verity at The Pennsylvania State University Center for Academic Computing. Formatting was accomplished using the SCRIPT text formater, and Generalized Markup Language, with camera-ready copy produced on a Xerox 2700 laser printer.

The authors wishes to thank William H. Verity for his assistance. Computer funds were provided by the College of Earth and Mineral Sciences, The Pennsylvania State University.

Keyword Index

Biologic Names Index

Author Index

Guide To Authors

The *NSS Bulletin* is a multidisciplinary journal devoted to speleology, karst geomorphology, and karst hydrology. The *Bulletin* is seeking original, unpublished manuscripts concerning the scientific study of caves or other karst features. Authors need not be associated with the National Speleological Society.

Manuscripts must be in English with an abstract, conclusions, and references. An additional abstract in the author's native langauge (if other than English) is acceptable. Authors are encouraged to keep in mind that the readership of *The Bulletin* consists of both professional and amateur speleologists.

For general style refer to the present *Bulletin* and the following guides: "Suggestions to Authors" (U.S. Geological Survey), "Style Manual for Biological Journals" (American Institute of Biological Sciences), and "A Manual of Style" (The University of Chicago Press). For assistance in writing an abstract see "A Scrutiny of the Abstract" by K. Landes, Bulletin of the American Association of Petroleum Geologists, vol. 50 (1966), p. 1992. Because good figures are an essential part of any paper, authors are encouraged to see what bad figures look like in the editorial on figures by K. Rodolfo in the *Journal of Sedimentary Petrology*, vol. 49 (1979), p. 1053–60.

Each paper will contain a title with the author's name and address. This will be followed by an abstract and the text of the paper. Acknowledgements and references follow the text. References are alphabetical with senior author's last name first, followed by the date of publication, title, publisher, volume, and page numbers. See the current issue of *The Bulletin* for examples.

Authors should submit two copies of their manuscript (include only copies of the illustrations) to the appropriate specialty editor or the senior editor. The manuscript must be typed, double space on one side of the page. Authors submitting manuscripts longer than 15 typed pages may be asked to shorten them. All measurements will be in Système Internationale (metric). Other units will be allowed where necessary if placed in parentheses and following the SI units.

Figures and lettering must be neat and legible. Figure captions should be on a separate sheet of paper and not within the figure. Most figures will be reduced, hence the lettering should be large. Once the paper has been accepted for publication, the original drawings (with corrections where necessary) must be submitted to the editor. Black-and-white photographs must be sharp, high contrast, and printed on glossy paper. Color prints will be printed at authors expense only.

All submitted manuscripts are sent out to two specialists for review. Reviewed manuscripts are then returned to the author for consideration of the referee's remarks and revision (where necessary). Revised manuscripts are returned to the appropriate editor who then recommends acceptance or rejection. Upon acceptance, the author should submit all photographs and original drawings to the editor.

Once the paper has been typeset and laid-out, the senior author will be sent one set of proofs for review. Any corrections other than printer errors will be done at the author's expense. A reprint order form will be sent with the proofs. At this time all authors will be requested to contribute page charges of $25 per page to help defray the cost of publication. The actual cost to the society is about $100 per page. Acceptance of manuscripts for publication is not contingent upon payment of page charges.

THE NSS BULLETIN

Volume 53 | December, 1991 | Number 2

CONTENTS

National Speleological Society
Cave Avenue
Huntsville, Alabama 35810