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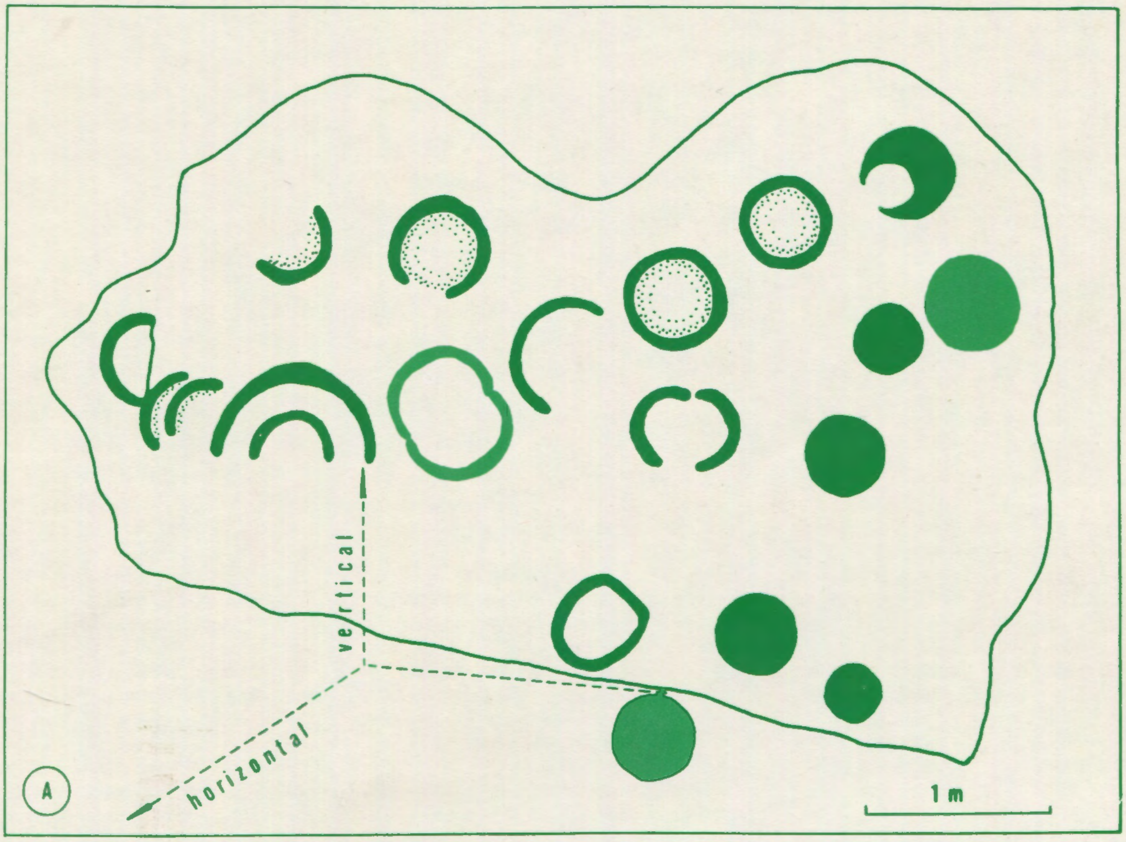
Journal of Caves and Karst Studies



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Cover: Lunar signs from the rocky-cave sanctuary near Lipnitza, Bulgaria. See Stoev and Stoyzchev, page 1.

Stoev, Alexey and Stoytchev, Todor—Archaeoastronomical Identification of the Functional Elements in the Rocky-Cave Sanctuary Connected with Ancient Cult Toward the Moon on Bulgarian Land: *NSS Bulletin* **54**: 1-6.

ARCHAEOASTRONOMICAL IDENTIFICATION OF THE FUNCTIONAL ELEMENTS IN THE ROCKY-CAVE SANCTUARY CONNECTED WITH ANCIENT CULT TOWARD THE MOON ON BULGARIAN LAND

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It is well known that Thracians inhabiting today's Bulgarian land only formed tribal units in the fifth century B.C. and during the Eneolith lived in separate tribes (1) hostile to each other. However, the necessity of measuring time dates back to oldest times (to Neolithic period) (2). It was not for mere practical purposes like plowing, sowing, etc., but also served the rites of numerous cults and rituals. Such holidays required precise regular observations not withstanding the changes in the climatic seasons. On the other hand the new interest in the heaven resulted in finding out the recurrent motion of the main bright luminaries in it. During that time some practical knowledge and habits were gained in the sphere of geometry and working out of the elementary mathematical problems of algebraic character. The use of already discovered objective laws was only possible if that information was put down in special places — rocky sanctuaries and peculiar shrines in natural caves.

As it is said in (3), there is a small travertine massif along the valley of Smolska river, near Bailovo, Sofia District. Four shallow caves and five outer monoliths are fored on it. On their walls numerous signs with round and oval shapes are well preserved (Fig. 1). Another author (4) supplies information about overall documentation of the signs, classifying them in the following groups: outlined, sunk and in bas-relief. It is also mentioned there that besides full circumferences there are half and quarter ones. The total number of registered figures in the sanctuaries is 236 — 126 outlined, 33 sunken, and 77 in bas-relief. They are different sizes, from 24 to 88 cm in diameter.

Closed semi-circumferences are of special interest (they are 19% of the total amount of figures). The three types of

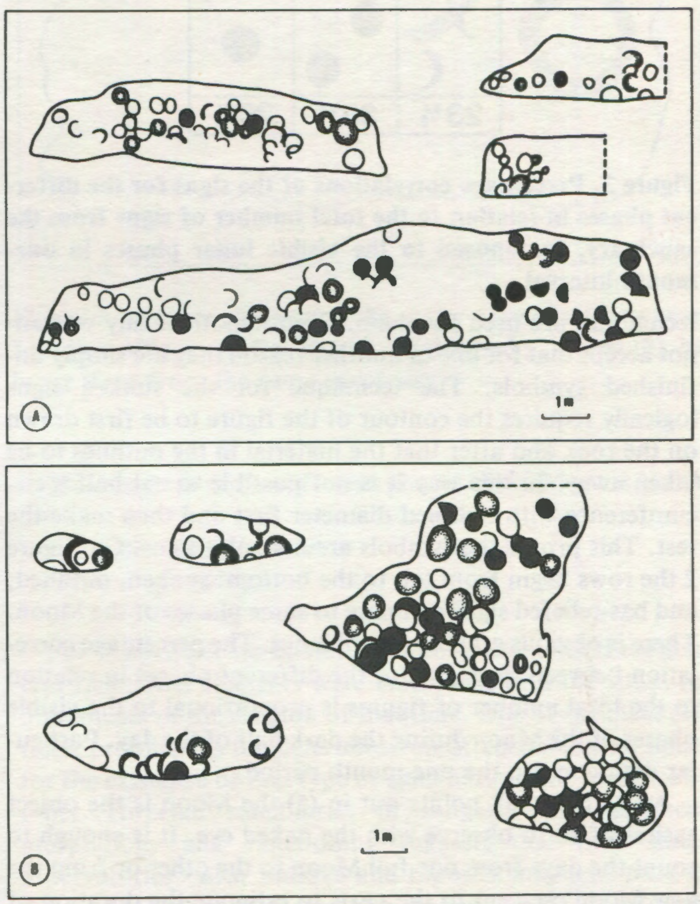

Figure 1. a) Circular signs in caves 2960 and 2961 near Bailovo. b) Circular signs from the monoliths of sanctuary near Bailovo village, Sofia district.

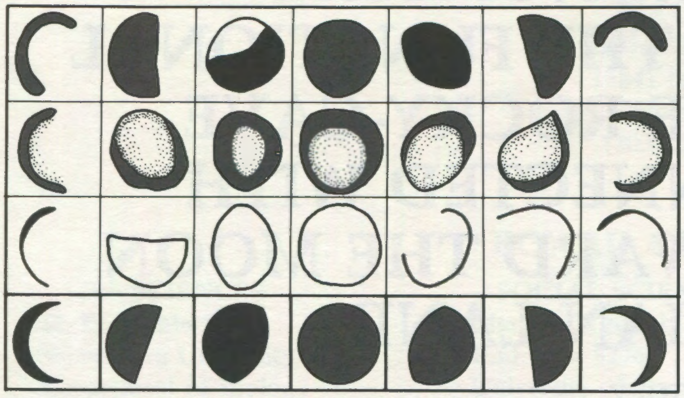

Figure 2. Signs, showing different phases and ways of making. From top to the bottom: sunken, bas-reliefed and outlined and their juxtaposing to real lunar phases.

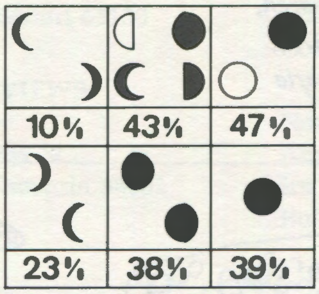

Figure 3. Percentage correlations of the signs for the different phases in relation to the total number of signs from the sanctuary, juxtaposed to the visible lunar phases in one-month interval.

techniques are used for them. Even hypothetically we cannot accept that for one or another reason they are simply unfinished symbols. The technique for the sunken signs logically requires the contour of the figure to be first drawn on the rock and after that the material in the outlines to be taken away. In this way it is not possible to cut half a circumference with outlined diameter first and then make the rest. This proves the symbols are not solar signs. On Figure 2 the rows begin from top to the bottom: sunken, outlined, and bas-reliefed signs compare to some phases of the Moon. There is obvious graphic resemblance. The percentage correlation between the signs for the different phases in relation to the total number of figures is proportional to the visible phases of the Moon during the dark half of the day. Particular data concern the one-month period.

As Al Marshak points out in (5) the Moon is the object easiest of all to observe with the naked eye. It is enough to count the days from one full Moon to the other or from the new Moon crescent to the next, to estimate the duration of the synodical month. We have made use of that method of approach when forming the archaeoastronomical hypothesis about the rocky-sanctuary.

All these signs, obviously connected with the different phases of the Moon, are peculiar calendar records reflecting certain intervals of time of different duration. Most probably the events coded in the beginning or end not only simultaneously with the full Moon, new Moon or advent and disappearance of the Moon crescent. That is the reason why calendars as records of consequent studying of all phases of a cycle cannot be seen on the walls of caves and monoliths as it was pointed out in (6). This archaeoastronomical object is completely different in character from the megalith moon observatories described in (8).

The need for measuring time might have arisen due to social-religious motives, military events or economic activities separately or as a whole. For example the writing of 3 connected full phases of the Moon made by the technique of sunken signs (Fig. 4), might be deciphered in the following

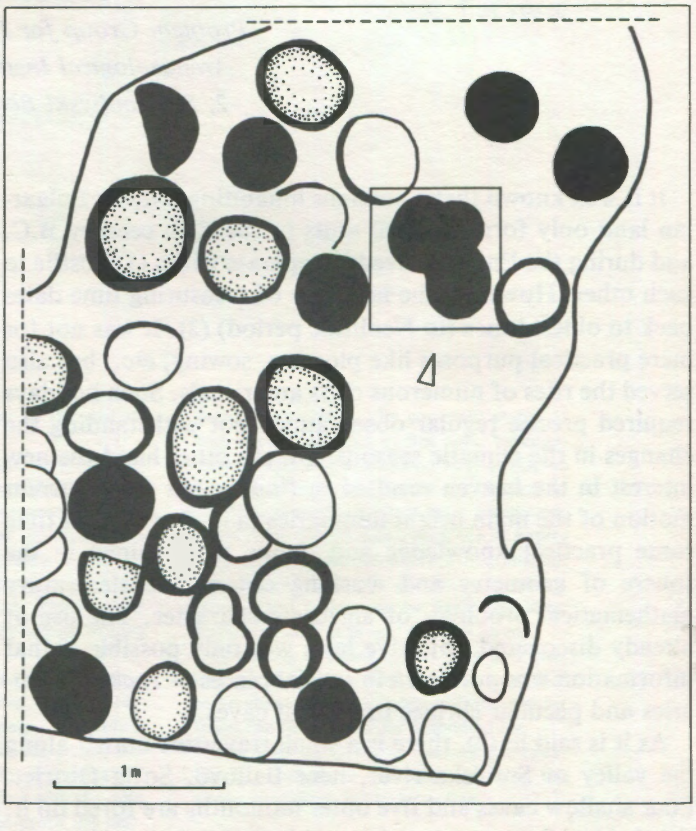

Figure 4. Calendar record from rocky monolith (the drawing in the square is interpreted in the text).

way: the time for repetition of two similar phases at rising and setting of the Moon (no matter which of the two events is recorded) is exactly 29.5 days (24 hours). Hence, the record is 3 x 29.5 days — approximately a season of 88.5 days. It might be the time for sowing, growth, and gathering the crops. For example the vegetative period of wheat. The meaning and content of the sign groups may be explained after deciphering maximum number of calendar records.

The various techniques used for the different phases of the Moon in the sanctuary show that they are made at different times.

A conventional periodization has been made as a working hypothesis for future calculations. The period during which outlined and shortly afterwards outlined and sunken signs were made use of, is marked as first period of using the sanctuary. The need to represent new Moon and full Moon on a general calendar record demanded the technique of the sunken signs.

The appearance and use of bas-reliefed signs of the Moon disk can be regarded as second conventional period. For the time being their content is not well understood, but it is possible that they represent the different phases of the lunar eclipse. Probably the bas-reliefed technique was used much later than the other two techniques because it is more complex and this fact is undisputable in terms of art history.

As it was mentioned above Thracian tribal communities were hostile to each other. And it is quite normal to find such a moon observatory in the rocky-cave sanctuary not far from Lipnitza, Sofia district. The distance between the two is about 60 km. Figure 5 (A and B) show the total number of lunar signs is 22. It is obvious this sanctuary functioned for a much shorter period than the one in Bailovo because the number of monoliths for writing is greater than the figures themselves. The presence of a second sanctuary of the same type allows us to explain and identify the separate functional elements in this kind of "lunar observatories."

Most of the elements in the two sanctuaries coincide with the general characteristics of the rocky sanctuaries, systematized by Naidenova in (9). In her study she relates these monuments to the sanctuaries honoured in a larger region and functioning continuously, for all that being quite far away from the bigger settlements. The general components in them can be enumerated in the following succession:

1. Built in a small travertine massif.
2. The massif is situated in a V-shaped river valley.
3. Presence of well worked-up "observatory platform."
4. Impossibility to observe the motion of the Sun from the "observatory platform" at the moment of rising and setting because of the great height of the local horizon and its proximity.
5. Good visibility of the Moon motion and possibility to follow the consequent changes of the lunar phases.
6. Presence of small caves in the travertine massifs.
7. Presence of a solid rock torn away from the travertine massifs by tectonic forces.
8. Presence of a water cave near the sanctuary, water resource.
9. Outer monoliths with lunar signs under the observatory platform.
10. Presence of steps round the monoliths with signs.
11. Specially levelled rocky platforms at the base of the monoliths with lunar signs.

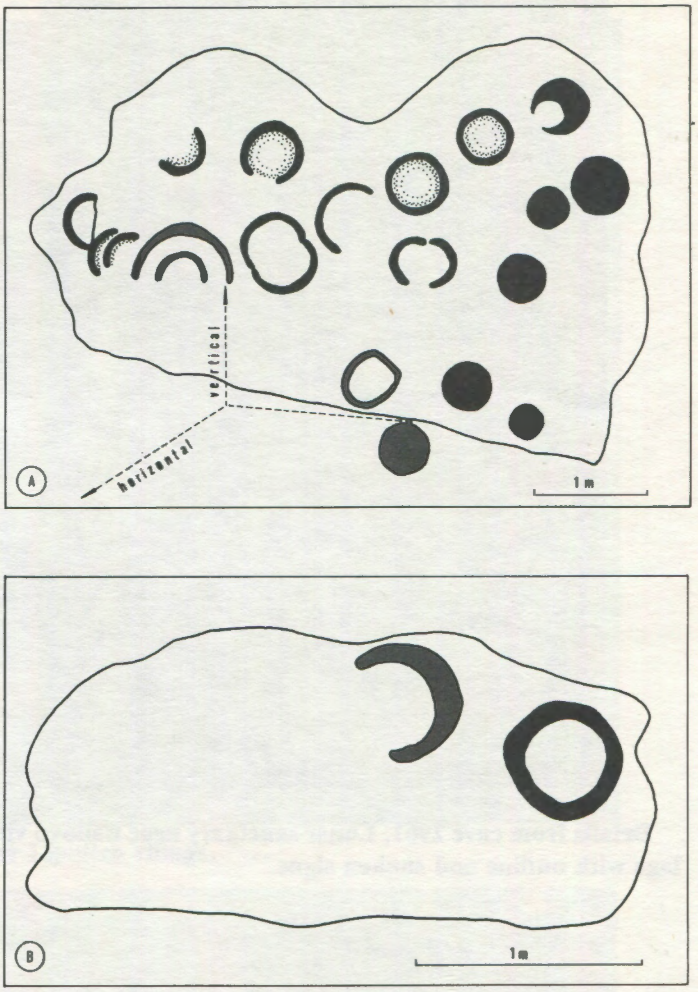

Figure 5. a) lunar signs from the rocky-cave sanctuary near Lipnitza village, Sofia district (main rocky monolith) b) lunar signs from the same sanctuary.

12. Drawings of the different phases of the Moon's visible motion
    a) bas-reliefed signs
    b) outlined signs
    c) sunken signs

For the present we do not know to what extent these general functional elements were connected with the ritual requirements of the religion of that time. One of the most difficult problems is the determination of chronological limits for the existence of that type of sanctuaries. The presence of other Thracian sanctuaries in Bulgaria with different morphology and functioning suggests that the "lunar observatories" near Bailovo and Lipnitza may date back to the end of the fifth and the beginning of the fourth millenium B.C. Overgrown relief forms of the local horizon make difficult astronomical reconstruction in time, as well as searching and finding sites for observations of the Moon.

Details from cave 2961, Lunar sanctuary near Bailovo village with outline and sunken signs.

Bas-reliefed signs from cave 2961.

Lunar signs, showing the use of three types of techniques in the travertine massif near Bailovo village.

Travertine massif near Lipnitza village.

Details from sanctuary near Lipnitza village with bas- reliefed, sunken and outlined signs.

The possibility of deciphering the arrangements of lunar signs in the two sanctuaries is connected with:

—obtaining data about the conventional periodization of cutting the different types of phases

—information about whether the ancient priests-astronomers observed lunar eclipses and if they could predict them (the presence of bas-reliefed figures directed our attention to these problems)

—realization and study of spatial models as well as their observant qualities in relation to prolonged astronomic observations in antiquity. Most probably all of them were quite simple because they were based on the patient empiric observation of the moon rise and set as well as of the change of lunar phases. Moreover, the observers then had to be able to count the days, nights and 24 hour periods and to have a method to record all that on stone.

The short distance between the two sanctuaries shows that every tribal community had its observatory platform, its astronomer and its system to register the time. If other lunar observatories are discovered they will give additional information about the method and system of moon observation.

As it was pointed out in (10) much later it became possible for the information to be registered by figures in the rocks. It was necessary to use protoscript describing a full calendar cycle through ideogram character. This is realized by means of monochromatic painting on the lunar figures which are the subject of this study.

LITERATURE

1. Oppermann M. (1984) Traker zwischen Karpatenbogen und Agais. -Urania Verlag, Leipzig, p. 80-81 FF.

2. Cochadjiev s. (1984) Archaeological data about a calendar in the beginning of stone-copper age. - Archaeology, XXVI (2-3), Sofia.

3. Stoytchev T. (1988) Sanctuarie rupestre thrace pres du village Bajlovo lie au culte envers la Lune. - Archaeology, XXX (2), Sofia, p. 32-39.

4. Zlatkova M. (1989) Rocky-cave sanctuary near Bailovo village, Sofia. Method of documentation. - V-th National Conference of Speleology, Sofia, p. 72-76. (in Bulgarian).

5. Marshak A. (1972) The roots of Civilization. -McGraw-Hill Book Co., New York, p. 43-55; p. 109-146.

6. Hawkins G. (1973) Beyond Stonehenge. - Harper & Row, London, p. 187-197.

7. Stoev A., Stoytchev T. (1988) The ancient moon observatories on our lands - structural elements and purpose. -First National Symposium on Archaeoastronomy "Tolbuchin; 88', Sofia, AIM - BAS, Interdisciplinary studies, vol. XV, p. 46-48.

8. Thom A. (1971) Megalithic Lunar observatories, Clerandon Pres, Oxford.

9. Naidenova V. (1986) Rocky Sanctuaries in Thracia. -Settlement life in Thracia, Yambol, p. 15-29. (in Bulgarian).

10. Stoev A., Guerassimova-Tomova, V., Stoytchev T. (1989) Complexe de grottes pres du village Bajlovo, region de Sofia (Bulgaria) et son utillisation par l'homme. - X-th International Congress of Speleology, Proceedings II, Budapest, p. 334-336.

KOTUMSAR CAVE ECOSYSTEM: AN INTERACTION BETWEEN GEOPHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS

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Kotumsar cave is characterized by relatively constant abiotic factors such as darkness, high moisture, and more or less constant temperature and water chemistry. In the present study, some of the geophysical and chemical parameters of Kotumsar cave ecosystem have been studied. Correlations of abiotic parameters with biotic factors present in this cave are attempted. A map of Kotumsar cave, as well as all the available informations on the morphological, behavioral, and physiological pecularities for the major types of cavernicoles inhabiting this cave are presented.

Kanger Valley National Park, Jagdalpur, India, is famous for a number of explored/unexplored natural limestone caves. Among these is "Kotumsar Cave," a large one open for tourists. It is situated along the bank of River 'Kanger' (Lat.:18° 52 09" N; Long.: 81° 56' 05 E), at an altitude of 560 m. A vertical fissure in the wall of the hill provides a main entrance to the irregular chambers of this cave. It is a narrow but twisted opening measuring about 15 m in length. In addition, several extremely narrow and twisted blow holes are also present. The main tunnel of the cave extends for more than 200 m and there are many downsloping side passages that are partially explored by our team (Fig. 1). The inner air filled irregular chambers are floored with either large rock or surface derived soils. Dripstone formations are throughout the major portions of the cave and cover the cave walls, ceilings, and even floors. The front of the cave is panoramic on account of colourful dripstone formations. However, a major portion of the floor is covered by a thick layer of clay deposits. Constant temperatures, high relative humidities, and perpetual darkness are features of the inner environment.

Despite the absence of permanent streams, there are several pools fed throughout the year by seepage water. In addition, the deepest parts of the cave remain moderately wet by drip water that ultimately forms a deep and long water ditch. However, flooding occurs during rainy seasons and underground drainage results in expelling excessive water in this cave.

In the present work a few geophysical, chemical and biological parameters of Kotumsar cave were studied and attempts were made to correlate with each other. At every al-

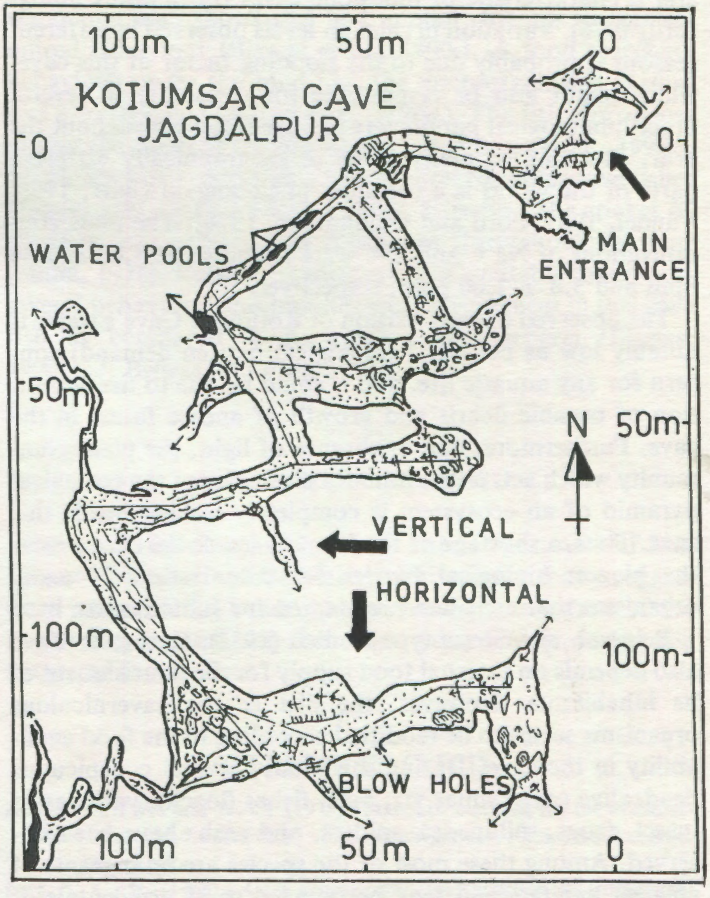

Figure 1. Plan of Kotumsar cave indicating location of water pools.

ternate month of year 1989, with the help of battery operated digital portable kit (Century, India) atmospheric and water temperture of the cave along with pH value, conductivity, and oxygen tension of cave water were recorded, at a particular site, level, (upper layer) and a particular time point. This was strictly followed to avoid variability due to place and time effects on any parameters. In addition, from the same sites water samples were collected during four different seasons of the same year and brought to the laboratory for ionic analysis. Sodium and potassium ions were estimated by flame photometry and calcium was determined by titrimetric method (APHA-AWWA-WPCF 1975).

Air temperature inside the cave remained fairly constant at 28° ± 1°C where as the temperature of the cave water varied between 22.9° to 29.3°C with an annual mean of 26.33° ± 0.96°C. The cave water has a pH of 8.04 ± 0.36; conductivity of 0.27 ± 0.03 micro mhos; DO (dissolved oxygen) = 6.42 ± 0.52 ppm and the percent oxygen saturation value of 74.83 ± 5.91%. The higher pH value of cave water could be related with the high ionic concentration of calcium ion, which has been found to be 76.75 ± 27.05 ppm. A high mean level of calcium ions has been reported in other caves and is characteristic of limestone caves (Ford and Cullingford, 1976). Variation in calcium levels observed in different seasons is probably due to the flooding factor of this cave, which might also be responsible for variability in several other limnological parameters of cave water throughout the year. Flooding of many caves in geographically different parts of the world is a common phenomenon (Barr, 1968; Vandel, 1965; Ford and Cullingford, 1978). The ionic concentrations of Na^+ and K^+ were found to be 4.62 ± 1.46 ppm and 5.8 ± 1.60 ppm, respectively.

The observed oxygen tension of Kotumsar Cave's water is notably low as per BOD (biological oxygen demand) concern for any aquatic life, and it could be due to the deposition of organic debris and growth of anoxic fauna in the cave. Furthermore, due to absence of light, the plant community which acts as the primary producers of the ecological pyramid of an ecosystem is completely lacking inside this cave. Thus, a shortage of food supply inside the cave acts as the biggest biological barrier for colonization of many organisms that are often preadapted for subterranean life.

Being an allochtone type Dudich (1932); Kotumsar Cave also depends on external food supply for the nourishment of its inhabitants. However, the diet of the cavernicolous organisms seems to be modified according to the food availability in the cave. During this study, several conspicuous dead/alive cave faunas viz; bats, fishes (loach), varieties of insect, frogs, millipedes, spiders, and crabs have been observed. Among these most of the species are immigrants of epigean habitats and may be referred to as accidentals or trogloxenes. However, few troglophiles and troglobites also are found in this cave. Based on the available organic mat-

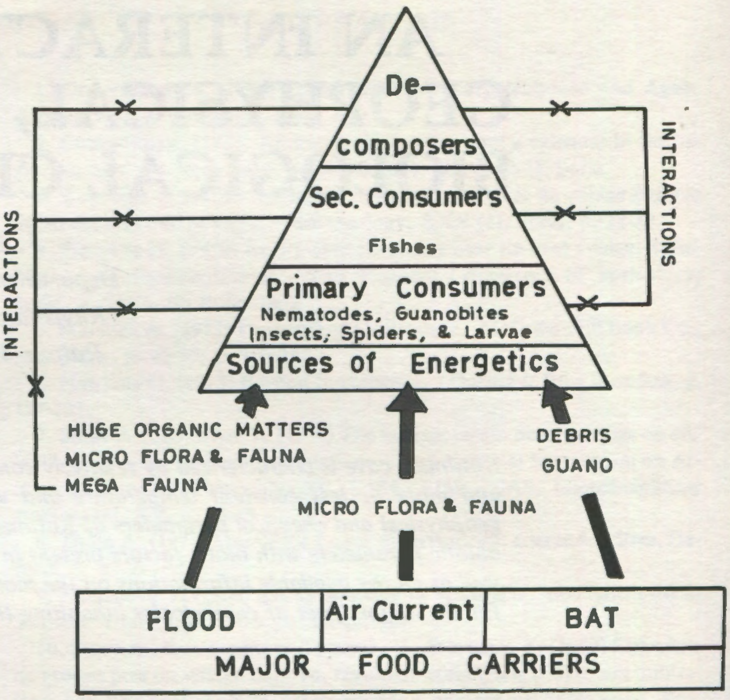

Figure 2. Summary of probable food cycles operating inside the cave ecosystem.

ter, and on the nature of cavernicoles feeding habits, a probable food pyramid is constructed (Fig. 2).

Among the major cavernicoles are two bat species *Hipposideros fulvus* and *H. speoris*, a cavernicolous cricket *Kempiola shankari* (Sinha and Agarwal, 1977) (Fig. 3) and a small population of aquatic (stream) loach *Nemacheilus evezardi* (Day). These species are successfully colonized in some of the limestone caves of Kanger Valley National Park, India. Related abiotic factors of this cave imposed a marked difference in the life processes of these cavernicoles

Figure 3. The cavernicolous cricket *Kampiola shankari* of Kotumsar cave region, large antenna clearly visible.

as compared to their nearest epigean relatives. However, bats use these caves to take shelter during the day time and visit at night periodically. A well established diel and annual rhythms have already been reported in its exodus flight pattern (Biswas and Kanoje, 1991).

In the Kotumsar cave, the cricket, *Kempiola shankari* is seen abundantly on the walls and crevices, with their head hanging downwards. In these insects, ocelli are completely absent, but a pair of regressed compound eyes are present. The whole body of *K. shankari* is thickly provided with sensillae. According to Sinha (1981), these insects cover long distances in proportion to their size and the habit of homing (returning back to the starting place after movement) is also very prominent. Besides a few primitive and/or adaptive characters are also well established in this insect (Sinha, 1976, 1977, 1978, 1981).

In small water ditches of Kotumsar cave the fish *Nemacheilus evezardi* is found, either freely swimming or buried under suitable stones/crevices. There are two morphological forms of this fish viz., one form is completely albinistic and blind (Fig: 4) while the other exhibits reduced pigmentation and regressed vision (Fig. 5). These fishes acquired a typical mode of air gulping behaviour, which is completely absent in its extant-living ancestor found in River Kanger flowing approximately 2.5 Km from this cave (Biswas et al., 1990a). However, except in a pond loach *Misgurnus fossilis*, this behavior is altogether lacking in the Cobitidae (loach family) (Das, 1945). Probably, the trait, dependence upon atmospheric oxygen for respiration, is developed in this fish due to lying in stagnant ditches. During the rainy season a stream flows within the cave however it ceases flowing during the dry season. Inside the cave diurnal variation in the water as well as air temperature due to natural photoperiod is also lacking and hence thermal convection is non-operational in the water pockets. Thus, it may be assumed that the DO of the deeper layer of water pockets is less as compared with the surface layer. This could be one (more) reason why these bottom dweller hypogean fishes frequently come to the surface for air gulping. Probably this air gulping behaviour has genetic background because this hypogean fish continues to exhibit this behavior even when maintained in aquaria with oxygen-rich water and also shows diel and annual rhythms in this acquired behaviour (Biswas et al., 1990a). A food searching behaviour under the mud i.e., the microorganisms in mud was also reported (Biswas et al., 1990c). The fish reproduces during the onset of the monsoon only (Biswas et al., 1990b), which is a well established phenomenon for other cave fishes also (Hawes, 1939; Poulson, 1964). However, the cricket *K. shankari* was reported to reproduce throughout the year (Sinha, 1976). Further, studies are also available that report several behavioral and physiological divergences in this cave fish as compared to its epigean counterparts (Biswas, 1990a,b,c,d; Biswas and Pati, 1991).

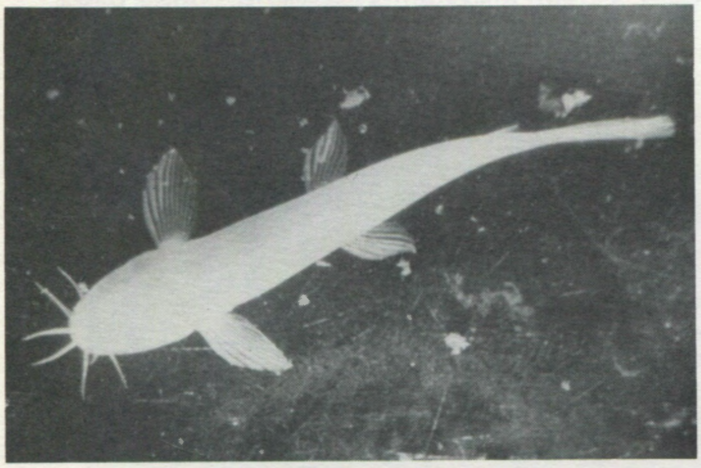

Figure 4. The cave fish *Nemacheilus evezardi*, albinic and blind.

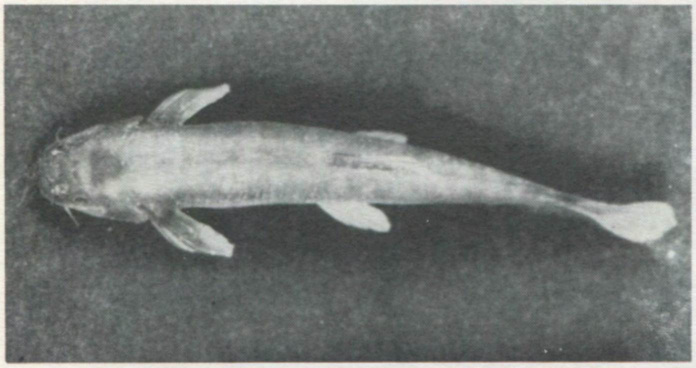

Figure 5. The cave fish *Nemachielus evezardi* with little pigmentation and regressed eyes.

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REFERENCES CITED

APHA—AWWA and WPCF (1975) - Standard methods for the examination of water and waste water: 14th edition, Amer. Publ. Health Assoc. Inc., New York.

Barr, T. C. Jr. (1968) - Cave ecology and the evolution of troglobites: *Evolutionary Biology* 2: 35-102.

Biswas, J. (1990)a - Biospeleolgoy: The Behavioural and Physiologic Adaptations in a Cavernicole.: Ph. D Thesis, Ravishanker University, Raipur, India.

Biswas, J. (1990)b - Annual modulation in diel motor activity rhythm of a dusk active loach *Nemacheilus evezardi* (Day): a correlation between daylength and circadian parameters. *Proc. Indian Nat. Sci. Acad.* 57, 339-346.

Biswas, J. (1991)c - Metabolic efficiency and regulation of body weight: a comparison between life in hypogean and epigean ecosystems. *Int. J. Speleol.* 20, 15-22.

Biswas, J. (1992)d - Constructive evolution: Phylogenetic age related visual sensibility in the hypogean fish of Kotumsar Cave. *Proc. Nat. Acad. Sci., Indian.* 62, (in press).

Biswas, J., Pati, A. K., and Pradhan, R. K. (1990)a - Circadian and circannual rhythms in air-gulping behaviour of cave fish. *J. Interdisc. Cycle Res.* 21, 257-268.

Biswas, J., Pati, A. K., Pradhan, R. K., and Kanoje, R. S. (1990)b - Comparative aspects of reproductive phase dependent adjustments in behavioural rhythms in epigean and hypogean fish. *Comp. Physiol. Ecol.* 15, 134-139.

Biswas, J., Pradhan, R. K., and Pati, A. K. (1990)c - Studies on burying behaviour in epigean and hypogean fish: an example of behavioural divergence. *Mem. Biospeleol.* 17, 33-41.

Biswas, J., and Pati A. K. (1991) - Influence of thyroid hormones on muscle tissue respiration in hypogean and epigean population of *Oreonectus evezardi* (Day). *Indian J Exp. Biology.* 29, 933-936.

Biswas, J., and Kanoje, R. S. (1991) - Seasonal and Photoperiodic control of the activity and daily exodus of a colony of cave-dwelling bat. *J Ravishankar University* (in Press).

Das, B. K. (1945) - On ecology and bionomics of an air-breathing loach *Lepidocephalus guntea* (Ham. Bucsh.), with a review on air-breathing fish: *Comptes Rendus, XII Congr. International Zool.* 2, 866-920.

Dudich, E. (1932) - Biologie der Aggteleker Trofsteinhohle "Baradla" in Urgarn: *Speleol. Mon (Wein)* 13, 1-246.

Ford, T. D., and Cullingford, C. H. D., (1978) - The Science of speleology. Academic Press, London.

Hawes, R. S. (1939) - The flood factor in the ecology of caves: J. Animal Ecol. 8, 1-5.

Poulson, T. L. (1964) - Animals in aquatic environments: animals in caves. In: *Handbook of Physiology* (D. B. Dill, Ed.) pp. 749-771 Sect. 4. *Adaptation to the environment* ch. 47. Amer. Physiol. Soc. Washington.

Sinha, K. M. (1976) - The life history of cavernicolous orthoptera *Kempiola shankari* Sinha & Agarwal (Orthoptera: Phalangopsida) *J. Bom. Nat. Hist. Soc.*, 74, 369-374.

Sinha, K. M. (1977) - Maxillary palpal muscles of cave cricket *Kempiola shankari* Sinha & Agarwal (Orthoptera: Phalangopsida) *Ent. News* 88, 197-198.

Sinha, K. M. (1978) - Sound producing organs of a cave cricket *Kempiola shankari* Sinha & Agarwal (Orthoptera: Phalangopsida) *J. Anim. Morphol. Physiol.*, 25, 243-248.

Sinha, K. M. (1981) - Some observations on the ethology of cave cricket *Kempiola shankari* Sinha & Agarwal (Orthoptera: Phalangopsida) *Uttar Pradesh J. Zool.* 1, 116-117.

Sinha, K. M., and Agarwal, S. M. (1977) - A new cavernicolous orthoptera *Kempiola shankari* n.sp. (Orthoptera: Phalangopsida) from Madhya Pradesh: *Ind. For.*, 103, 150-152.

Vandel, A. (1964) - Biospeleology: Pergamon Press., Oxford, London.

Hill, Carol A.—Subaqueous Flowstone—A New Speleothem Subtype, Blanchard Springs Cavern, Arkansas: *NSS Bulletin* 54: 11-13.

SUBAQUEOUS FLOWSTONE—A NEW SPELEOTHEM SUBTYPE, BLANCHARD SPRINGS CAVERN, ARKANSAS

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A new speleothem was noted while on a show cave tour (the "Discovery Tour") of Blanchard Springs Cavern, Arkansas. A shallow cave stream, approximately 10 m wide and 0.2 m deep, flows by the Natural Entrance—this stream quickly tumbles over cobble-sized (0.1-0.2 m) clasts in the stream bed (Fig. 1). Overlying these clasts, arranged in a streamlined "finger"-like pattern, is an orangish, calcite, travertine material (Fig. 2). The calcite occurs as clear, transparent, equant to prismatic crystals, 0.1 mm or so in size, with the long axes of the prisms oriented perpendicular to the growth surface of the travertine, as is typical of flowstone (Hill and Forti, 1986a). The orange color derives from silt impurities coating the clear crystals. This new speleothem was not noticed on an earlier trip to the cave (Hill, 1981).

Speleothems with morphologies similar to those in Blanchard Springs Cavern have been noted in Marvel Cave, Missouri (W. B. White, personal communication, 1991), and in Birmingham Crawlway Cave, Pennsylvania (White, 1956). In Marvel Cave, there is a side passage on a wall

Figure 1. Stream flowing by the Natural Entrance, Blanchard Springs Cavern. The water is shallow and fast-flowing: as it tumbles over the stream clasts, calcite is precipitated as a flowstone material over the clasts (from left to right in photo). Photo by Kevin Feltz.

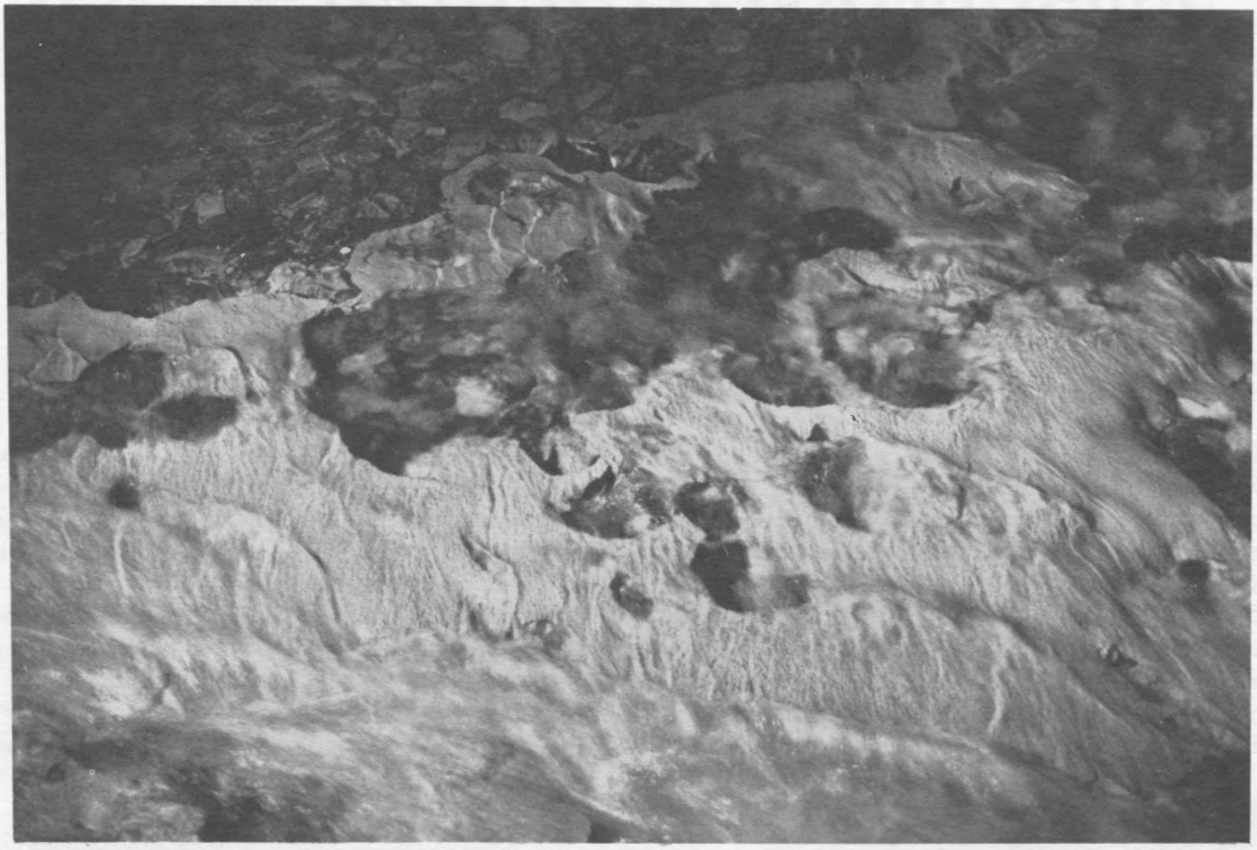

Figure 2. A close-up of the subaqueous flowstone. Photo by Jim Glock.

which has a stream of water pouring out as a small waterfall. The stream is depositing flowstone on the floor of the passage as well as at the lip of the falls. The flowstone extends up the passage, completely covered by the shallow stream, and there is clearly a continuum between flowstone under deep water and flowstone under only a thin film of moving water. In Birmingham Crawlway Cave, a small stream is depositing calcite flowstone on the stream bed before emerging as a spring.

Classifying and naming this speleothem in Blanchard Springs Cavern proved to be perplexing. The speleothem *looks* like typical flowstone, but *forms* in the manner of rimstone dams—that is, by the turbulent loss of carbon dioxide at an obstacle (the stream clasts) with subsequent precipitation of calcium carbonate over the obstacle. In the case of rimstone dams, turbulence occurs at the lip of a dam, but in the case of the Blanchard Springs speleothem the turbulence, the CO_2 loss, and the precipitation of calcite occurs where saturated cave water rapidly tumbles over the cobble-sized clasts in the stream bed. Since the stream is shallow, and the depth of water does not significantly exceed the height of the clasts, carbon dioxide is readily lost to the cave air and precipitation of calcite occurs.

Because of their similarity in origin, I first considered the Blanchard Springs travertine to be a subtype of rimstone dam. However, the speleothem does not resemble a rimstone dam. Rimstone dams are "barriers of calcite, aragonite, or other material that obstruct cave streams or shallow pools" (Hill and Forti, 1986a, p. 55). The Blanchard Springs travertine does not form a "barrier," nor does it "obstruct" or dam the stream: the cave stream rapidly flows over the streamlined travertine material.

Upon further reflection, it was decided that this speleothem should be classified as a subtype of flowstone. While classification should be based both on morphology and origin whenever possible (Hill and Forti, 1986b), the most frequent method of classification is by morphology rather than origin. Thus, Hill and Forti (1986a) divided the speleothem types "coatings and crusts" and "coralloids" into subaerial and subaqueous subtypes, even though the subaerial varieties form from thin films of water while the subaqueous types grow completely submerged. Davis (1989) made a similar distinction when he divided the speleothem type "helictite" into subaerial and subaqueous varieties based on their similarity of shape. Such a distinction is now being made for the speleothem type "flowstone." It is proposed that the stream-deposited, flowstone-like travertine in Blanchard Springs Cavern be named "subaqueous flowstone" and be classified as a subtype of flowstone.

REFERENCES

Davis, D. G., 1989, *Helictite bushes—a subaquaeous speleothem:* National Speleological Society Bulletin, v. 51, p. 120-124.

Hill, C. A., 1981, *Mineralogy of Blanchard Springs Cavern:* Cave Research Foundation Annual Report, no. 23, p. 6-7.

Hill, C. A., and Forti, P., 1986a, *Cave Minerals of the World:* National Speleological Society, Huntsville, Alabama, 238 p.

Hill, C. A., and Forti, P., 1986b, *The classification of cave minerals:* Proceedings 9th Congresso Internationale de Espeleologie, Barcelona, Spain, p. 60-61.

White, W. B., 1956, *Birmingham Crawlway Cave:* Netherworld News, v. 4, no. 3, p. 53.

Hill, Carol A. and Buecher, Robert H.—Nitrocalcite in Kartchner Caverns, Kartchner Caverns State Park, Arizona: *NSS Bulletin* 54: 14-16.

NITROCALCITE IN KARTCHNER CAVERNS, KARTCHNER CAVERNS STATE PARK, ARIZONA

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Nitrocalcite ($Ca(NO_3)_2 \cdot 4H_2O$) is a deliquescent mineral, efflorescent only under very low humidity conditions (around 50% for a normal range of cave temperatures; Fig. 1). Nitrocalcite has been mentioned as occurring in a number of eastern United States caves, but these are pre-1900 citings which are erroneous since eastern caves have relative humidities approaching 100%. Brief mention of nitrocalcite as a cave mineral has been given for one cave in the southwestern United States and one cave in Italy (Hill and Forti, 1986). This is the first authenticated, detailed description of nitrocalcite as a cave mineral.

Nitrocalcite occurs in Kartchner Caverns as cave cotton growing from sediment in scattered areas along the Entrance Passage (e.g., Babbitt Hole and LEM Room, Fig. 2) where cold, dry, winter air flows into the Entrance Passage from the surface. Mineralization occurs as efflorescent cotton mats, consisting of colorless to milky-white, silky-to-transparent, slender needle crystals up to 0.5 mm in length and <0.1 mm in width (Fig. 3). Birefringence is high: third order yellows, pinks and greens. One optical indice measured <1.50, another >1.50. Some (less than half) of the needle crystals examined looked eaten-away along their edges, and many (more than half) had a thin coating of clay

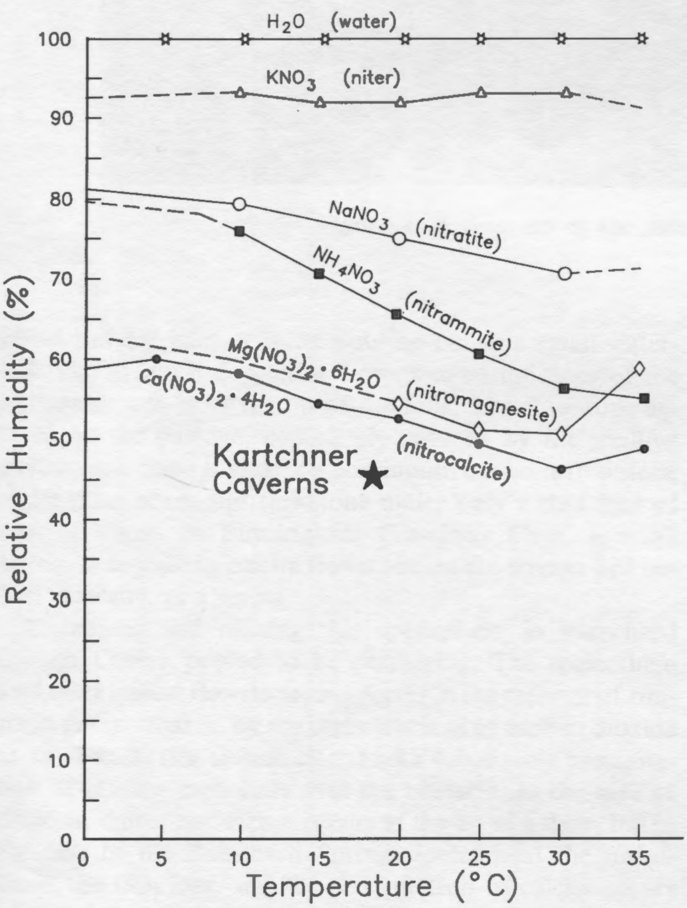

Figure 1. Stability of nitrate minerals in a cave environment with respect to temperature and humidity, showing the Kartchner Caverns nitrocalcite (star) plotted below the nitrocalcite line in the zone of efflorescence. Modified from Hill (1981) and Hill and Forti (1986).

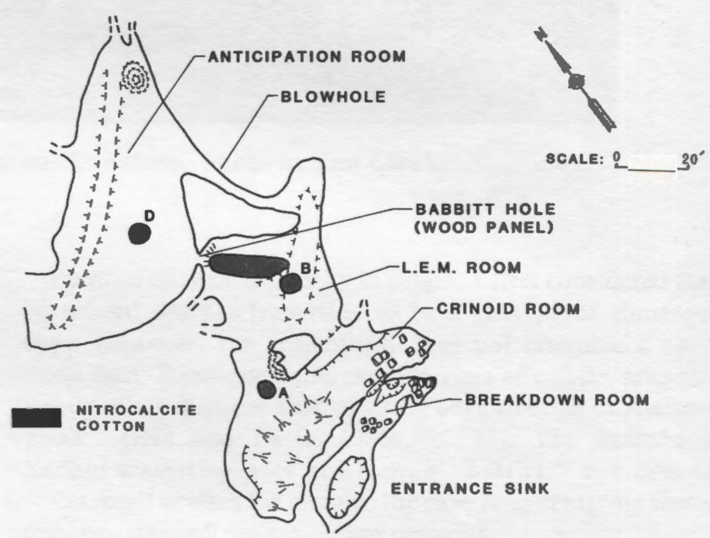

Figure 2. Location of nitrocalcite in the Entrance Passage, Kartchner Caverns.

Figure 3. An efflorescent mat of nitrocalcite cotton, Entrance Passage. Photo taken on December 14, 1989 by R. Buecher.

on their surfaces. The mineral has a strong, bitter-cool taste.

The deliquescent cotton was collected in the Entrance Passage in December of 1989, and was kept in a closed container containing desiccant until analysis in June of 1991. Mineral analyses were performed by D. Bish of Los Alamos Laboratory using an X-ray diffraction technique whereby the diffractometer was kept below 10% relative humidity. A composite powder of the cotton was X-rayed: peaks exhibited were for calcium nitrate hydrate (not a named mineral species), calcite, quartz, and possibly an unidentified clay mineral. It seems unlikely that the calcium nitrate hydrate was the original mineral collected in the cave, considering the relative humidity of the cave (around 45-50%) and the much lower relative humidity of the closed container after collection and the diffractometer chamber during analysis (< 10%). More likely, the mineral collected in the cave was nitrocalcite (four waters of hydration), which dehydrated to calcium nitrate hydrate (two waters of hydration) in the closed container and/or diffractometer chamber.

The growth of nitrocalcite in the Entrance Passage was monitored by a data logging system which recorded cave temperature and relative humidity on an hourly basis. A weather station was also operated on the surface near the cave entrance. From December 10, 1989 to December 16, 1989 the weather on the surface was unusually dry and cold, with the outside humidity dropping to 23%. The cotton was first noticed on December 12 in front of the Babbitt Hole, two days after the significant drop in surface humidity. Maximum growth was noted on December 14th at Babbitt Hole as a loose mat 1-2 cm thick when the cave humidity and temperature measured 45.3% and 15.6°C, respectively (star, Fig. 1). When both surface and cave humidity rose a few days later the nitrocalcite slowly deliquesced and disappeared back into the floor sediment. A humidity of 49-50% or below appears to be needed for crystallization, and the humidity needs to remain low for a few days before significant cotton effloresces. This corresponds to a time when the cave is "breathing in"—that is, when cold, dry air is coming into the cave from the outside. When the cave "breathes out," warm moist cave air quickly causes the mineral to deliquesce and disappear back into the cave sediment.

Interestingly, maximum nitrocalcite growth does not occur in undisturbed dirt off the trail, but it occurs where dry sediment of the Entrance Passage becomes compacted and smeared with mud by crawling cavers returning from the wet, muddy interior of the cave. It may be that, where sediment becomes compacted, nitrocalcite cannot crystallize within sediment pore spaces but must crystallize at the surface of the sediment. It has been noted that crystallization obliterates boot and knee-pad marks in the sediment within a few days time; evidently, sediment particles are forced upward by crystallization within sediment pore spaces. Scattered patches of dark bat guano can be seen along the Entrance Passage where the trail has not been crawled over. Cave rat trails can also be seen along the passage walls. Bat and rat guano could both be possible sources of nitrate for the nitrocalcite mineralization.

REFERENCES

Hill, C. A., 1981, *Mineralogy of cave nitrates:* National Speleological Society Bulletin, v. 43, no. 4, p. 127-132.

Hill, C. A., and Forti, P., 1986, *Cave Minerals of the World: Huntsville, Alabama,* National Speleological Society, 238 p.

SECRECY: AN ALTERNATIVE AND SUCCESSFUL MODEL FOR CAVE EXPLORATION

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INTRODUCTION

The famous Western explorer of the 19th Century, 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 (Powell, 1878). The West is different. And, cavers have also followed different policies in cave exploration in the West.

The West, particularly the Southwest, is mostly dry and has low rainfall. Consequently, the caves are typically dry and lack mud. Most caves do not flood. The population density in the West is lower than east of the 100th Meridian. Unlike the East and Midwest, the federal government owns most of the land. Landowners and managers generally do not live near their caves. The West has fewer caves. Physical access to the cave entrances is mostly harder than in the East. Long hikes, backpacking, and difficult cross-country routes are commonly necessary.

HISTORICAL DEVELOPMENT OF THE PRACTICE

The unique qualities of the West prompted the practice of "secrecy." The concept was first strongly advocated by members of the Stanford Grotto of the NSS in the 1950's. Art Lange, Ray de Saussure, and others opposed the publication of *Caves of California* and refused to provide information from their files. There was a battle that ended with some fine cavers and speleologists abandoning the NSS when mainstream organized cavers refused to respect their insistence on putting the best interest of the caves (as they saw it) ahead of the interest of the cavers.

The Stanford Grotto was disbanded and some of the members reorganized for several years as the Western Speleological Institute (WSI). WSI was affiliated with the Santa Barbara Museum of Natural History and the Nevada State Museum. Later, during most of the 1960's and 1970's, many of the same members continued their work and philosophy under the banner of the independent Cave Research Associates (CRA). These workers, Art Lange, Ray de Saussure, George Mowat, Tom Aley, and various associates, probably did more original exploration in California, Nevada, and Arizona than any group before or since. Their accomplishments were remarkable.

They wrote detailed personal logs filled with valuable information. In addition, they documented most of their finds in the *Stanford Grotto Monthly Reports, WSI Technical Reports, Cave Notes, Cave Studies, Caves and Karst,* and National Park Service files. Their writings were always low-key, technical, and pointedly minimized the adventure side of their activities. They also wrote reports about the caves in scientific publications like *Science, Plateau, American Antiquity,* publications of the California Academy of Sciences, and the *NSS Bulletin.* The specificity of a cave's location was only given to the detail demanded by the topic, commonly identified by drainage basin and the name of the encompassing rock formation. Reports to agency files commonly provided more precise locations.

USING SECRECY TO PRESERVE CAVES FOR FUTURE

River of Towers System—Big Foot Cave

Probably the most famous of the CRA-affiliated discoveries is the cave now called "Big Foot Cave" in the Marble Mountains of California. The cave was first discovered in 1962 and named "River of Towers System" by members of the University of California Hiking Club—Caving Section* (UCHC) (Aley, 1991). Backpacking into the area and using cable ladders and wool clothing, Phyllis Aley, Tom Aley, and Pete Huntoon entered the "Nevermore Abyss" entrance (called the Big Foot entrance today) and explored the cave past the Lurking Fear. They reached what today is called the Terminal Room on August 31, 1964. They explored the caves in the Marble Mountains and logged their findings. In *Cave Notes,* they discussed and illustrated their unique setting at the contact of the marble and schist (Aley, 1965). No one seems to have taken much note of their accomplishments, described in a very low-key manner.

The area was re-discovered about a decade later by Steve

*The UCHC caving group was closely tied to CRA with charter members including CRA cavers Tom Aley and Ray de Saussure.

Knutson, Wayne Walent, and friends who were apparently completely unaware of the CRA work. They discovered the publication after finding inexplicable footprints deep in the cave.

One of the pitfalls of secrecy is that its practitioners' hard work and accomplishments are rarely acknowledged. Knutson (1985) discussed the history of the exploration of the Big Foot system but chose to totally ignore the exploration of the UCHC/CRA in the 1960's. Just as cavers commonly ignore the previous exploration by local kids, prospectors 100 years ago, or native Americans 500 years ago because those events did not contribute to the present knowledge of the cave, it might be reasonably argued that CRA does not deserve recognition for their accomplishments in the Marble Mountains.

A more noble argument may be that the practitioners of secrecy deserve special recognition for allowing a future generation to experience the thrill of discovering the cave again. The early explorers accomplished a remarkable piece of exploration, documented their findings in an appropriate journal and chose to minimize the fanfare. They, in effect, chose to "recycle" the cave instead of promoting their own accomplishments. How could they have acted more admirably? Not every cave discovery should be kept so quiet, but neither should we discount the work of those who choose to do so.

Silent River Cave

Another outstanding discovery of the CRA cavers in the early 1960's was Silent River Cave in the Grand Canyon. Unlike the River of Towers System, however, they wrote extensively about the scientific wonders discovered in the cave. They even published a photograph looking out the entrance into the Canyon, although their photo was touched up with a cumulus cloud to obscure the distinctive buttes in the background (Cave Notes, v. 2, n. 3). While they did not reveal the exact location and their descriptions were technical, they did provide sufficient information for the next generation of cavers to find the cave directly from the trail they had left. CRA did not promote the cave. They did not directly encourage others to follow. Their clues were obscure enough to prevent the casual caver from stumbling down to their find. But, they gave enough information to motivate and guide some hard-core cavers.

In the 1970's, the cave graced the covers of other journals. Its entrance appeared in the first color photo cover on the *NSS News* in December 1976. It was often featured in the NSS photo salon and is probably the best known of the Grand Canyon caves. The cave has also suffered from the attention. Despite its relatively remote location and difficulty of access, the cave has been inadvertently damaged by careless cavers (Figs. 1 and 2) (Hose, 1991).

Figure 1. Careless, and probably tired, cavers have left footprints within clusters of selenite needles on the floor of Silent River Cave.

Figure 2. The famous gypsum rope in Silent River Cave in 1975 before it was completely torn off the wall 1.5 cm from its point of extrusion (Strong, 1976). Secrecy protected it for about a decade until the cave became well-known.

Secrecy and Cavers' Contributions to the Caving Community

Ganter (1989) discussed the ethics of surveying and documenting caves during exploration. He regarded the concept of "recycling" caves as being " . . . interested only in the visceral, tacit pleasure of pushing caves." He missed the point. Practitioners of secrecy, like CRA, do not necessarily fail to contribute to the knowledge of the community of cavers. They attempt to keep the location of caves secret, not to suppress information that might add to human knowledge. CRA's scientific contributions were outstanding. They were just subtle in their presentation. The knowledge is available to those who look for it. Additionally, most secrecy-oriented cavers selectively apply the concept. Many cavers openly discuss and conspicuously publish some of their finds but carefully conceal others.

Figure 3. Split-twig figurine in a little-known Grand Canyon cave.

The Stanford Grotto/WSI/CRA crew did not seem to hesitate to cooperate with other scientists, including biologists, paleontologist, and geologists. They were particularly helpful to archeologists. It was a natural alliance. Archeologists are mostly dedicated practitioners of science and secrecy. The WSI discoveries led to at least one major archeological study in a Grand Canyon cave. Despite some excavation and considerable documentation of the work, the cave still is little known among cavers and very rarely visited. Split-twig figurines (Fig. 3), skeletal remains of an extinct mountain goat, and beautiful, unvandalized speleothems remain in the cave. A tremendous amount of valuable, scientific information has come out of this cave but the reports were technical and low-key. Consequently, only dedicated cavers chase the information down and visit the cave.

Recycling Caves and the Practice of Secrecy

The concept of "recycling" does not pretend to recycle virginity. Instead, the experience of discovery and the pristine beauty of the cave are recycled. Just as the earlier exploration of central American caves by Maya of the past does not remove the thrill of discovery from modern explorers, many cavers find that rediscovery of a secret, nearly pristine cave is equally exciting to the discovery of a virgin cave.

Recycling of a cave reached a third generation in Cave City Cave in California. The cave has been well-known, heavily visited, and heavily vandalized since 1850 (Halliday, 1962). Tom Aley, Phil Scott and Howard Sturgis, however, followed a miserable crawl into a previously unknown, pretty part of the cave in the early 1960's. Fearing that others might discover the pristine area and that would lead to its destruction, they marked the wall on the entrance side of the crawlway with a commonly used symbol of the day that indicated that the lead was a deadend. This, of course, extends beyond secrecy to outright deception and, by today's standards, vandalism. They viewed the act as " . . . minor vandalism to prevent major damage" (Tom Aley, written communication, 1991).

The passage remained undisturbed for about a decade until NSS cavers, Mike McEachern and Mark Grady, decided to check the "deadend" passage. They were the second generation to visit the room beyond. They, however, appreciated the philosophy of the previous explorers and generally kept the area a secret. As with most secret caves and passages, however, they did show it to a few trusted friends.

It was about another decade later when the cave was threatened by a proposed development on the surrounding surface. Local cavers asked Tom Aley's advice on the matter and he revealed the cave's secrets to a third generation of cavers. They pushed the cave even further and made a commercial venture of spelunker tours into the "Jungle Room." What a special sequence of events. At least three generations of modern cavers were able to experience the thrill of true exploration in a cave that was otherwise heavily visited and vandalized.

Another cave in the West is too visible to hide from a nearby trail. The entrance is too large to gate and it was far too remote for the land manager to closely monitor. CRA decided to provide partial protection by blocking the already obscure crawlway into the most delicate passage, an area first discovered in 1965. The floor of the hidden area is covered by crystals of gypsum and mirabalite that would be easily destroyed by traffic. Blocking the passage again involved active intervention but the blockage was completely obvious to any experienced caver who might happen upon it. In addition, the CRA cavers gave the passage a completely different name from the rest of the cave. Thus, the passage was called "ABC Cave" even though it was a part of the moderately well-known "XYZ Cave." Using this strategy, if anyone heard them talking about the secret passage, the listener would think that it was an entirely different cave.

The passage was discovered by a second generation of cavers about 8 years later. Like the six cavers on the initial discovery trip, the six cavers who discovered it the second time have chosen to forsake the recognition and ego-stroking associated with revealing it to the caving community. It has been left for yet another generation for over 18 years. Has there been a third discovery within the 26 years since its first exploration? If so, the legacy continued and it is still there for you to experience the thrill of discovery.

PROLIFERATION OF THE PRACTICE OF SECRECY

The practice of secrecy was embraced and aggressively advocated in the late 1960's and 1970's by UAAC Grotto and other western cavers. Locations were rarely given to *any* cave. The spread of the secrecy concept brought broader methods of application. The new practitioners of secrecy often wrote trip reports in a more adventurous tone. There was generally, although not completely, less emphasis on making scientific contributions. Some practitioners of secrecy documented nothing. Some collected considerable data but hoarded it from the scientific and caving community. Some gave virtually nothing to the caving community, although they typically took very little, also.

There was more active intervention. Key passages were commonly blocked rendering them nearly undetectable. In some cases, passages opened by digging were re-filled. Elsewhere, elaborate blockades that were totally unnatural to the cave were constructed. At least one passage on federal land was cemented closed at the whim of two cavers. These extensions of the original Stanford Grotto philosophy happened for several reasons. First, and probably most important, was the personalities of the practitioners. Secondly, some of the caves were relatively close to large populations of "speleoboppers." In addition, southern Arizona has a particularly severe problem with unethical mineral collectors denuding the caves of speleothems. The land managers, however, were not close enough to the caves to protect them.

Another difference between the practice of secrecy in the early 1960's and the practice in the latter 1960's and 1970's was the composition of people in the groups making new discoveries. Stanford Grotto, WSI, and CRA seem to have been very tight, like-minded groups who did not generally cave with "outsiders." When they made a discovery, they all seemed to agree on the course of action and acted accordingly. As secrecy spread, practitioners found themselves discovering delicate passages while accompanied by neophytes with no appreciation of the value of secrecy. They saw the cave's only hope with active intervention to conceal the find. The result was that the "In" cavers would know the secret. Neophytes, unproven cavers moving in from out-of-state, unpopular cavers, and cavers who refused to adopt and support the concept of secrecy would soon learn about the cave but were frustrated by the secrecy surrounding its location. Resentment built. Grottos were even split apart (Vance A. Nelson, personal communication, 1991).

"Half" secret caves are the most controversial. There is really no controversy, except in academic debates, about truly secret caves. If people do not know a cave exists, how can they be upset about not being given its location? Unfortunately, caves near population centers are typically only "sort-of" secret.

The more successful and less controversial practice of secrecy keeps the existence as well as the location of the cave completely secret from all but those directly involved in the cave or with a "need to know" (usually for scientific reasons). Practitioners of secrecy at this level accept that friendship does not demand that every cave location be shared.

CAN FIELD SITES BE KEPT SECRET IN PEER-REVIEW SCIENCE?

Specific locations are rarely necessary for the purposes of providing data or interpreting results in journal articles. However, "peer-review" science requires accountability and enough information for other qualified researchers to duplicate the results. Archeologists commonly meet this requirement while not revealing the precise location by providing a site number. In this system, archeological sites are recorded and assigned a number by a designated agency such as the state museum and federal land manager. The agency files contain an exact location but are carefully protected. The location to any site is provided to qualified researchers following established agency guidelines. At this time, however, similar systems are not commonly established for caves. Among federal agencies where such files are maintained, few have clearly established, consistent guidelines concerning how requests for locations are to be handled.

The Federal Cave Resources Protection Act of 1988 may be prompting a positive change towards gathering and centralizing data collected on caves while protecting information on exact locations. The Act directs federal land managers to " . . . foster increased cooperation and exchange of information between governmental authorities and those who utilize caves located on Federal lands for scientific, education, or recreational purposes" and to protect information on the specific location of caves except when the request meets specified guidelines. Some regional offices in the U.S. Forest Service and the National Park Service are beginning to catalogue cave locations and resources while developing policies for appropriate protection and distribution of the information. Whether these new systems will be accepted among karst researchers (and cavers) to the degree that archeological site numbers and inventories have been accepted will probably depend on the agencies' diligences in maintaining the data base and appropriately protecting and distributing the records.

One can envision a day when a person can use a GIS system to find site numbers to all recorded caves with a specific resource. If the specific location of a relevant cave is protected, the GIS manager could provide the location based on the researcher's qualifications and the merit of their research proposal. However, if the data manager gives locations to delicate, "secret" caves to "cave-for-pay" operations or college outings courses under the interpretation that they are bona-fide educational institutes entitled to the information, many cavers and karst researchers may refuse to put information into the system.

The question of accountability in peer-review science when a specific site location is not provided is more problematic for caves that are not covered by a carefully monitored but peer-accessible data base. Editors and authors have responsibilities to assure that some method of accountability is built into the paper. In some cases, a committee within the association publishing the journal might record the specific location and follow prescribed guidelines before providing the information to other researchers.

WHEN AND WHERE SECRECY WORKS

It is a commonly held belief of many cavers that secrecy does not work. Or, that secrecy does not work if the cave is large or significant. This myth just is not true! Secrecy works for some caves and it works extremely well. Cavers argue that it is only a temporary measure. But, experience in the West has shown that it can work for decades. All management policies are temporary relative to a cave's existence. They should be reviewed periodically. Secrecy is no different. In many places, secrecy has worked far longer and required less maintenance than most cave gates. Elsewhere, secrecy has protected the cave until a well-considered, alternative policy was established.

USING SECRECY WHILE DEVELOPING OTHER MANAGEMENT STRATEGIES

There is one major difference between secrecy and other exploration and management policies. Secrecy must be practiced from the moment of the initial discovery. Cavers cannot successfully apply secrecy after other techniques have failed. For this reason, it seems reasonable that secrecy should be the first reaction to a new find until the situation is fully evaluated and the consequences of other actions are considered. Keeping a new cave or cave passage a secret until the needs of the cave, landowner or manager, and cavers are evaluated would save the caving community a lot of grief. Depending on the circumstances, the evaluation period may occur during the drive home or it may take years.

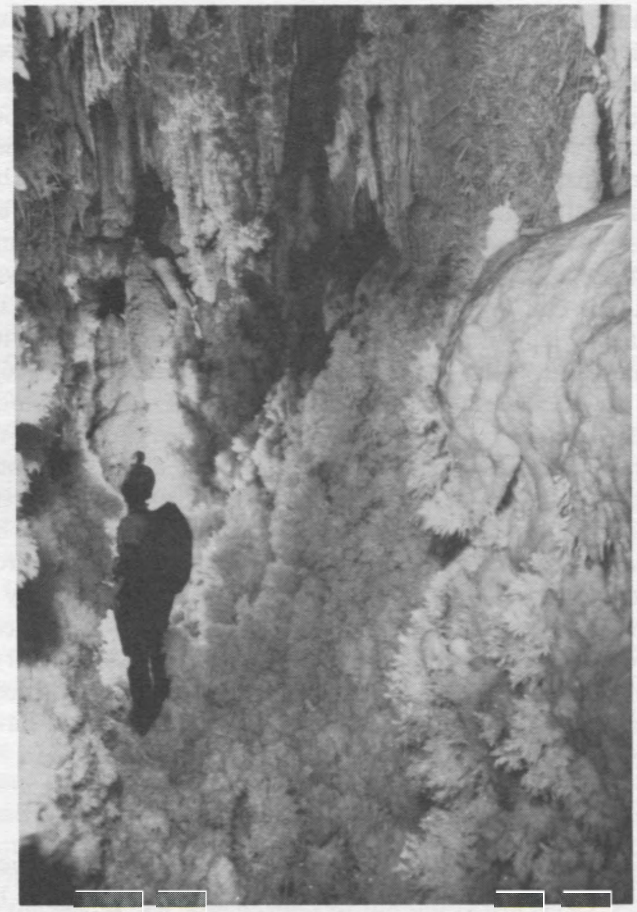

Figure 4. Extremely delicate, secret passage filled with clusters of aragonite in a cave west of the 100th meridian.

Perhaps the best known and successful use of the practice of secrecy was applied to the nearly four kilometer long Kartchner Cavern in southern Arizona. The cave was discovered by Gary Tenen and Randy Tufts in 1974 (Tufts, 1989). They shared their secret with a few, secrecy-oriented cavers and a supportive landowner. Their dream was to see the cave commercialized as a means of protecting it while sharing its beauty. After 14 years of effort, they succeeded in convincing the State of Arizona to develop the cave as a State Park.

Archeological Sites

Secrecy is commonly applied and works well at archeolgoical sites. However, cavers must be careful. In one case, secrecy among cavers was not enough. A cave was discovered in the early 1970's by a conscientious group of cavers. Split-twig figurines were found in the entrance area. Being responsible people, they reported their find to the National Park Service. The cave and its treasures were known only by a handful of careful, secrecy-oriented cavers. Unfortunately, one of the Park Service employees shared the information with a friend who was a mule train guide at the Park and the word ultimately got back to the Park Archeologist that a "mule-skinner" knew about the find. The Park decided to "salvage" the site before any damage could be done. All of the figurines were removed. No one will ever be able to see these elegant artifacts *in situ* in this cave again.

A professional archeologist who assisted with the removal told me that he thought there was never anything lost to archeology by complete secrecy of such a remote site and its resources (Mark A. Grady, personal communication, 1976). He stated that the cavers would have served archeology better by taking their practice of secrecy even further and to have not let the Park Service even know about the find. Grady reasoned that archeologists already have an overwhelming number of sites that are threatened and should be investigated. As long as a newly discovered site was protected, whether by effective administrative control or by a combination of a remote location and secrecy, archeological investigation of the site was not as important as inventorying and salvaging high-risk sites. At the very least, the more prudent course for the split-twig figurine site would have been to only inform the Park Archeologist of the find.

Wilderness and Other Remote Areas

Secrecy commonly works in extremely remote caves, even with large entrances. The pressure for access is minimal. In addition, in wilderness areas and places like the Grand Canyon where the land and subsurface are managed as *de facto* wilderness, there is almost no risk from peripheral damage. The caves will not be quarried or polluted. It is hard to find a persuasive argument in favor of publicizing most caves in Wilderness Areas beyond stroking cavers' egos.

Many areas in the West are not included in official wilderness areas but are still currently safe from peripheral damage. One short cave is 100's of kilometers from any population base and is heavily decorated with unique formations. It is possible to drive to about one kilometer from the large entrance to the cave. The cave has been known for more than 15 years yet there apparently have only been four trips made by eight people. The cave remains pristine and without notable damage.

Secrecy is probably the method of choice for extremely delicate caves in relatively remote areas. This method works particularly well if the entrance or key passage can be well-hidden. Passages like the one shown in figure 4 could not possibly tolerate traffic. Each traverse does significant damage and there is no bypass. Who would choose who gets to destroy the passage? The discoverers have chosen to share their find with a few trusted cavers who have shared secret discoveries with them before. Otherwise, they are leaving the cave for the next true **explorers** to find.

Secrecy Used to Maintain Land Owner/Manager Relationships

Secrecy has also been successfully applied to caves where the landowner or manager is not easily receptive to cavers. One multi-kilometers-long cave has very skittish landowners who do not particularly like outsiders on their property. It was clear to the cavers who discovered the cave that they were lucky to receive permission to cave on the property and that each visit by themselves or others might jeopardize their chances of returning by pressing the patience of their hosts. Instead of seeking some sort of exclusive agreement with the landowners, they resolved to not raise any interest in the area by not sharing news of their finds.

The cave is also extremely delicate. Traffic would easily harm it (Fig. 5). Secrecy serves two purposes for this cave: 1.) Minimizing the traffic and, hence, damage to this fragile cave. 2.) Minimizing the stress and irritation to the landowners.

Figure 5. The floor in many places in one secret western cave is completely covered with gypsum flowers. The discoverers have chosen to not cross these areas until the rest of the cave is completely explored and no bypasses are found. They try to insure that their policy is followed by keeping the existance, name, and location of the cave a secret.

The policy of secrecy has cost the project participants. Exploration has been slow. Some project members have died, grown too old, or grown too fat to see exploration completed. The discoverers will probably never have their pictures and names in the *NSS News, Sports Illustrated, Smithsonian, National Geographic,* or *Audubon* magazines. They will never appear on To Tell the Truth. They never made any money from their involvement with the cave. Stories of the cave's exploration will probably never help anyone win a Lew Bicking Award.

On the other hand, they have had many benefits. The cave is in excellent condition. There have been no power plays to keep others out. Anyone who has the motivation to find it can explore it. Landowner relationships have been as good as can be expected. Some real, published science has been done. Perhaps most importantly, there have been no conflicts. Everyone involved with the project has been happy.

Suggested Guidelines and Considerations for the Application of Secrecy

Although the policy of secrecy seems to be more practiced in the western United States than in most areas, there are common considerations that may apply anywhere.

1. Secrecy should be the first reaction to a new find until the situation is fully evaluated and the benefits and consequences of other actions are considered. One can rarely return to a policy of secrecy once the word is out.

2. The vulnerability of the cave to damage by surface exploitation such as quarrying, oil and gas drilling, road construction, etc. should be considered. Caves with such vulnerabilities are rarely good candidates for complete secrecy. For this reason, caves in wilderness or de facto wilderness are often the best candidates for the effective application of a practice of secrecy.

3. The interest and feelings of the landowner/manager should be considered. Some landowners prefer that caves on their property be kept secret. Their wishes should be honored. Conversely, the landowner or land manager may be capable and interested in managing the cave to the benefit of many visitors and have a good record of protecting caves on their property. In such cases, the practice of secrecy may only be appropriate until an active management plan is developed.

4. The likelihood of the cave being discovered by less conscientous visitors should be considered. Will someone in the discovery group return with friends who will not respect a policy of secrecy? If the cave is vulnerable to visitation by people who will significantly damage it, a more active form of cave management should be developed.

5. What are the resources in the cave? If there are archeological resources, the discipline has an institutionalized practice of secrecy that may be appropriately applied to the cave. Certainly, an archeologist should be involved in decisions on the management of the cave.

6. How hardy is the cave and its inhabitants? Will each visit cause noticeable damage? Is the site a habitat for sensitive, threatened, or endangered species? Is it in the best interest of the case and its inhabitants to severely limit human visitations? If so, a policy of secrecy may be an effective and fair tool for management.

7. What are the scientific resources in the cave? Are they likely to be damaged or destroyed by human visitations? Is there information about the cave that will benefit science if it is distributed? Is there an established, secure data base where the site information and location can be archived without publishing a location in the literature? Information about caves and their general locations in referreed literature usually does not quickly transfer to demands by cavers for recreational access. The extensive publications of WSI/CRA in scientific journals show that the tone of one's writing style often determines the pressure put on a cave by people demanding recreational access. While not truly practicing secrecy, carefully written scientific articles can minimize the visibility of the cave while providing the pertinent data.

Conclusions

Secrecy as a style of cave exploration and management is exceedingly attractive. No one is kept out. The policy is democratic. Caves and passages are recycled to the next caver who pushes hard enough to find them. Not only are the caves kept in better condition than they would be if their location and splendor were revealed, the thrill of discovery is also recycled.

Practitioners of secrecy have frequently been accused in the past of being selfish. They are said to defy the "fellowship of cavers." But, they actually seem to be among the least selfish of all cavers. They have sacrificed self-glorification for the sake of protecting the caves. They have traded the opportunity for their contemporaries to visit and, hence, damage the caves by riding on their efforts for the opportunity to preserve the caves in a pristine state for future generations of cavers and researchers. As the pushers of the 1970's and 1980's enjoyed re-discovering some of the finds of the WSI/CRA, the pushers of the future will reap the rewards of secrecy practiced today. Some caves are being recycled.

With the growing trend towards publicity outside the caving community, we run the risk that the heroes of today's young cavers will be the media stars of caving. We might reasonably expect that future cavers may be falling over each other for public recognition. However, we need to recognize the power and palatability of "secrecy" for **some** caves and appreciate its practitioners who have explored hard, contributed heavily to the scientific literature, and left many of their discoveries pristine and free of flagging tape. A future generation of cavers will undoubtedly be grateful for their thoughtfulness.

Acknowledgements

I would like to thank Tom Aley, Ray de Saussure, Arthur Lange, John E. Mylroie, Thomas R. Strong, John Wilson, and Thomas Wynn for reviewing earlier drafts of this paper. Tom Strong also helped with some of the photography. He and the late Mark Grady provided many useful discussions in the past. Mostly, I would like to express my appreciation for the many practitioners of secrecy, past and present.

REFERENCES

Aley, Tom, September 9, 1991, written communication, 2 p.

Aley, Tom, 1965, *Corrasional Cave Passage Enlargement:* Cave Notes, v. 7, n. 1, p. 2-4.

Ganter, John, 1989, *Will We Map As We Survey?:* NSS News, v. 47, n. 6, 143-144.

Halliday, William R., 1962, *Caves of California:* Western Speleological Survey, Seattle, Washington, 194 p.

Hose, L. D., 1991, *Growth Rate of Fibrous Gypsum:* Geo², v. 19, n. 1, p. 16.

Knutson, Steve, 1985, *Marble Mountain Majesty:* NSS News, v. 43, n. 4, p. 149-156.

Powell, J. W., 1887, *Report on the Lands of the Arid Regions:* Washington, D.C.

Strong, L., 1976, *Silent River Cave trip report for 23-24 July 1976 with Observations on Previously Unrecorded Geological and Biological Features in the Cave:* an unpublished report submitted on 19 September 1976 to the files of the Grand Canyon National Park, 3 p.

Tufts, R., 1989, *Kartchner Caverns—Arizona's Newest State Park:* Arizona Highways, v. 65, n. 3, p. 4-9.

LaRock, E. J. and Cunningham, K. I.—Discussion of Some Geologic Features in Wind Cave, Wind Cave National Park, South Dakota: *NSS Bulletin* **54: 25-27.**

DISCUSSION OF SOME GEOLOGIC FEATURES IN WIND CAVE, WIND CAVE NATIONAL PARK, SOUTH DAKOTA

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We discuss two separate features of geologic interest in Wind Cave, Wind Cave National Park, South Dakota which relate to articles in the December 1989 National Speleological Society (NSS) Bulletin (Palmer and Palmer, 1989; Miller, 1989). One feature is the exhumed "sediment wall" (Fig. 1) along Selenite Avenue near the south-central margin of the cave. The sediment wall is an Oligocene(?) cave fill and supports pre-Oligocene re-solutional enlargement of Wind Cave. The other feature is a fault on the ceiling of the Atlas Underground Chamber (Fig. 2) near the eastern margin of the cave that helps support a thrust fault interpretation for the fault in Gateway Hall.

Previous workers noted the presence of quartzite-bearing gravel in Wind Cave (Aberle and Hughes, 1961; Loskot, 1973; Palmer, 1981). Aberle and Hughes suggested that gravel in the Historic Section could have been washed in from Quaternary terraces north of Wind Cave canyon. Both Loskot and Palmer concluded that red fills containing Precambrian pebbles represented a second phase of cave filling extending from early Oligocene to the Holocene. Flurkey (1988) concluded the sediment wall was at least early Tertiary (60 Ma) or younger in age.

The sediment wall in Selenite Avenue near survey station SA10 is one of the thicker sections of known fill. The 20-40 ft. tall sediment wall is exposed in a solutional pocket along the southwest wall of Selenite Avenue which is undercut by, and collapsed into, a calcite-coated passage. The red clay in the sediment wall contains well-rounded, small cobbles of Precambrian quartzite derived from the nearby core of the Black Hills uplift. The quartzite cobbles are dispersed throughout the laminated red clay as coarse- to medium-grained lenses containing other rock fragments. Similar quartzite cobbles have been found at a small outcrop of Oligocene (25-35 Ma) White River Group at Bison Flats above the southern margin of Wind Cave (DeWitt and others, 1989). Several magnetic reversals have been detected (F. Luiszer, Boulder, CO, written communication, 1992) in the clay layers of the sediment wall.

A west-to-east profile extending through Selenite Avenue (Fig. 1) demonstrates the relationship of the White River

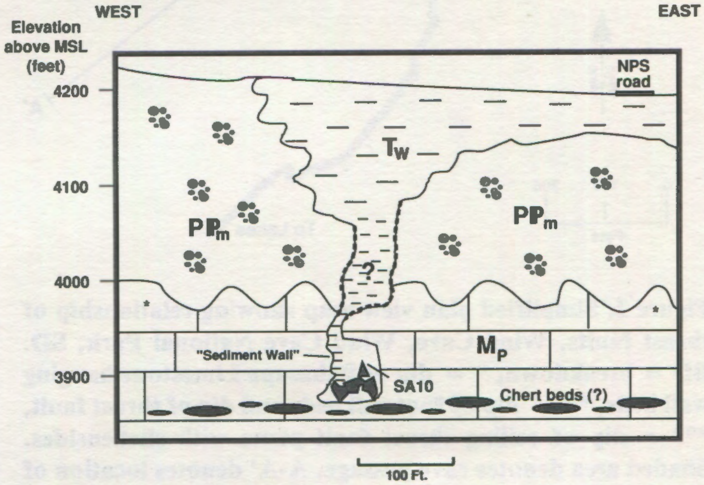

Figure 1. Geologic profile through Selenite Avenue (SA10), Wind Cave, Wind Cave National Park, South Dakota. Tw= Tertiary White River Group, P Pm = Permian and Pennsylvanian Minnelusa Formation, Mp = Mississippian Pahasapa Limestone, * = downdip projection of top of Pahasapa from natural entrance area.

Group outcrop to the subsurface sediment wall. Cave sediments at SA10 may prove to be Oligocene, an age that supports Eocene re-solution of Wind Cave followed by Oligocene ponding and sediment filling (Palmer and Palmer, 1989). Figure 1 was constructed using digital line plots and a topographic map overlay provided by G. Petrie (Hillsboro, OR, written communication, 1990) and J. Nepstad (Hot Springs, SD, written communication, 1990).

A slickensided fault plane was found on the ceiling of the Atlas Underground Chamber (XS13) in June 1989; a few poorly exposed tension gashes indicate thrust motion. The structural attitude was measured in August 1990; the fault plane dips 15 degrees to the southeast. The relationship of this fault to the fault measured in Gateway Hall (JF64) is shown in Figures 2 and 3 (which are based on line plots by G. Petrie and in-cave observations made by A. Flurkey or the authors). The Gateway Hall fault plane dips 30 degrees

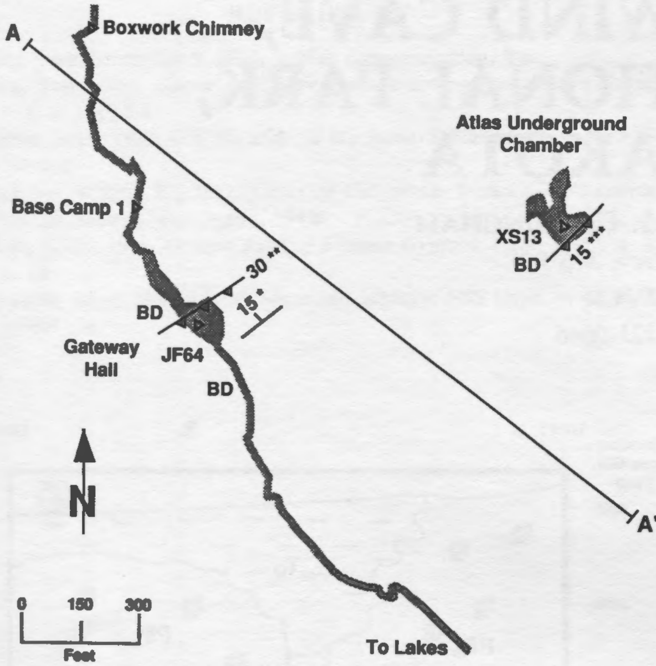

Figure 2. Simplified plan view map showing relationship of thrust faults, Wind Cave, Wind Cave National Park, SD. BD = breakdown, * = dip of Pahasapa Limestone hanging wall beds, ** = dip of footwall beds and dip of thrust fault, * = dip of ceiling thrust fault plane with slickensides. Shaded area denotes cave passage. A-A' denotes location of structural profile shown on Figure 3.**

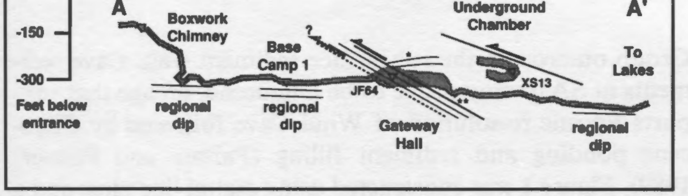

Figure 3. Simplified structural profile A-A' showing cave passages and structural features projected onto a plane striking 127 degrees, Wind Cave, Wind Cave National Park, SD. Regional dip = 5 deg SE. * = dip of Pahasapa Limestone hanging wall beds, ** = dip of Pahasapa Limestone footwall beds and thrust fault in Gateway Hall. ? = proposed imbricate thrust fault.

to the southeast and is parallel to the dip of a small block of footwall beds exposed below the fault. The footwall beds (Fig. 3) deviate from the regional 5 degree southeast dip of the Pahasapa Limestone (Palmer, 1981). The 14 degree northeast dip of the hanging wall is due to rollover into the Gateway Hall fault.

The low angle thrust fault in the Atlas Chamber projects along strike toward the Gateway Hall fault. The rollover in the hanging wall of the Gateway Hall fault can be produced by a low-angle thrust fault or a low-angle normal fault. No kinematic indicators are present in Gateway Hall to support either interpretation. However, the deviation of the dip of the footwall beds from the regional 5 degree southeast dip of the Pahasapa Limestone supports the interpretation of a small offset thrust fault in Gateway Hall (Palmer and Palmer, Fig. 9, 1989). The footwall dip may be explained by a proposed duplex thrust or imbricate thrust fault (LaRock, 1987) buried under breakdown blocks below the observed Gateway Hall fault (Fig. 3). The high angle (80 degree) normal fault in Gateway Hall proposed by Miller (Fig. 4; 1989) is precluded by the measured structural attitudes. The hanging-wall limestone unit pointed out by Miller (Plate 4; 1989) is abruptly lower to the right but lies in the footwall, indicating reverse motion.

Wind Cave lies on the southeast-plunging nose of the Black Hills uplift near the northwest flank of the Cascade anticline. Flurkey (1988) and Lisenbee and DeWitt (in press) have discussed the westward vergence and associated reverse faults of the Cascade anticline. This Laramide structure could produce small, westward-directed thrust faults related to bedding plane slip in the Pahasapa Limestone. Such thrust faults may locally ramp up-section, imbricate, and return to bedding planes to produce the geometry observed at Gateway Hall. If any Quaternary normal faulting occurred as proposed by Miller (1989), it may be due to localized extensional rotation along the preexisting thrust fault plane. Later extension or listric normal faulting is common in thrust systems that have the geometry observed in Wind Cave (Boyer and Elliott, 1982).

Our interpretation of the features discussed above support current geologic models of Wind Cave (Palmer and Palmer, 1989; Miller, 1989). The Oligocene(?) sediment wall supports the Eocene resolution event proposed by Palmer and Palmer. The interpretations presented for the Atlas and Gateway faults offer a logical compromise between the thrust-fault model of Palmer and Palmer and the normal-fault model of Miller.

REFERENCES CITED

Aberle, P. P. and Hughes, L. J., 1961, *The formation and detailed description of a portion of Wind Cave and the mineralogy of cave earth* [B.S. thesis]: South Dakota School of Mines and Tech., 23 p.

Boyer, S. E. and Elliott, D., 1982, *Thrust systems:* American Association Petroleum Geologists Bulletin, v. 66, p. 1196-1230.

DeWitt, E. and others, 1989, Geologic map of the Black Hills Area, SD and WY: US Geological Survey Miscellaneous Investigations Series Map I-1910.

Flurkey, A. J., 1988, Geology field trip road log: 1988 National Speleological Society Convention Guidebook, G. Schilberg and D. Springhetti, eds., National Speleological Society, Huntsville, AL.

LaRock, E. J., 1987, Wind Cave celebrates 50th mile: Depths of the Rockies v. 4, p. 8-10.

Lisenbee, A. L., and DeWitt, E., (in press), *Laramide evolution of the Black Hills uplift:* in Snoke A. W., Steidtmann, J. R., and Roberts, S. M., Geology of Wyoming, Wyoming Geological Survey Memoir 5.

Loskot, C. L., 1973, *Deposition of cave material in Wind Cave* [M.S. thesis]: South Dakota School of Mines and Technology, 66 p.

Miller, T. E., 1989, Evidence of Quaternary tectonic activity and for regional aquifer flow at Wind Cave, SD: National Speleological Society Bulletin, v. 51, p. 111-119.

Palmer, A. N., 1981, *The Geology of Wind Cave:* Wind Cave Natural History Association, Hot Springs, SD, 44 p.

Palmer, A. N. and Palmer, M. V., 1989, *Geologic history of the Black Hills caves, SD:* National Speleological Society Bulletin, v. 51, p. 72-99.

Lewis, Warren C., M.D.—A Letter to the Editor: On the Origin of Cave Saltpeter: A Second Opinion: *NSS Bulletin* 54: 28-30.

ON THE ORIGIN OF CAVE SALTPETER: A SECOND OPINION

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Cave saltpeter originates in bacterial action on highly organic surface soils and the nitrate thus formed is transported to the cave by seeping groundwater.[1] In the decade that followed this Bulletin article pronouncement, no one openly challenged this interpretation. Perhaps it was because it was buttressed by much hard work by members of the Cave Research Foundation as well as by the work of others. It is my contention that the data should be interpreted in another way.

I was with a group of visitors who were walking on the huge piles of spent saltpeter earth in the Rotunda Room near the Historic Entrance of Mammoth Cave. In a pit several meters below us could be seen an almost buried leaching vat. "The saltpeter is still here," said our Ranger-Guide. He allowed the dry dirt to trickle through the flame of a borrowed Bic lighter. It sparked beautifully. How did the saltpeter get back in this leached earth? I looked around for evidence of seeping groundwater and saw little or none. What I saw was bone-dry passages with bare walls.

It is my opinion that saltpeter originates in the cave itself by bacterial action on nitrogen from the air. In the dry passages it remains near the site of formation in solution in the residual pore water of the soil. You may ask whether or not such a distinction is of any importance. The interpretation of saltpeter origin has much to do with explaining its distribution in caves and with clarifying our understanding of movement of salts in groundwater. It contributes to our concept of the movement of the groundwater itself. This could be of practical importance to our Nation in time of war if the petrosynthesis of nitrates were to be disrupted. Adequate understanding of the regeneration process would be necessary for optimal production of saltpeter. I believe that the data support my interpretation.

Locations in which this process can be clearly observed are those found in Mammoth Cave, Kentucky and nearby Dixon Cave. In particular let us pay attention to the nitrates extracted from upper level passages of Mammoth Cave. Several hundred thousand tons of saltpeter came from this area. Geologically these passages represent long-abandoned stream channels. Two nitrate forming bacteria, *Nitrobacter agilis* and *N. winogradskyi,* are widely distributed through these soils.[2] The passages lie far above the level of the rivers now present in Mammoth Cave. These passages, many of which are on the tourist trails, are free of streams or ponds. The water from the few springs in this part of the cave, sinks almost immediately to some lower level. In essence, these are dry passages in which saltpeter is formed. It seems to me that they depend primarily on the cave air for their moisture.

It is true that saltpeter can be found in wet soil in stream caves as well as in dry caves. It occurs under shelter-like overhangs which are open to outside air, in limestone quarries, in shallow caves and cave soils deep underground. Nitrates also occur in caves in sandstone and other non-carbonate rocks. They are found in soils enriched by bird, bat and other animal excreta, and various types of vegetable debris. These sites will not be addressed at this time. The model described here is thought to apply to the dry saltpeter caves in the area of the South-Central Appalachian Mountains, the Greater Bluegrass and Volunteer Regions, and the area extending westward into the Ozarks:

The 1981 Bulletin article has this to say:

> "(1.) Surface soil nitrate transported into the cave by seeping groundwater is the most likely source of cave saltpeter. (2.) The proposed mechanism that drives seeping groundwater towards the cave is evaporation at the cave air-bedrock interface which produces a moisture density gradient within the limestone. (3.) Reduced nitrogen (NH^{4+}) is transported from the surface through the zone of aeration to cave bedrock and sediments where it is oxidized to nitrate by *Nitrosomonas* and *Nitrobacter*. (4.) The seeping groundwater model explains such characteristics of saltpeter caves and sediments as regeneration, areal and vertical extent, and nitrate within cave bedrock."[1]

(1.) It is the opinion of this writer that very little nitrate from undisturbed surface soils is transported underground in the cave region. In general, the surface soils of this area are poor in nitrates. It is true that some of the cave areas are overgrown with oak or oak-hickory forests but these trees do not produce nitrates. Some trees such as the alder are able to fix nitrogen but are rare or absent here. Nitrogen fixation is found in many members of the Leguminosae or Pea Family. Trees included in this Family are the Kentucky coffee tree, the locusts, and the redbud as well as briars and clovers. These were not noted to be particularly plentiful over the caves before the land was cultivated. In fact, nitrogen values were so low that as the land came under cultivation, many of the fields were rapidly depleted of nitrogen by planted crops.

As for the role of seeping water, there is little evidence of seepage of water in this part of the cave. There are few if any formations in the passages aside from occasional gypsum crusts and flowers. If groundwater containing calcium salts and nitrates were evaporating from the walls, one would expect to find calcium deposits. Stains of seeps, excrescences, blooms and moonmilk are absent from most of these side walls. Almost no flowstone or dripstone has been deposited. The walls are uniformly bare and dry, even dusty. The cave soils on the floor which are of several types show little sign of recent water movement. Of course, much of the soil has been disturbed by leaching for saltpeter or by the feet of visitors. Even so, there is minimal evidence of salts left by evaporation since the miners replaced the spent earth in the cave corridors over a century ago. In those areas in which dripping water percolates the cave soil, no saltpeter is found.

(2.) Evaporation from the cave wall in this locality does not draw seeping groundwater out of the rock. The moisture gradient at the air-bedrock interface is not a strong unidirectional force because moisture moves both ways. Both evaporation and condensation take place on the surface of the rock. Water is lost or gained depending on relative temperatures of air and rock, available moisture, wind speed and heat conduction of the rock. This process varies with the season of the year. For example, after the cave rock is well cooled by winter air, the first moist air of spring in the cave may condense on walls, ceiling, and on cave soil. This part of the cave may become wet with water dripping from the ceiling and even flowing in thin sheets down the walls. If conditions are right, this may happen several times in one year. Not all caves act seasonally in this way. Some caves in Tennessee are wetter in Winter. Such moisture may take a long time to evaporate, especially when the level of moisture in cave air remains near the saturation point. Condensation, in my opinion, plays an important role in moistening the soil of dry passages.

Without evidence of formations, flowstone or crusts, on walls or ceiling, we can infer that very little water is moving through the bedrock in this portion of the cave at the present time. Little groundwater is moving either horizontally or vertically in the rock. Such underground water as there is seems to find a direct path to the lower levels. This has been documented by the presence of dome-pits along the edge of the Big Clifty Sandstone that acts as a cap rock in this region. Much more data is needed to work out a water budget for this area. However, the present water flow appears to be much too small to carry that heavy load of saltpeter.

(3.) Very little reduced nitrogen (NH^{4+}) is transported through the soil. Some of the nitrogen in the form of ammonia or ammonium ion is utilized at the surface by plants and by nitrifying bacteria such as *Nitrosomonas europaea*. Some is trapped by organic material in the soil. A large portion is rapidly adsorbed on clay particles which are negatively charged. These ions are slowly released or exchanged over a period of several months to be utilized by growing plants and bacteria. Some ammonia is washed away by rainfall causing unwanted blooms of algae in streams and ponds. Excess ammonia from application of fertilizer is more likely to appear as run-off in surface streams than be found to have percolated through the soil and bedrock. Very little ammonia is found in caves under normal conditions. If a few parts per million of dissolved or ionized ammonia should be carried into this cave, it would be readily consumed by the nitrate bacteria.

(4.) It has been known for several hundred years that leached saltpeter earth would accumulate saltpeter again, especially if replaced in the cave. This replenishment was known as regeneration. The process did not occur just on the cave floor. There were tales of regeneration occurring when the spent dirt was placed on boards in a cave. In Dixon Cave, near Mammoth Cave, spent earth placed on a rock ledge and wall by Civil War miners was found to have regenerated saltpeter. It is difficult to see how the soil in a passage which showed no signs of flooding, or soil which had been placed on a wall or ledge, could have been percolated by groundwaters. To this writer, regeneration of cave soils has become one of the strongest arguments for on-site production of saltpeter.

Saltpeter has been found on the walls and ceiling of Dixon and Mammoth Caves as well as in the cave soils. Basically, areal and vertical distribution is quite similar throughout the caves. Even concentrations from the depth of drill holes tend to be similar to the wall surface. This observation would seem to favor the concept of local production of saltpeter over the entire cave surface rather than at the localized sites of seepage of groundwater. In our model the cave is one big culture tube with the entire interior surface covered with bacterial growth and saltpeter both of which penetrate the walls.

Release of the nitrate ion (NO^{3-}) by *Nitrobacter* has a destructive effect on carbonate rocks. As the contact layer reacts to nitric acid, the rock becomes rotten or chalky and may flake off. In Dixon Cave miners used a pick or a maul to remove this surface layer for its saltpeter. In this cave also are huge man-made piles of breakdown blocks possibly loosened by "saltpeter rot" along the fissures and bedding planes. This deterioration is similar to that from carbonic acid or sulphuric acid in caves but is likely to penetrate more deeply into the pores and minute fissures in the rock.

Nitrate bacterial colonies may grow below the surface of the rock, even into the pores of the rock, as far as moisture and oxygen can penetrate. These bacteria will thrive even under reduced oxygen tension. As a result, the saltpeter content may be elevated in rock below the surface anywhere in the cave. Concentrations of saltpeter may be high at the foot of the walls if the salt is carried there by water of condensation. Major cracks and fissures will also be found to be colonized by nitrate bacteria. This concept of widespread saltpeter distribution conforms to the results of drilling in these caves. However, the high values found in drill holes also suggests that sampling cores of cave walls is an unreliable method of ascertaining the saltpeter content of the native bedrock.

Nitrate bacteria are not dependent on ammonia or its salts in their substrate. *Nitrobacter* makes its own supply from nitrogen in the atmosphere. The energy for this process is derived from oxidation of the nitrite ion. Its companion bacterium, *Nitrosomonas*, derives its energy from the oxidation of the ammonium ion. The cave setting supports bacterial growth although the cave is colder and the soil is drier than is optimal.

A poor correlation has been reported between *Nitrobacter* counts and saltpeter concentrations.[2] Consider that the present bacterial population may not have formed the saltpeter. It also might be noted that rapidly growing nitrate bacteria often assume mobile forms with flagellae. They are chemotactic and will swim toward a more desirable alkaline environment. Since saltpeter is mildly bacteriostatic, the bacteria also are likely to move away from areas of high saltpeter concentration. Because of this, a high correlation between bacterial counts and saltpeter levels is not to be expected. If the bacteria indeed produce saltpeter in the cave close to the site at which it is found, many of the problems of transport and deposition of nitrogen compounds noted in this article,[1] will disappear. The requirements for bacterial growth will be met by the rock and clay and the underground atmosphere.

In summary, saltpeter, in my opinion, is formed in dry cave passages by bacteria that are not in contact with moving groundwater.

The role of living organisms in the formation of minerals is just beginning to be appreciated. About sixty different minerals are now known to be formed by biologic organisms of fifty-five phyla.[3] In spite of their hardy nature, nitrate bacteria are quite sensitive to chemical poisoning. An appreciation of this fact should give impetus to our desire to avoid pollution and to preserve saltpeter caves as a unique habitat for the nitrate bacteria as well as a repository for saltpeter. Let us agree to conserve this renewable resource.

REFERENCES

1. Hill, Carol A. (1981)—Origin of Cave Saltpeter, *NSS Bulletin*, Vol. 43, No. 4, pp. 110-126. October.
2. Fliermans, C. B. and E. L. Schmidt (1977)—*Nitrobacter* in Mammoth Cave: *International Journal of Speleology*, 9:1-19.
3. Lowenstam, Heinz A., and Stephen Weiner (1989)—*On Biomineralization*, Oxford University Press, New York, pp. 324.

Hill, Carol A.—On the Origin of Cave Saltpeter: A Second Opinion—: *NSS Bulletin* 54: 31-32.

ON THE ORIGIN OF CAVE SALTPETER: A SECOND OPINION—REPLY

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I would like to reply to Warren C. Lewis' "second opinion" on my "Origin of Cave Saltpeter" article, published in the National Speleological Society Bulletin, v. 43, no. 4, p. 110-126. Lewis' comments will be addressed in the order that he presents them in his article.

1. The "hard work" associated with the retrieval of data for my article on saltpeter was done *mainly* by myself, and working within the "buttress" of the Cave Research Foundation has nothing to do with my research not being challenged over the last decade. The implication of Lewis' statement is that the Cave Research Foundation somehow "protects" its researchers from criticism. This is hardly the case. The Cave Research Foundation encourages free discussion of all research done under its auspices.

2. At the core of Lewis' criticism of my work seems to be his misconception of what the term "seeping groundwater" means. He says of Mammoth Cave saltpeter passages: "what I saw was bone-dry passages with bare walls." Exactly. "Bone-dry" passages are *always* where saltpeter accumulates. It *never* occurs where there is dripping or flowing water because that water will leach the very-soluble nitrate away. I refer Lewis to p. 116 of my NSS Bulletin article where I say:

> "Dripping or flowing vadose water does not exist in the saltpeter passages of Mammoth and Dixon caves. Recent studies in Mammoth Cave show that wherever water drips into the cave sediments, nitrates are leached away. Carbonate speleothems formed from dripping or flowing vadose water (e.g., stalactites, flowstone) are totally absent in the saltpeter passages of Mammoth and Dixon caves; however, sulfate mineralization (gypsum crusts and flowers) does exist in some passages. These sulfate speleothem types are deposited by *seeping* groundwater, not by dripping or flowing water."

Nitrates are never deposited in areas of "flowstone," "dripstone," or "domepits."

The zone of seeping water is also called the zone of percolation, the zone of capillary, or, in its upper extent, the subcutaneous storage zone. This zone is characterized by a significant water storage capacity and sufficient interconnection of water to slowly diffuse through the rock (Williams, 1983). Such diffuse flow is responsible for seeping water speleothems such as gypsum crusts and also for nitrate impregnation of the bedrock (i.e., the nitrate is in a deliquesced state in high-humidity eastern caves). Seeping water evaporates upon reaching the cave passage wall, but the cave passage wall itself feels "dry."

3. It is Lewis' opinion that "saltpeter originates in the cave itself by bacterial action on nitrogen from the air." If this is true, then why are not *all* caves saltpeter caves? Why is there a specific geographic distribution to saltpeter caves (see Hill, 1981, p. 115, her Fig. 7).

4. I doubt if "it is true that saltpeter can be found in wet soil in stream caves as well as in dry caves." Does Lewis have any chemical data to support this statement? Wherever a cave is "wet," nitrate is leached away. Wherever the bedrock itself is located in a wet zone (i.e., exposed to surface rainfall and moisture), nitrate values are extremely low (see Hill, 1981, her Figs. 4 and 5). Nitrate can only accumulate in places such as rock shelters and caves where there is an overhang or cavity to protect the nitrate from being leached away.

5. I have never heard of "regeneration occurring when the spent dirt was placed on boards in the cave." Does Lewis have a reference that supports this assertion? It is conceivable that much regeneration might take place *if* the boards were in contact with saltpeter dirt and capillary water seeping through that dirt. Lewis is referred to Figure 16 of Hill (1981) to see that I have never said that saltpeter regeneration takes place "just on the cave floor." It most certainly forms on walls and ceilings too, and in Dixon Cave spent earth shovelled back onto cave-wall rock ledges has been regenerated in nitrate (see Hill, 1981, p. 119 and her Table 8).

6. The crucial evidence supporting the seeping groundwater origin for cave saltpeter is high nitrate values at least up to 30 cm (1 ft) into the cave bedrock, with little sign of decrease (Hill, 1981, her Fig. 5). Note in Figures 4 and 5, however, that it is only under *nonexposed* cave conditions that this bedrock nitrate is high (thousands of ppm); in *exposed* locations nitrate values are very low (a few ppm). How did this nitrate get so deep inside the cave wall if not by surface water moving by gravity towards the dry cave? From nitrogen or ammonia in the air? The data precludes this. To test this very hypothesis is why I drilled at the entrance of Carlsbad Cavern (where one can smell the ammonia from the cave swallows and bats) and in New Cave (in a bat guano area). Note in Figure 5 of Hill (1981) that nitrate in the bedrock of these arid-climate, poor-soil zone caves is ex-

tremely low (<10 ppm), even where ammonia in the air is relatively high.

7. According to my bacteriology book the process of nitrification involves the transformation of ammonia to nitrate which proceeds in two steps and which is catalyzed by two different groups of bacteria, *Nitrosomonas* and *Nitrobacter:*

(1) $2NH_3 + 3O_2 = 2NO_2^- + 2H^+ + 2H_2O$ (*Nitrosomonas*)

(2) $2NO_2^- + O_2 = 2NO_3^-$ (*Nitrobacter*)

The first step is accomplished by *Nitrosomonas* which must use the ammonium ion (not atmospheric nitrogen) for its metabolism, while the second step is accomplished by *Nitrobacter* using the nitrite first made by *Nitrosomonas*. Neither of these two bacteria have anything to do with nitrogen fixation (the removal of nitrogen from the air). Nitrogen fixation is done by plants—plants which live on the surface and which are the ultimate source of nitrogen to the cave according to the seeping groundwater model. The bacteria *Nitrobacter* cannot "make its own supply from nitrogen in the atmosphere."

8. The "poor correlation between *Nitrobacter* counts and saltpeter concentrations" has been explained by Hill et al. (1983). When saltpeter dirt is leached, nonnitrifying bacterial populations decrease while *Nitrobacter* populations increase as excess and inhibiting nitrate and competing bacteria are removed. The highest *Nitrobacter* counts are found in saltpeter dirt that has just been leached of nitrate; lower *Nitrobacter* counts occur where nitrate has become concentrated in the dirt.

REFERENCES

Hill, C. A., 1981, Origin of cave saltpeter: National Speleological Society Bulletin, v. 43, no. 4, p. 110-132.

Hill, C. A., Eller, P. G., Fliermans, C. B., and Hauer, P. M., 1983, Saltpeter conversion and the origin of nitrates: National Geographic Society Research Reports, v. 15, p. 295-309.

Williams P. W., 1983, The role of the subcutaneous zone in karst hydrology: Journal of Hydrology, v. 61, p. 45-67.

SOME COMMENTS ON "EXTRAORDINARY SUBAQUEOUS SPELEOTHEMS IN LECHUGUILLA CAVE, NEW MEXICO"

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Davis, Palmer, and Palmer are to be congratulated for their fine article on subaqueous helictites in Lechuguilla Cave (*NSS Bulletin*, v. 52, p. 70-86). These authors present convincing arguments for the subaqueous origin of helictites and for the precipitation of calcite by the common ion effect. However, what these authors do not adequately explain is how these subaqueous helictites *work*.

A helictite grows by hydrostatic pressure where solutions are forced through a central capillary canal and deposition occurs at the tip of the growing helictite (Hill and Forti, 1986). Davis, Palmer, and Palmer demonstrate that the subaqueous helictites of Lechuguilla Cave possess central canals and that they probably thicken by intracrystalline seepage as has been shown for "normal" subaerial helictites, but they do not explain how hydrostatic pressure necessary for helictite growth can be achieved in a cave-pool environment. Subaerial helictites are almost always associated with carbonate coatings; upon cutting through these coatings water under considerable pressure is released (e.g., as when cutting through a calcite coating during trail construction, Caverns of Sonora, Texas; J. Burch, personal communication, 1989). Either that, or helictites form along the sides of a soda straw when the end of the straw becomes blocked and pressure builds up within the straw. Either way, a helictite begins growing as water is forced by pressure through the coating or straw wall.

In all of the 18 locations of subaqueous helictites in Lechuguilla Cave mentioned by Davis, Palmer, and Palmer, the helictites seem to be universally associated with shelfstone. Such pool shelfstone is not known for being a type of speleothem substrate on which helictites grow. Why would "water seep through pores in the shelfstone" (p. 77)? Why wouldn't it flow over the shelfstone and directly into the pool? How can shelfstone provide the hydrostatic pressure necessary for helictite growth? Why should water enter a cave pool as "discrete strands" (p. 70) or as "narrow, independent streamlets" (p. 77)? Does each helictite correspond to a "discrete strand" of water? And, even if water does enter cave pools in individual streamlets, how do these streamlets produce a central capillary canal within each helictite? In other words, how do the Lechuguilla Cave subaqueous helictites grow via their capillary canals? An explanation, with appropriate diagram, would be very helpful in understanding the mechanism by which these very unusual speleothems grow.

One final comment concerning the subaqueous speleothems of Lechuguilla Cave: in particular, the iron-oxide stalactites mentioned by Davis, Palmer, and Palmer. There are a number of Mississippi Valley-type sulfide gossan masses in the Guadalupe Mountains which are stratigraphically and structurally related to cave genesis (Hill, 1991). From the authors' description: "the leached bedrock is so heavily coated with a residue of iron oxide as to resemble weathered iron ore" (p. 85), it is suggested that sulfide minerals such as pyrite, sphalerite, or galena might be found in the vicinity of this probable gossan mass.

REFERENCES

Hill, C. A., and Forti, P., Cave Minerals of the world: Huntsville, Alabama, National Speleological Society, 238 p.

Hill, C. A., 1991, Sulfuric acid speleogenesis of Carlsbad Cavern and other caves in the Guadalupe Mountains: American Association of Petroleum Geologists Bulletin, v. 74, no. 11, p. 1685-1694.

Davis, Donald G., Palmer, Arthur N.—Extraordinary Subaqueous Speleothems in Lechuguilla Cave, New Mexico—Reply. *NSS Bulletin* 54: 34-35.

EXTRAORDINARY SUBAQUEOUS SPELEOTHEMS IN LECHUGUILLA CAVE, NEW MEXICO
REPLY

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Carol Hill raises valid questions about the origin of subaqueous helictites in Lechuguilla Cave. Most of the helictites are inactive, and the morphology of their capillary tubes is known only from a single fragment. Until that sad day when someone applies a chisel to the rim of shelfstone from which they emanate, little will be known about their internal workings.

It is possible to add a few details without speculating too wildly. Except for carbon-dioxide loss, the growth mechanism described in our paper agrees closely with that of Hill and Forti (1986, p. 44): "A porous rock face (usually covered with a thin carbonate coating. . . .) is required for the beginning of helictite growth. Hydrostatic pressure forces a small amount of solution out of a pore in the wall or coating, and carbon dioxide loss results in a thin carbonate film being deposited around the pore." High hydrostatic pressure may or may not be required for subaerial helictites, but it clearly is unnecessary for the subaqueous variety. In the latter, water moves through capillary tubes under small hydraulic gradients created by the slight elevation of the marginal slopes that supply the incoming water. Heads are rarely more than a few centimeters relative to the pool surface. Flow may be enhanced by density differences between the water in the tubes and in the pools, but their relative density may occasionally reverse and is more likely to determine only whether the helictites descend or ascend.

The most persistent question is not how water travels through the tubes, but why the helictites grow in elongate forms. Calcite appears to precipitate preferentially at the tube outlet, which implies that the necessary conditions are triggered by mixing between the tube water and the pool water. All water entering the pools is supersaturated with calcite, and uptake of gypsum would cause calcite to precipitate by the common-ion effect from that point on. Thus it is possible that water in the helictites has bypassed the gypsum blocks and that only the surficial flow into the pools has been enriched by gypsum. In this way, calcite deposition by water in the helictites would be delayed until the waters join at the helictite tips. Meanwhile the pool water and its surficial inputs precipitate a crust on all available surfaces, including the helictites. In the observed examples, the gypsum blocks are small isolated fragments that could very well have affected only certain parts of the water entering the pools. Testing of this hypothesis will require extremely precise chemical sampling, hampered by the dormant or inactive state of most subaqueous helictites.

As to how the helictite-forming water becomes divided into discrete strands, we suggest the following. When a thin sheet of gypsum-rich water flows into a calcite-saturated pool (or vice versa), the common-ion effect promotes the calcite growth where the two waters mix. This calcite initially forms shelfstone (or pool crust on walls beneath the surface). These deposits are at first rather porous, but continued growth reduces the size of the pores. As each orifice pinches down to capillary dimensions, calcite deposition is restricted to a ring around the poolward side of the opening. As flow continues through the pore, the zone of interaction moves farther from the wall, extending the ring into the cylindrical geometry of a subaqueous helictite. The length, width, and inclination of the helictites, which vary systematically between pools and between different parts of some pools, presumably reflect input flow rate and differences in ionic concentration of the interacting solutions.

The iron source above the "rusticles" seems to be an irregular lenticular mass within the reef limestone. Behind the iron-oxide coating is what appears to be bleached whitish limestone, not gossan material of ore grade. The iron may have been mobilized from sulfide minerals as the bedrock was corroded by ancient acidic condensation, but the visible surfaces are thoroughly oxidized, and if sulfides survive, they are hidden within the wall rock. To date, only one of the authors (Davis) has observed the iron source, and no samples have been obtained.

Similar calcite speleothems with iron oxide cores are found in Mystery Cave in Minnesota. Their forms, however, are clearly of subaerial origin, and they do not contain organic filaments. The source of iron oxide is pyrite bodies within the Ordovician Dubuque Limestone.

Since our paper went to press, the reported locations of subaqueous helictites in Lechuguilla Cave have increased from 18 to 20. Also, we wish to correct three errors overlooked in proof: Pellucidar is in the Western, not the Southwestern, Branch (p. 71); "Davis (1990)" on p. 86 should read "Davis (1989)"; and Figure 17 is a cross section of the soda straw in Figure 16, not Figure 15. Finally, we would like to thank the National Park Service and the explorers of the Lechuguilla Cave Project for their invaluable aid.

Guide To Authors

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