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Cover: Bone Cave. See Hubbard and Barber, page 154.

CONDENSATION CORROSION IN MOVILE CAVE, ROMANIA

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Condensation corrosion is the dissolution of carbonate by acidic vapors condensing above the water table. This process is rarely noted and receives little attention in the mainstream cave literature. The oolitic limestone walls in Movile Cave's upper dry passages are severely altered by a selective corrosion mechanism. Temperature differences between the water in the lower passages and the walls in the upper passages and high concentrations of CO_2 in the cave atmosphere create favorable conditions for condensation corrosion to take place. Carbon and oxygen stable isotope data support the hypothesis that condensation corrosion is the major mechanism currently affecting the morphology of Movile Cave's upper dry level.

Condensation corrosion is the dissolution of carbonate by acidic vapors condensing above the water table (Ford & Williams, 1989). This carbonate dissolution process is rarely noted and receives little attention in the mainstream cave literature (Jameson, 1991). The effects of condensation corrosion were reported from several non-thermal caves (Jameson, 1991; 1995) as well as from many hydrothermal caves which exhibit specific dissolution patterns (Bakalowicz et al., 1987; Cigna & Forti, 1986; Collignon, 1983; Palmer & Palmer, 1989). Cupola-form solution pockets have also been modeled as condensation corrosion cells (Szunyogh, 1984). It appears that condensation corrosion is a quantitatively important force of speleogenesis in semi-desert karst areas of Central Asia according to A. Maltsev (personal communication) as well as in the Mediterranean region (Pasquini, 1973). Several studies performed in caves developed in soluble rocks (i.e. gypsum), attempted to determine the amount of bedrock dissolved by condensation corrosion (Cigna & Forti, 1986; Calaforra et al., 1993).

The mechanism proposed for condensation corrosion is simple: water vapors condense when the temperature decreases reaching the dew point; drops of water or thin water films result when condensation occurs on walls; water drips from walls and ceiling if condensation rates are sufficiently large (Jameson, 1995); carbon dioxide from the cave atmosphere dissolves in the condensate to form carbonic acid [1].

$$CO_2 + H_2O \rightarrow H^+ + HCO_3^- \qquad (1)$$

Carbonic acid reacts with the carbonate bedrock forming bicarbonate [2] which is transported by the condensate as it drains down the cave walls.

$$2H^+ + CO_3^{2-} + CaCO_3 \rightarrow 2HCO_3^- + Ca^{2+} \qquad (2)$$

High concentrations of carbon dioxide in the cave atmosphere favor the production of large quantities of carbonic acid thus accelerating the process of limestone dissolution (James, 1994).

Movile Cave in southeastern Romania was discovered in 1986 when an artificial shaft intercepted a natural cave passage at the depth of 18 m below the surface (Lascu, 1989; Sarbu & Kane, 1995; Sarbu et al., 1996). It consists of an upper dry level (total explored length: 200 m) and a lower submerged level (total explored length: 40 m). For information on the location and detailed map of Movile Cave see Sarbu & Kane (1995). The cave is developed in oolitic and fossil-rich limestone of Sarmatian age (i.e., late Miocene, about 12.5 Ma) that contains numerous molluscan fossils (Lascu, 1989). Following the examination of the cave's morphology, Constantinescu (1989) concluded that the cave has a phreatic origin. He also pointed out that the upper level of the cave is extremely dry as a consequence of the lack of water infiltration from the surface and considered that the lack of speleothems is the effect of the dry climate in the region. (Average annual precipitation in southeastern Dobrogea is 350 mm). The lower level is flooded by thermal water (20.9°C) flowing at a rate of 5 l/s (Sarbu & Kane, 1995). The water contains significant amounts of sulfide (0.3mMol/l), ammonium (0.3mMol/l) and methane (0.2mMol/l). An abundant and diverse microbiota lives in the sulfidic waters and on the cave walls adjacent to the water (Sarbu et al., 1994). The food produced *in situ* by chemoautotrophic microorganisms supports a rich community of cave limited invertebrates (Sarbu et al., 1996). The atmosphere in Movile Cave is rich in carbon dioxide and depleted in oxygen (Sarbu & Kane, 1995). Hydrogen sulfide is present in the cave atmosphere in the lower level of the cave, but has not been detected in the upper dry cave level (Sarbu, unpublished).

In the upper dry level of Movile Cave, the surface of the cave walls is soft, and petrographic analysis showed that the bedrock is severely corroded (Horoi, 1994). Individual oolites detached from the cave walls by selective corrosion accumulate at the base of the walls (Horoi, 1994).

The current study was performed in the upper dry level of Movile Cave, located five meters above the water level. The experimental sites were chosen at distances of 15 to 45 m from the water surface. The cave passages in the upper dry level of Movile Cave have a cylindrical cross-sectional morphology and their diameter ranges between one and two meters.

The presence of corroded walls in the upper cave passages led to the hypothesis that condensation corrosion may represent the major limestone dissolution mechanism currently affecting the morphology of Movile Cave's upper dry level.

METHODS

Measurements of oxygen, carbon dioxide, and water vapor concentrations in the cave atmosphere were performed *in situ* using Draeger tubes and a Draeger hand pump. Gas samples, which were later analyzed by gass chromatography, were also collected in 50 ml glass vials sealed with Teflon lined rubber septa. These measurements were performed at three-month intervals between 1993 and 1996.

Temperature measurements of water, air, and cave walls were performed with an EXTECH digital thermometer. These measurements were performed at 15-day intervals for a period of one year.

Glass plates with an area of 200 cm^2 were suspended 10 cm from the cave walls and one meter above the passage floor in various locations in the cave to estimate the amount of liquid condensing on the cave walls. Plastic funnels placed under the plates collected the condensed water in containers for subsequent analysis. The amounts of condensate were determined each month and stable isotope measurements were performed.

Fluorescein grains were applied to the cave walls to visualize the movement of the condensate along the cave walls. Observations were performed at 30 day intervals.

A three-millimeter-thick stainless steel wire was used to measure the thickness of the soft, corroded layer of bedrock throughout the entire cave.

Samples of rock and of water collected in Movile Cave were sent to the Department of Geological Sciences, University of Michigan for carbon and oxygen stable isotope analysis. Samples of atmospheric carbon dioxide were analyzed at the Department of Geology, University of Illinois. Results are expressed as δ values. [Values of δ (per mil) are calculated as $X=[(R_{sample}-R_{standard})/R_{standard}]x10^3$ where X is $\delta^{13}C$ or $\delta^{18}O$ and R is $^{13}C/^{12}C$ or $^{18}O/^{16}O$. Standards are Pee Dee belemnite for carbon and oxygen. Precision of measurements was 0.2‰ or better.]

RESULTS AND DISCUSSION

The temperature of the water in the lower cave passage is 20.9°C. The temperature of the cave walls reaches 20.7 to 20.9°C in the lower level of the cave and 19.0 to 20.1°C in the upper level. Additionally, the floor of the dry cave passages is 0.2 to 0.3°C warmer than the ceiling due to the thermal flux (Figure 1) generated by the warm sulfidic reservoir. The air temperature ranged between 20.7 and 20.9°C in the lower cave passage, while in the upper cave passage the air was on average 0.5°C warmer than the cave walls. The warm vapor produced at the surface of the sulfidic lake (Figure 1) ascends along the cave passages into the upper cave level where it condenses on the cooler cave walls and especially on the ceiling. Amounts of 10 to 15 ml of condensate / 100 cm^2 / month were collected in several locations in the upper cave passage, supporting the above hypothesis. No seasonal variations were noticed in the amount of condensate collected. The upward movement of the warm and moist air from the lower to the upper cave level is slow and it is difficult to determine how much air ascends per unit time. Due to the decreased wall temperature, condensation is greater in the upper cave level and is lacking almost completely in the proximity of the lake where the cave walls are warmer. Through capillary movement, the condensate drains down along the walls at rates of up to 10 cm/month.

Compared to the surface atmosphere, the atmosphere in the upper dry level of Movile Cave is depleted in oxygen (reaching 19.5 to 20%), and is enriched in carbon dioxide (up to 1.5%; Figure 1). There are no local or seasonal variations in the chemical composition of the atmosphere in the upper cave level. The high levels of carbon dioxide in the atmosphere of Movile Cave accelerate dissolution by the condensed water on the surface of the limestone walls. Carbon dioxide in the cave atmosphere is isotopically light ($\delta^{13}C$ = -22 to - 24‰; $\delta^{18}O$ = +4.9 to 5.7‰; Figure 2) compared to surface carbon dioxide ($\delta^{13}C$ = -7.8‰), indicating that methane oxidation (Vlasceanu, unpublished) and metabolic activity of the cave biota (Sarbu et al., 1996) are the main sources of carbon dioxide in Movile Cave.

The superficial corroded layer of bedrock reaches a thickness of up to eight centimeters and consists of uncemented oolites. Due to preferential dissolution of the carbonate matrix (Horoi, 1994), oolites become detached from the wall and accumulate on the floor of the cave passage primarily at the base of the walls. Not being affected by condensation corrosion, the noncarbonate component of the bedrock accumulates on the surface of the corroded walls or may become detached and accumulate at the base of the walls along with oolites (Figure 1).

The deep limestone bedrock which has not been exposed to the cave atmosphere is isotopically heavy both for carbon and oxygen ($\delta^{13}C$= -2.6 to - 0.2‰; $\delta^{18}O$= 0 to 1.2‰; "A"s in Figure 2). The surface of the cave walls affected by corrosion and the detached oolites, as well as the boulders of bedrock lying on the passage floor are isotopically lighter than the limestone bedrock ("B"s and "C"s in Figure 2). The enrichment in light carbon isotopes of the bedrock exposed to the cave atmosphere may be the result of an interaction between the bedrock and the isotopically light CO_2, but the mechanism of this hypothetical

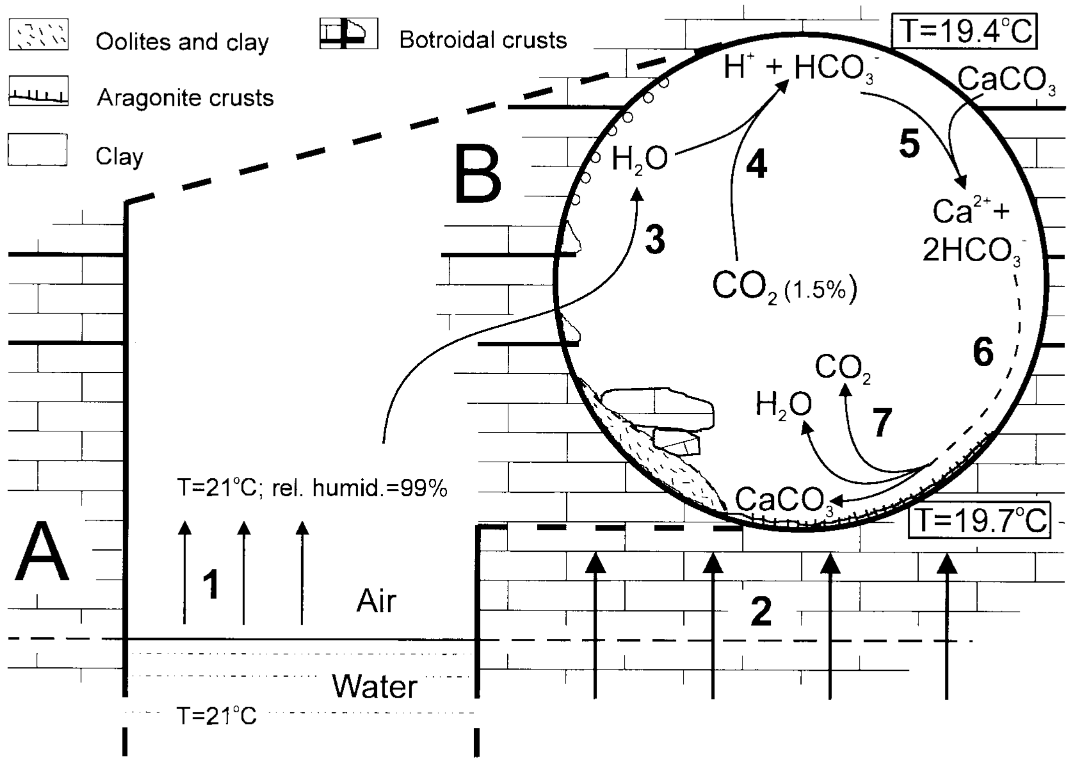

Figure 1. Schematic profile view of Movile Cave. A. Lower passage; B. Upper dry passage.
1.- Evaporation of water at the surface of the lake.
2.- Thermal flux through the bedrock.
3.- Condensation of water vapors onto the colder cave walls and ceiling in the upper cave passage.
4.- Dissolution of CO2 into the condensate and formation of carbonic acid.
5.- Reaction between carbonic acid and the carbonate bedrock with formation of bicarbonate.
6.- Transport of bicarbonate along the walls. 7.- Precipitation of aragonite crusts and dissociation of bicarbonate.

interaction is unknown.

Numerous botryoidal calcite crusts interbedded within the limestone (Diaconu & Morar, 1993) fill the fractures within the bedrock and appear to be more resistant to corrosion compared to the bedrock. They often protrude from the cave walls, forming small ledges on which the uncorroded limestone residue (i.e. clays) accumulates (Figure 1). Examination of the edges of these crusts shows that they are eventually affected by corrosion which transforms them into a fine white powder often found on the passage floor. The botryoidal crusts that are in contact with the cave atmosphere are also isotopically lighter than the bedrock ("D"s in Fig. 2).

The floor of the cave passage as well as the base of the walls are covered by carbonate crusts that consist of aragonite as the main mineral (Diaconu & Morar, 1993; Engel & Lascu, 1996). This work proposes that the water film covering the cave wall is loaded with bicarbonate when it reaches the floor of the cave passage. Upon reaching warmer temperatures and evaporative conditions at the base of the walls and at the floor of the upper passage, the capillary water approaches saturation with respect to calcite. Evaporation can actually drive the solution to supersaturation with respect to the more soluble aragonite. Magnesium ions present in the water inhibit precipitation of calcite, causing the aragonite to be the main precipitate, even though aragonite is more soluble. Bicarbonate dissociates as a consequence of aragonite precipitation [3].

$$2HCO_3^- + Ca^{2+} \rightarrow H_2O + CO_2 + CaCO_3 \quad (3)$$

The aragonite crusts are isotopically light both with respect to carbon and to oxygen ($\delta^{13}C$ = -16.6 to -21.4‰; $\delta^{18}O$ = -10.9 to -11.17‰; "E"s in Figure 2). This suggests that the bicarbonate generating the crusts results from the isotopically light carbon dioxide in the cave atmosphere ("F"s in Figure 2), the water vapor condensing on the cave walls ($\delta^{18}O$ = -41‰), and the isotopically light limestone bedrock. The very negative $\delta^{13}C$ values for the crusts also suggest a possible epigenetic interaction between the crusts and the light carbon dioxide in the cave atmosphere.

CONCLUSION

Carbon and oxygen stable isotope data support the hypothesis that condensation corrosion is the major mechanism currently affecting the morphology of Movile Cave's upper dry level. The peculiar morphology of the cave passages, the unusual temperature regime of this cave, and the high concentrations of CO_2 in the cave atmosphere favor the process of condensation corrosion. As supported in this work, water vapor is produced in the warm lower level of the cave, it ascends into the upper dry cave level condensing onto the cold cave walls. Carbon dioxide from the cave atmosphere dissolves in the condensate and forms carbonic acid. This reacts with the carbonate cave walls forming bicarbonate. The condensate containing bicarbonate is transported downward along the cave walls, reaching the warmer cave floor to precipitate aragonite. Water evaporates and CO_2 is released in the cave

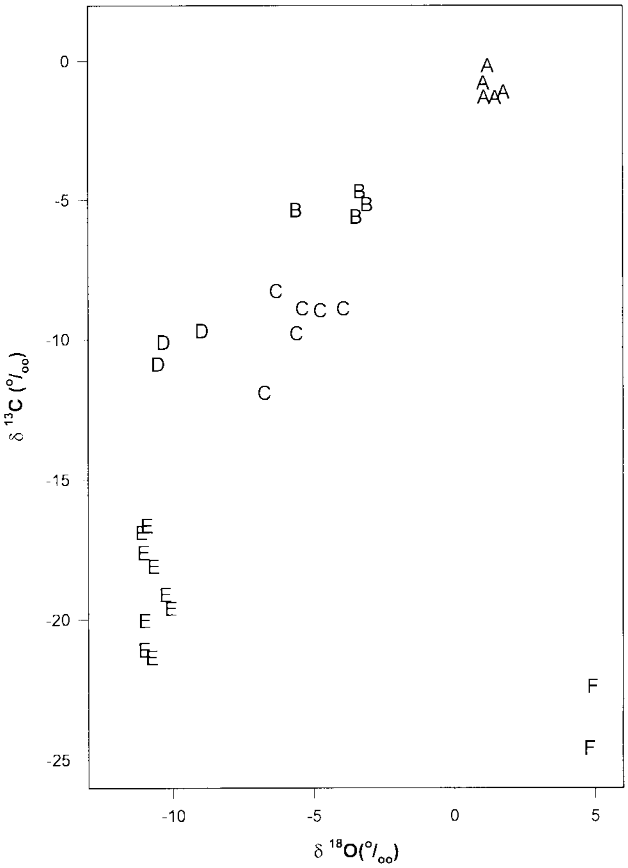

Figure 2. Carbon and oxygen stable isotope ratios in samples of carbonate and carbon dioxide from Movile Cave. A.- Limestone bedrock not affected by corrosion. B.- Corroded surface of passage walls and detached oolites. C.- Boulders of limestone bedrock lying on the passage floor. D.- Botryoidal calcite crusts filling the fractures within the bedrock. E.- Aragonite crusts covering the passage floor and the base of the walls. F.- Carbon dioxide from Movile Cave.

atmosphere.

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GENERATION OF CAVE AEROSOLS BY ALPHA PARTICLES: CRITICAL EVALUATION OF THE HYPOTHESIS

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The paper evaluates the feasibility of the hypothetical mechanism of cave aerosols generation under the action of natural radioactivity. Analysis has been performed from the standpoints of nuclear physics and aerosol mechanics. The hypothetical mechanism involves dislodgment of atoms and ions and knocking-out of larger fragments due to the bombardment of the bedrock by alpha-particles residing in the cave air. Calculations show that the largest amount of atoms and ions that could be generated by alpha-bombardment does not exceed 0.1 g from 1000 m² of the cave surface per 1 million years a quite negligible value. Presence of any water film thicker than 0.1 micron on the cave wall would completely prevent the dislodgment. The hypothetical mechanism, though physically plausible, cannot play any essential role in the generation of cave aerosols, and much less in the formation of speleothems.

The hypothesis about growth of certain types of speleothems from aerosols is becoming increasingly popular. One of the crucial problems with the aerosol mechanism is how does the speleothemic material (e.g., calcite or gypsum) get into the cave air and becomes an aerosol? The most intuitively comprehensible mechanism is the dispersion of water drops falling from a cave ceiling or generated by rapids and waterfalls in cave streams (Gadoros & Cher, 1986). This mechanism, however, is not applicable to many caves that do not contain any dripping or running waters. In 1994-1995 Klimchouk et al. published two papers (one in the *National Speleological Society Bulletin*) where, among other ideas, they discussed the possibility that cave aerosols are generated under the action of natural radioactivity. In the present article we will evaluate the feasibility of this hypothesis.

Four mechanisms of aerosol generation were suggested by Klimchouk et al. (Figure 1):

(1) Radioactivity (alpha, beta, and gamma) ionizes the cave air and the ions serve as condensation nuclei. Radon daughters can also behave as light ions and form molecular groups with water, oxygen, and other gas molecules, which can induce condensation.

(2) High-energy alpha particles formed in the cave air near the walls (zone 1 in Figure1) dislodge atoms and ions out of bedrock and these dislodged particles become aerosols.

(3) Alpha particles formed within the bedrock due to radioactive decay dislodge atoms and ions from a thin near-surface layer of the bedrock (zone 2 in Figure 1).

(4) Alpha particles knock out mineral fragments from the bedrock, generating small-size aerosol particles.

Now, let us quantitatively evaluate the possible contributions of each of these processes to the transfer of bedrock material into the cave air.

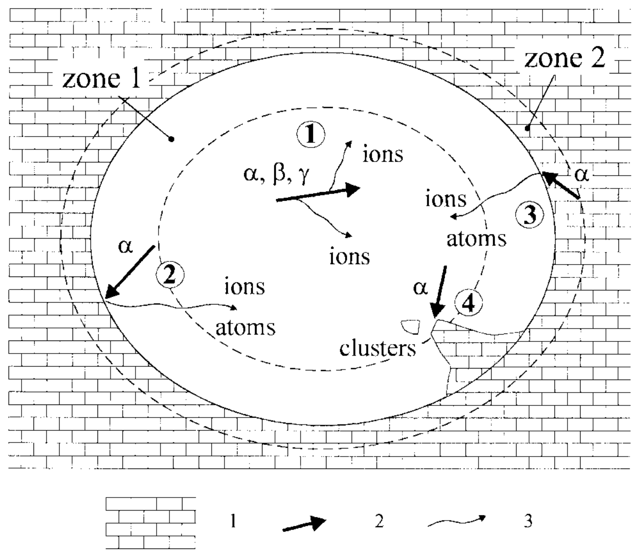

Figure 1. Processes responsible for generation of aerosols in caves by alpha particles as suggested by Klimchouk et al. (1995): 1 - bedrock; 2 - action of radiation; 3 - movement of atoms and ions. Numbers in circles correspond to the processes discused in the text. Zones 1 and 2 are explained in the text.

Process 1. Alpha particles, as they move through the air, create a dense chain of ions. The total number of ions created by a single alpha particle along its path (the mean free length for alpha particles in the air varies from 6 to 10 cm) reaches 10^5-$2\cdot10^5$ (Berthelot, 1948). Thus, in caves, where the radioactivity of the air typically varies from 10^4 to 10^5 Bq m^{-3} (Klimchouk et al., 1995), some 10^9-10^{10} pairs of ions are created in one cubic meter of the air every second. At high supersaturation levels these ions may serve as condensation nuclei for vapor present in the cave air, and thus, produce hydroaerosols. However, these supersaturation levels must be much higher than can be achieved in even the most humid cave in order for this condensation mechanism to become important (as in a Wilson cloud chamber). Also, as Klimchouk et al. admit, this process cannot play a significant role in the mass transfer of bedrock material because vapor in the cave air does not contain solutes.

Process 2. The number of atoms (n_{atom}) that can be dislodged by alpha particles out of bedrock may be defined as:

(1)

$$n_{atom} = B\frac{\pi}{8} N_{air} L_{air} St,$$

where B - is the number of atoms or ions dislodged by impact of a single alpha particle; N_{air} is the radioactivity of the cave air [Bq m^{-3}, or s^{-1} m^{-3}]; L_{air} is the mean free length for alpha particles in the air [m], S is the surface area of the bedrock exposed to radiation [m^2], and t is the time [s]. For further calculations we need to estimate B. Theoretically, its maximum value may be as high as 10^6. This number reflects a purely hypothetical situation in which the entire energy of the alpha particle (≈ 5 MeV) is spent for the dislodgment of atoms from a solid surface. In reality, however, such a situation is impossible because particles lose energy as heat and ionization while moving in the air and even more so in the near-surface layer of solids. As those losses are great (Radioactivity..., 1954; Novikov & Kapkov, 1965), the most conservative estimation would give B ≈ 10^3, which means that each alpha particle on impact with the cave wall can dislodge 1000 atoms of the bedrock material. Substituting of B = 103, $N_{air} = 10^5$ Bq m^{-3}, L_{air} = 0.1 m, S = 1000 m^2, and t = 1000 years in Eq. (1) gives for the number of dislodged atoms: $n_{atom} = 10^{20}$. In terms of the mass this corresponds to the removal of ≈ 0.01 g of the bedrock material from 1000 m^2 per 1000 years.

To enable aerosol mass-transfer it is necessary that atoms and ions are not only dislodged from the crystal lattice, but are also transferred into the cave air. Because of the quite-high diffusion mobility (≈ 0.05 cm^2 s^{-1}) of the atoms, the probability that such atoms will hit the wall and then get stuck back to it exceeds 99% (Foux, 1955). If this process of diffusion re-precipitation is taken into account, the proportion of dislodged material that can become aerosol is even less: ≈ 0.1 g from 1000 m^2 of the cave surface per 1 million years.

Process 3. Let us estimate how much material can be dislodged out of a cave wall surface by alpha particles formed due to radioactive decay inside the rock. The mean free length for alpha particles in solids varies from 20 to 50 microns (zone 2 in Figure 1), depending on density of solids. The radioactivity of the rock N_{rock} is defined as:

(2)

$$N_{rock} = \lambda_{Rn} C_{Rn}$$

where λ_{Rn} is the decay constant for radon [s^{-1}], and C_{Rn} is the concentration atoms of radon within zone 2 [m^{-3}]. Concentration of radon in the rock is described by equation (3) (Novikov & Kapkov, 1965):

(3)

$$C_{Rn}(x) = \frac{\lambda_{Ra} C_{Ra}}{\lambda_{Rn}}\left[1 - \exp\left(-\left(\frac{\lambda_{Rn}\eta}{D_{rock}}\right)^{1/2} x\right)\right]$$

where λ_{Ra} is the decay constant for radium [s^{-1}], C_{Ra} is the concentration of atoms of radium in the rock [m^{-3}], η is the porosity of the rock [parts of unity], D_{rock} is the coefficient of diffusion of radon in the rock [m^2 s^{-1}], and x is the distance from the cave wall into the rock [m]. Concentration of radon deep inside the rock (x = α) is defined as:

(4)

$$C_{Rn}(\infty) = \frac{\lambda_{Ra} C_{Ra}}{\lambda_{Rn}}$$

Measurements in different geological settings yield D_{rock}/η ranging from $5 \cdot 10^{-2}$ to $2 \cdot 10^{-4}$ cm^2 s^{-1}, and the upper estimates of radioactivity of the rock, N_{rock} (a), do not, normally, exceed $4 \cdot 10^6$ Bq m^{-3} (Novikov & Kapkov, 1965).

The final equation defining the number of atoms (ions) dislodged out of solid surface by alpha particles acting from inside the rock may be written as:

(5)

$$n_{atom} = N_{rock}(\infty)\frac{\pi}{8} StB_{rock}\int_0^\infty\left[1 - \exp\left(-\left(\frac{\lambda_{Rn}\eta}{D_{rock}}\right)^{1/2} x\right)\right]dx$$

For further calculations we need to estimate B_{rock}, which is the analogue of B in Eq. (1). In solids, the take-off of atoms and ions is only possible from a very thin near-surface layer less than 0.01 micron thick (which is the maximum free length of recoil atoms; Radioactivity..., 1954). The majority of alpha particles in zone 2 lose their kinetic energy well before reaching this zone (the energy being spent for heat and ionization). Analysis of energy losses (Radioactivity..., 1954; Novikov & Kapkov, 1965) gives the most reliable estimate of B_{rock} ≈ 1. It can be computed from Eq. (5) that the mechanism under consideration may disperse some 0.003 g of solid material out of 1000 m^2 of the cave wall per 1000 years. Taking into account diffusion re-precipitation (see discussion of process 2), the fraction of this material which can become an aerosol will be ≈ 0.000003 g. In other words, the hypothetical process 3 may generate approximately 0.003 g of aerosol from 1000 m^2 of the cave wall per 1 million years.

Process 4. Klimchouk et al. (1995) hypothesize the "knocking-out" of mineral fragments from cave walls by alpha particle bombardment. The essence of this hypothesis is as follows. The adhesion energy of a particle 0.1 micron in size is ≈ 0.1 MeV, whereas the energy of alpha particle is ≈ 5 MeV. Hence, the alpha particle may easily dislodge such a particle from the surface, and, given that the circumstances are favorable, can do the same to 50 more adhesion particles. It is assumed here, however, that the particles are already removed from a crystal lattice (by some unspecified process) and are attached to the bedrock surface by adhesion only. Much greater energy would be required to "knock out" such large particles from the lattice. Besides, using only the energy conservation law, the authors of the hypothesis failed to consider the actual physics of the process. Having energies far exceeding that characteristic of crystal lattice bonds, alpha particles interact mainly with atomic nuclei, dislodging or shifting them by no more than 10-20 nanometers. Those effects are well-known in nuclear physics (Radioactivity..., 1954), and the theory of diffusion and recoil was developed in the late 1930s (Flugge & Zimens, 1939). In particular, it has been demonstrated in the later work that the recoil atom may penetrate through the solid no more than 10 nanometers, and most of its energy is spent for melting of an area of similar size. Taking all that into account, process 4 also does not look possible.

In all of the above, we have discussed only the interaction of alpha particles with a DRY cave wall. However, due to the fact that caves almost always possess high humidities, it is quite typical of cave walls to be wet. As mentioned above, the mean free length for recoil atoms, clusters, and fragments created by impact interaction of alpha particles with solid surface does not exceed 100 nanometers: hence, any water film thicker than 0.1 micron would completely absorb them.

CONCLUSION

Ideally speaking, the mechanism of aerosol generation by dislodging particles out of bedrock under the action of natural radioactivity, as suggested by Klimchouk et al. (1994; 1995), is physically plausible. However, quantitative estimations show that this mechanism cannot play any essential role in the generation of cave aerosols, much less in the formation of speleothems. We would like to emphasize that this conclusion does not imply that formation of speleothems by an aerosol mechanism is impossible in principle, and we will discuss this possibility in a later article in the *Journal of Cave and Karst Studies*.

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J. Philip Fawley and Kenneth M. Long-Harlansburg Cave: The Longest Cave in Pennsylvania. *Journal of Cave and Karst Studies 59*(3): 106-111.

HARLANSBURG CAVE: THE LONGEST CAVE IN PENNSYLVANIA

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Harlansburg Cave is a network maze developed in the Vanport Limestone. The cave covers an area of approximately 200 meters by 200 meters, and 6647 meters of passage have been mapped. Typical passages are mud and water floored. Three pools in the southern portion of the cave were studied for their geological and biological characteristics. Geological studies indicate the cave to be a reservoir for water seepage from the overlying fields. The water is highly aggressive as a result of the overlying Kittaning Sandstone. Biological analysis indicate that the bacteria/actinomycete populations are the result of infiltration from the overlying fields. The exception is Hafnia sp. *which apparently arises from the raccoon population which frequents areas of the cave.*

The cave was discovered in October of 1950 as crews started to open a road cut west of the village of Harlansburg, PA (News, 1950a; Smith, 1970). As the blasting holes were drilled, numerous large voids were encountered 5-10 m below the surface. When the blasting charges were detonated, seven entrances were revealed. The local newspapers reported that the roadway appeared to have cut through the center of a cave system.

Newspapers published numerous features on this newly discovered natural wonder (News, 1950b; News, 1950c). The cave was reported to contain underground lakes, millions of bats, huge speleothems, vaulted rooms, bottomless pits and mud. The mud covering the floor of the cave was said to be a few centimeters to over a meter in depth. In several areas the mud was noted to be overlaid with up to one meter of water (News, 1952).

Soon after the cave was opened, hundreds of explorers attempted to enter the mysterious maze. Carl Leathers, a local resident and competent cave explorer, often discussed the poor state of preparedness of the amateur speleologists (Moody, 1966). Unfortunately, the reckless manner of early visitors led to vandalism, littering, and near tragedy.

On October 23, 1950, three explorers (12, 17, and 30 years of age) entered the cave. The trio became disoriented and as their flashlights dimmed they decided to wait for help. When their plight became apparent, a massive rescue ensued. Pennsylvania Power provided “a mile of wire to light the passages if the need arose.” A bloodhound was sent for by the local sheriff. Hundreds of well-meaning volunteers assisted in looking for the lost trio. After eleven hours the three explorers were found “1500 feet underground” and “2000 feet from the entrance” (News, 1950a).

On October 25, 1950, a group of scientists from Carnegie Museum entered the cave. Prominent in the group was John Guilday. They explored about “3600 feet into the maze” and placed Harlansburg as the “most outstanding [cave] in this part of the country” (News, 1950b). A second group of scientists from Kent State University entered the cave on October 30, 1950. Led by Dr. Elizabeth Smith, the group captured and banded several bats (News, 1950c). Attempts to locate records of these early studies have been unsuccessful.

The cave was officially closed the next weekend by Sheriff Coen despite requests from several groups to keep it open. He spoke of the dangers lying in wait for any explorer. Trips apparently continued to the cave over the next several years (News, 1952; Moody, 1966).

One local entrepreneur, Challice Bruce of New Castle, felt the cave was worthy of commercialization. He stated that if the mud could be removed, the cave had great potential. He started to map and photograph the cave. In May of 1952 he reported that the cave extended from Leesburg in the north to Rose Point in the south with the exposed Harlansburg’s entrances in the center of the maze (News, 1952). This description would mean the cave covered a distance of over eleven miles. Many residents still remember and believe these reports.

Challice Bruce is also remembered as “the founding father of the Mid-Appalachian Region of The National Speleological Society (White, 1990). After Mr. Bruce’s death, his widow gave his records, photographs, book collection, and memorabilia to a local high school. Unfortunately, these records were discarded by officials as space was needed for other materials.

The cave remained accessible and was frequently visited until 1966. Three inexperienced explorers precipitated a rescue that brought news media, onlookers, volunteers, and much unneeded anger from local officials (News, 1966a; Moody, 1966). Seven days after the rescue, the local highway superintendent, with reporters witnessing the event, poured concrete into the entrances. The cave was now officially closed.

In 1977, the authors began a systematic study of the cave. The cave is again open and traffic into the cave is moderate.

MAPPING

First trips into the cave revealed an intricate, mud-floored maze. The floors of the passages are typically soft mud (10-75 cm deep) covered with a layer of water (3-100 cm deep). Breakdown predominates in many sections of the cave.

The cave consists of essentially two portions separated by the road cut. Survey efforts concentrated on the apparently larger, southern section (Figure 1). The northern section has some highly unstable areas as a result of repeated attempts to seal these entrances by blasting.

Initial mapping trips were hindered by the complexity of the maze coupled with some erratic compass readings as a result of the magnetic properties of the overlying Buhrstone Iron deposit (White, 1976b). Although this layer is only a few centimeters thick, it complicated compass readings when survey teams inadvertently established mapping stations on pieces of magnetized former ceiling. The data were collected in the field using standard compass and tape techniques (Hosley, 1971). Multiple azimuths were taken from each station; any variation between forward and reverse measures necessitated resampling of that segment. Data were analyzed after each trip using a computer program designed by the authors.

The cave is a network maze with the larger passages running north to south from the entrance. These passages are up to four meters high in the eastern portion of the cave (average height of approximately two meters) and gradually diminish in height as you move towards the west. In is not uncommon to find high passages in certain portions of the western region of the cave. The east/west interconnecting passages are typically lower than the major north/south passages.

The first major accomplishment came with the completion of a survey of the cave's periphery. One hundred eighty stations were measured with a closure error of 1 meter for every 387 meters surveyed. The average sighting distance was 5.8 m. Ceiling heights ranged from 0.5 to 3.4 m with an average of 1.8 m. This loop established the approximate dimensions of the cave and allowed the authors to divide the remaining cave into workable sections. The mapping phase took seven years to complete. Over one hundred Westminster College students participated in the project. The Westminster Student Grotto, with the authors' guidance, made over 120 survey trips into the cave. This translates into 4800 hours expended in mapping "our" cave.

The cave has 6647 m (21808 ft) of passage contained in a area 200 m by 200 m. The general trend of the major passages is a 160 degree azimuth. The breakdown that litters the floor of the cave may be partially a result of the draining of the cave and the subsequent drying after opening (White, 1976b).

To the east of the entrance room are two prominent areas with an abundance of actinomycetes. The rooms have been labeled by early explorers as the "Glow Rooms" due to the reflectance of water condensed on these microbes. Although found in many areas of the cave, these two rooms have the largest population of these organisms.

Also, on the eastern side of the cave is Coon Heaven. This region is located about 100 m southeast of the entrance. The passages are 3-4 m in height and 2-3 m wide with the Kittaning Sandstone apparent in the ceiling. The floor is firm mud with a relatively smooth surface resulting from periodic flooding and draining of this region. As the name indicates, numerous raccoon tracks can be seen in the mud. The entrances for these animals from the outside are abundant but too small to allow human passage.

To the southwest 55 m, one encounters the Smoking Room region. The area was named by some earlier unknown explorer who wrote with a carbide flame on the wall. The passages are 2.5 m high and 2 m wide with a solid limestone ceiling. The floor is again firm mud. This area served as a base station during our mapping and, if located, can serve as a convenient way to easily find other regions of the cave.

To the west another 45 m is Carls Table. This room is characterized by a large flat piece of ceiling breakdown that sits prominently in the center of the room. The passages leading north from Carls Table enter the cave's largest room. This room's width is about five meters with a ceiling capped with Kittaning Sandstone. The ceiling height is approximately 5.5 m but the height is masked by the large quantity of breakdown on the floor. What has developed is a 5.5 m high room with a 3.5 m mountain of breakdown in the center.

The Ruby Room and Crystal Lake are another 60 m to the west. The Ruby room is named for its ferruginous dripstone and flowstone deposits (Long, 1981). The presence of the iron in these speleothems was verified by dissolving a small broken piece of speleothem breakdown in hydrochloric acid and performing a standard test for the iron ion. The bright red-orange speleothems are the most colorful in the cave. Next to the Ruby Room is a small passage (0.4 m high) that leads to a room with several undisturbed soda straws, stalactites, and stalagmites. These two areas contain most of the remaining speleothems in the cave. There is evidence that larger speleothems existed in the northwest section of the cave but only fragments survive the early collectors' removal of souvenirs.

Crystal Lake is a series of water-filled (0.5-1.2 m deep) passages which have an abundance of excellent crinoid stems in the walls and ceilings. North of Crystal Lake 75 m is the Hub Room complex. As the name suggests, several high passages radiate from this area. Ceiling height is about 2.5 m with several large *Lepidodendron* leaf fossils in evidence.

Just 20 m north of this region is the Catacombs. The name again results from an unknown caver's carbide lamp. The passages are 1.0-1.5 m high with an average width of 1.0 m. The floor consists of firm mud and the network pattern forms a small regular maze. Evidence exists in this area of significant speleothems. Unfortunately, all that remains are fragments too large for early explorers to have removed easily from the cave.

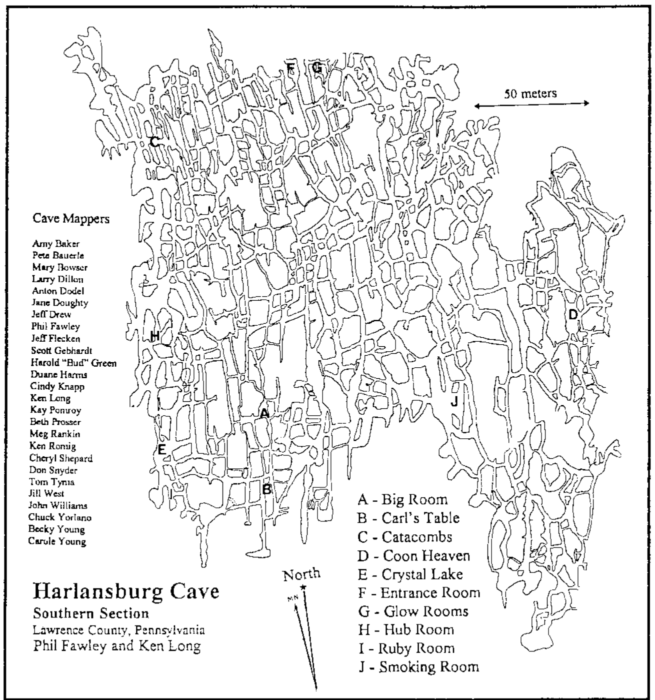

Figure 1. Map of Harlansburg Cave, Southern Section, Lawrence County, Pennsylvania.

GEOLOGY AND HYDROLOGY

Harlansburg Cave is formed in the Vanport Limestone (White, 1976). This is a dense gray formation in the Allegheny Group of the Pennsylvanian System (Poth, 1963). The Vanport Limestone has a low magnesium carbonate content, averaging 1.4% for a total of 18 samples in the Lawrence and Butler Counties (O'Neill, 1976). Silica averaged 2.8% and calcium carbonate 93.6%. Trivalent metal oxides averaged 2.2% in the 16 samples for which analyses were reported. Crinoid and brachiopod fossils are common.

Just east of the cave, where the village of Harlansburg is located, a stream channel has been cut through the Vanport Limestone and the underlying Clarion, Homewood and Mercer Formations. The bedrock in the stream is the upper Connoquenessing Sandstone (Poth, 1963).

In some locations in the cave, 10 to 20 cm of the Buhrstone iron ore, a limonitic iron ore (Poth, 1963), lie atop the Vanport Limestone while the iron ore appears to be missing in other places in the cave. Overlying the iron ore in this area is the Lower Kittanning Formation, a channel sandstone. The total thickness of the Kittanning and the overlying unconsolidated deposits ranges from 7.5 to 15 m in this locality. There are places in the cave where blocks of limestone breakdown have thin (two to five cm) Kittanning beds "draped" over them.

Where passages are wide (two to three meters), there is danger of breakdown of the Kittanning Sandstone. One member of a mapping team was narrowly missed by a block of rock weighing perhaps 40 to 50 kg. In a number of places, compression fossils and casts of plant stems are visible in the Kittanning ceiling and in blocks of breakdown. On the other hand, narrow passages tend to taper to a narrow fissure at the top and appear to be quite stable.

In the area where the cave is located, the thickness of the Vanport Limestone varies between 4.5 and 5.5 m (Poth, 1963). This and the experiences of the mapping teams contradict reports of a 90-foot (30 m) pit (Smith, 1970).

Maze development is typical of caves in the Vanport Limestone. Other examples are Brady's Bend Cave, Hineman Cave, Sarah Furnace (Porter's) Cave, Portersville Cave and Rose Point Cave (White, 1976). This common pattern of development has been attributed to seasonal fluctuations in the level of the streams draining the area. At high flow levels, water would be forced into the joint system and later drained when the stream level fell during late summer. This mechanism prevents the development of one trunk passage with few parallel passages. "The lack of high velocities and the moderated flow permits all joints to open uniformly thus developing the closely packed network of passages" (White, 1976). Here the main cave passages are approximately parallel to the stream channel at Harlansburg.

Although Harlansburg Cave is very wet, no large water inlets have been found. At times of heavy rainfall or snowmelt there is rapid dripping at many points in the cave. At such times the water level rises quite quickly and then falls more slowly. While the water level is high, water may be seen flowing within the cave. The observed flow has been to the west and north in the western half of the cave. In the east central part of the cave, no water movement has been observed while farther east there are gravel floors in some passages. This indicates that at some times flowing water must have removed the clay and mud that form the floor in other parts of the cave. About 63 m west of the entrance, water that has moved north and west reaches a drain where it flows underneath the side wall of a passage.

HYDROLOGY STUDY

To further characterize the cave, two pools were selected for study of their water chemistry and microbial content (Long & Fawley, 1981). Carls Table Pool is located next to a large flat-topped block of limestone breakdown located 115 m south of the entrance (Figure 1). An overhanging ledge protects the adjacent pool from casual intrusion by cavers. When near its low level it has an area of about 7 to 8 m^2 and has a reverse "J" shape. The average temperature of this pool is 9.8 ± 0.1ºC.

Crystal Lake, about 130 m south-southwest of the entrance, is much larger with a surface area of about 175 m^2, extending through approximately 128 m of passages. Occasionally the water is stirred up by cavers who walk through its cold (average temperature 9.4 ± 0.1ºC) waters that are up to 1.0 m deep. The walls of the passages are nearly vertical so that the area occupied by the lake does not change very much when the water level changes.

In each pool an arbitrary reference point was established so that water levels could be measured without entering the water. All levels in Figure 2 are based on the reference point in Carls Table Pool. On sampling trips, the pH of the pool waters was determined (Long & Fawley, 1981). The pH of a sample of water which was removed and saturated with excess recrystallized calcium carbonate was also determined (Picknett, 1964). In addition, pairs of water samples were collected from each pool. One sample in each pair was saturated with excess calcium carbonate. Each pair was then analyzed for total calcium (as $CaCO_3$) by EDTA titration. (For tables of data, see Long & Fawley, 1981.)

Since the water levels in the pools varied during the study period, the question arose as to how these water levels were related to ground water levels. Ground water data from USGS well number 1201 (latitude 41º05’38”N, longitude 80º28’08”W), the USGS well nearest the cave, were obtained from the Pennsylvania Geologic Survey as a computer printout. The data are expressed as depth below the land surface to the surface of the water in the well. The water level showed large fluctuations during the period from February 1979 to September 1979 with a range of 150 cm. The level tended to fall during the study period (Figure 2).

The water levels of both pools varied but also tended to decrease during this time span. However each cave pool varied over a much smaller range than the water table as measured in the USGS well during this time, a range of 28.4 cm for Carls Table Pool and a range of 14.8 cm for Crystal Lake. Since the pool levels were measured from a reference point below the surface of the pool, a low level was indicated by a smaller measurement. On the contrary, a low water level in the well was indicated by a larger measurement. Thus, the data show a negative correlation coefficient, -0.8740 for Carls Table Pool (Long & Fawley, 1981).

Water levels in the cave increase rapidly during the spring thaw or if there is continued heavy rainfall. When water levels fall, they do so more slowly. Evaporation in this environment is minimal. Clearly in the case of Carls Table Pool the major way in which water can leave is by slowly seeping through the clay that forms the sides and bottom of the pool. Probably the same is true of the much larger Crystal Lake except during very high water levels when flow to the north has been observed.

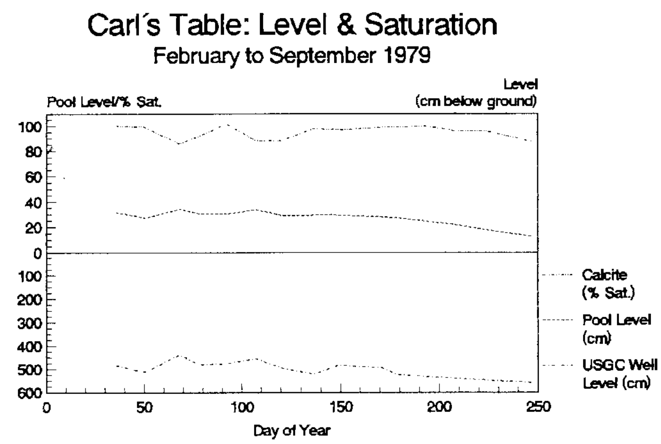

Figure 2. Carls Table Pool Level and Percent Saturation as Compared with USGS Reference Well.

From the titration data, the ratio of the concentration of calcium carbonate in the pool waters to the concentration of the paired saturated sample was determined and expressed as a percent. A graph of these data is shown as Figure 2. (Again, Crystal Lake data are very similar so only one graph is presented.) When the water levels rose sharply, the concentration of $CaCO_3$ fell as would be expected if the added water diluted the water in the pools. This water was much more aggressive as indicated by larger amounts of calcium carbonate required to saturate the paired samples. Since very little limestone lies over the cave in these pool areas, little additional calcium carbonate can be dissolved by the entering water.

As the water level falls, the concentration of $CaCO_3$ increased, but the water actually became a bit more aggressive as indicated by somewhat larger increases in the amount of $CaCO_3$ required to saturate the water. Thus, the percent saturation fell slightly. The higher concentrations of $CaCO_3$ in the water can be explained if there is some dissolution of the limestone that is in contact with the pool water. These changes cannot be due to loss of CO_2 from the pool water.

Microbiology Study

Despite a paucity of nutrients and other biotic factors in caves of this region, a wide variety of organisms have been described in cave environments throughout the world. In Harlansburg Cave, the authors have encountered larger troglophilic/trogloxenic animal life such as salamanders, bats, meadow voles, earthworms, and raccoons.

The basal trophic levels of this cave’s environment were investigated for this project. Specifically studied were the microbe populations of three pools within the cave. These pools were determined appropriate for study by the work of Hale (1980). Samples were taken from the Carls Table pool and Crystal Lake. In addition, water was collected from a pool near Coon Heaven.

All samples were collected in sterile sampling bottles as soon as the area was approached so as to allow for minimal contamination of the area. Care was taken not to agitate the pool or touch the water with clothing or body. The water was removed from the cave, kept cool during transit, and sampled for analysis within four hours after collection.

One milliliter aliquots were removed, serial dilutions made, and transferred to a series of agar plates. Nutrient agar (Difco Laboratories) was used for bacterial culture. (Buchanan, 1974) Actinomycetes were grown on a starch casein agar (Difco Laboratories) with 20 units/mg penicillin and 40 micrograms/ml streptomycin (Johnson, 1972). Bristol’s agar (Difco Laboratories) was used for the isolation of algae (Starr, 1950). All plates were incubated at 37ºC with the algal plates placed under fluorescent lighting.

Preliminary counts indicated that the Coon Heaven samples had the highest bacterial counts on any sampling day. The raw data indicated a range of 890-4100 cells per ml of water. The actinomycete counts typically varied from 1-160 cells/ml of water. No algae were detected in any Coon Heaven sample.

Crystal Lake samples yielded lower counts for bacteria (820-2400 cells per milliliter) and actinomycete (1-140 cells per milliliter). Algae were not detected in any sample.

Carls Table had the lowest counts of the three areas studied. Bacterial counts ranged from 35-1050 cells per milliliter. Actinomycete counts were quite low at 0-12 cells per milliliter. Again, no algae were detected in any sample.

In an attempt to characterize the bacterial samples further, subcultures were made of the plated samples. A total of seven distinct colony types were noted in the samples collected. The individual colonies were then subjected to a series of presumptive and confirmatory tests to determine their identity (Johnson, 1972; Buchanan, 1974). The tests used are listed in Table 1.

Table 1. Tests applied to characterize the individual bacterial colonies collected from Harlansburg Cave. Each trial was run using standard qualitative procedures (Buchanan, 1974; Johnson, 1972).

Bacterial Characterization

Gram Reaction
Morphology

Fermentation Reactions	**Specific Enzyme Systems:**
Glucose	Malonate Utilization
Lactose	Phenylalanine Deaminase
Sucrose	Beta-D-Galactosidase
Salicin	Indole Production
Adonitol	Hydrogen Sulfide Production
Inositol	Lysine Decarboxylase
Sorbitol	Ornithine Decarboxylase
Arabinose	Urease
Maltose	Arginine Dihydrolase
Trehalose	Citrate Utilization
Xylose	

The identities of the seven colonies are given in Table 2. Six of the colonies are typical soil bacteria and could have entered the water by percolating through the overlying strata or carried into the area by various organisms (Caumartin, 1963; Johnson, 1972). The seventh colony was identified as *Hafnia ssp*. This organism is commonly found in feces of mammals. Since the field above the cave has not been used for grazing or farming and few bats were observed in these areas, the authors believe the existence of *Hafnia* was due to the raccoon population in the cave.

Based on the large number of raccoon tracks and the consistent finding of *Hafnia* in the water samples, it appears there is a southeast entrance to the cave system. During the mapping, several small passages were noted at the cave's southeast margin. These are separated by less than 30 meters of limestone from the limestone outcropping east of the cave complex. None of these would allow human passage but a raccoon would experience little difficulty.

The bacterial counts did relate to changes in the water level of Carls Table and Crystal Lake. The counts appeared to rise when moderate to heavy rainfall occurred. We concluded that the source of the bacterial and actinomycete contamination was from water seeping into the cave from the overlying strata and the mammals which frequent the cave (Long, 1981).

The lack of algae in any plated sample would indicate that the flow from the surface to the cave pools was sufficiently slow as to allow for the destruction of any photosynthetic organisms (Johnson, 1972).

Table 2. The identification of the seven bacterial colonies cultured from water samples taken from Harlansburg Cave (Johnson, 1972; Buchanan, 1974).

Microbe Identification
Micrococcus roseus
Streptococcus ssp.
Arthrobacter ssp.
Enterobacter aerogenes
Bacillus subtilus
Pseudomonas ssp.
Hafnia ssp.

CONCLUSIONS

Harlansburg Cave is a network maze with a generalized north/south orientation of the major passages. The evidence available to the authors indicates that the southern part of the cave, described in this paper, is larger than the unmapped northern part. At least part of the northern section could be mapped, although some areas appear to be quite hazardous due to possible breakdown. Geological studies indicate that the cave is currently a reservoir for the water seepage from the overlying fields. The biological data indicated that the bacterial populations in the three pools studied were primarily of seepage origin. The exception was *Hafnia,* which appears to arise from raccoon fecal contamination. Invertebrates and vertebrates have been observed but not systematically collected and identified.

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HYDROCHEMOGRAPHS OF BERGHAN KARST SPRING AS INDICATORS OF AQUIFER CHARACTERISTICS

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Berghan Spring is located in the southern part of Iran, northwest of Shiraz. The catchment area of the spring consists of the southern flank of the Gar Anticline, which is made up of the karstic calcareous Sarvak Formation. There are no sinkholes or other karst landforms in the catchment area. Because of the existence of several faults, the aquifer has been brecciated and may have caused karstification to occur in most of the pores and fissures. The specific conductance, pH and water temperature were measured once every twenty days for a period of 32 months and water samples were analyzed for major anions and cations. Flow rate was measured daily during the recession, and once every three weeks during the rest of the study period. Using the WATEQF computer model, the partial pressure of carbon dioxide and the saturation index of calcite and dolomite also were estimated. Three distinct periods, the first recession, the second recession, and precipitation, were observed in the hydrograph of Berghan Spring. No considerable differences were observed between the first and second recession coefficients. Base flow constitutes 71.5%, 100% and 66.2% of total flow in the first recession period, the second recession period and the precipitation period, respectively. The variation of specific conductance, calcium and bicarbonate concentrations and calcite saturation indices are not significant during the study period, implying that aquifer characteristics control the chemical behavior of the spring. The morphology and geology of the Berghan Spring catchment area, and data from hydrographs and chemographs, show that the hydrologic system is dominantly diffuse flow. Evidence for this is shown by autogenic recharge, a brecciated aquifer, and small values and slight differences in hydrograph recession coefficients. In addition, specific conductance, calcium and bicarbonate concentrations, and water temperature did not show significant variations during the study period suggesting a diffuse flow aquifer.

Studies have been conducted during the last three decades on the variations of physical and chemical properties of springs in order to understand the hydrogeological behavior of karst aquifers. Such studies generally began with the work of Garrels and Christ (1965) in which underground flow in carbonate rocks was divided into open and closed systems. In an open system, there is no limit on the amount of carbon dioxide available for the dissolution of calcium carbonate, whereas in a closed system, once the available carbon dioxide is used up, the dissolution of limestone terminates. Zötl (1960), and Smith and Mead (1962) used the time variations of chemical parameters to identify hydrogeological characteristics of karstic aquifers. White and Schmidt (1966) and White (1969) divided the flow in karstic aquifers into conduit and diffuse systems, based on spring behavior. Shuster and White (1971) made the same division based on time variations of temperature, specific conductance, and calcium, magnesium, and bicarbonate concentration. Newson (1972) and Ternan (1972) confirmed this division. Jacobson and Langmuir (1974), in their studies in Pennsylvania, divided karst flow systems into conduit, diffuse-conduit, and diffuse.

In a diffuse system, laminar flow occurs through interconnected fissures smaller than one centimeter. In this type of system springs are generally numerous and have small discharges. Diffuse flow is relatively uniform through the aquifer and there is small variation of physical and chemical properties in the springs. A diffuse system is mostly fed directly from carbonate rocks and the soil covering these rocks. The coefficient of variation of total hardness in diffuse flow is less than 5% and few karst geomorphological features are present in the catchment area of these springs. Turbulent flow occurs in conduits ranging from one centimeter to more than one meter and the groundwater generally discharges through one large spring. Specific conductance and other physical and chemical properties are non-uniform in conduit systems. Conduit systems are fed through sinkholes and solutional joints in bare rocks. The coefficient of variation of total dissolved solids ranges from 10 to 24%.

Bakalowicz (1977) suggested that the structure of a karst aquifer cannot be defined from the coefficient of variation of chemical variables, as was suggested by Shuster and White (1971). Atkinson (1977) also noted that the very small range in calcium carbonate concentration in resurgences from the Mendip Hills, England, would suggest that they are diffuse flow springs according to Shuster and White's criteria, yet are known to be fed largely by conduit flow. He concluded that flow in carbonate aquifers is a combination of diffuse and conduit systems and divided them into "quick" flow and "slow percolation" flow according to velocity. Scanlon and Thrailkill (1987), using the suggested criteria by previous workers, carried out a comprehensive study of conduit and diffuse regimes in the Inner Bluegrass of central Kentucky. Their results were not consistent with those of previous workers and indicated that spring water chemistry could not be related to the physical characteristics of karst aquifers in this area. Raeisi et al. (1993) attempted to determine the Sheshpeer

Spring flow system using criteria proposed by various authors, but obtained contradictory results.

Seasonal variation in water temperature is another criterion that may be used to distinguish diffuse and conduit flow. When water flows turbulently through large conduits in a karst aquifer, spring temperature is affected by atmospheric temperature. When water flows slowly through small joints, as in a diffuse-flow system, however, spring temperature is not affected by atmospheric temperature variations because it is dampened by rock mass temperatures. Cowell and Ford (1983) found the water temperature deviation to be 5.9ºC in conduit springs and 1.32ºC in diffuse springs on the Bruce Peninsula, Ontario, Canada. Ede (1973), in a one year survey of the South Wales region of Great Britain, found the temperature of conduit springs to range from 6.5ºC to 11ºC and that of diffuse springs to vary from 10.9ºC to 11.1ºC.

The shape of the outflow hydrograph of a spring is a unique reflection of the response of an aquifer to recharge. Broad reviews of this subject have been given by Ford and Williams (1989). The analysis of spring hydrographs offers considerable potential insight into the structure and hydraulics of karst drainage systems and is further improved if the hydrographs are analyzed with corresponding chemographs. Bakalowicz and Mangin (1980, quoted from Ford and Williams, 1989) showed how the degree of heterogeneity of karst aquifers may be deduced from hydrograph and chemograph data. Raeisi and Karami (1996) suggested that if the physicochemical characteristics of a karst spring are to be used to determine the properties of the corresponding aquifer, the effect of external factors on the outflow should be evaluated first, and then the characteristics of the karst aquifer should be determined.

The objective of this study is to use hydrochemographs of the Berghan karst spring along with knowledge of the local geology to determine some of the aquifer properties, including the type of flow system. An attempt is then made to propose a probable model of groundwater flow in the Berghan aquifer.

HYDROGEOLOGICAL SETTING

The study area is located 80 km northwest of Shiraz, in southern of Iran. This region is situated in the Zagros thrust zone. Geologic formations in decreasing order of age are the Hormuz (Palaeozoic), Khami Group (Lower Jurassic-Albian), Kazhdomi (Albian-Cenomanian), Sarvak (Albian-Turonian), Pabdeh-Gurpi (Santonian-Oligocene), Asmari-Jahrum (Paleocene-Miocene), Razak (Early Miocene), and Bakhtiari (Late Pliocene-Pleistocene) (Figure 1). The detailed lithology of these formations is described by James and Wynd (1965), and Stocklin and Setudehina (1977).

The Barm-Firooz and Gar Anticlines (Gar Mountain and Mor Mountain) are situated on the general northwest trend of the Zagros Mountain Range. The cores of the anticlines are comprised of the calcareous Sarvak Formation (Albian-Turonian) which is sandwiched between the two impermeable Kazhdomi (Albian-Cenomanian) and Pabdeh-Gurpi

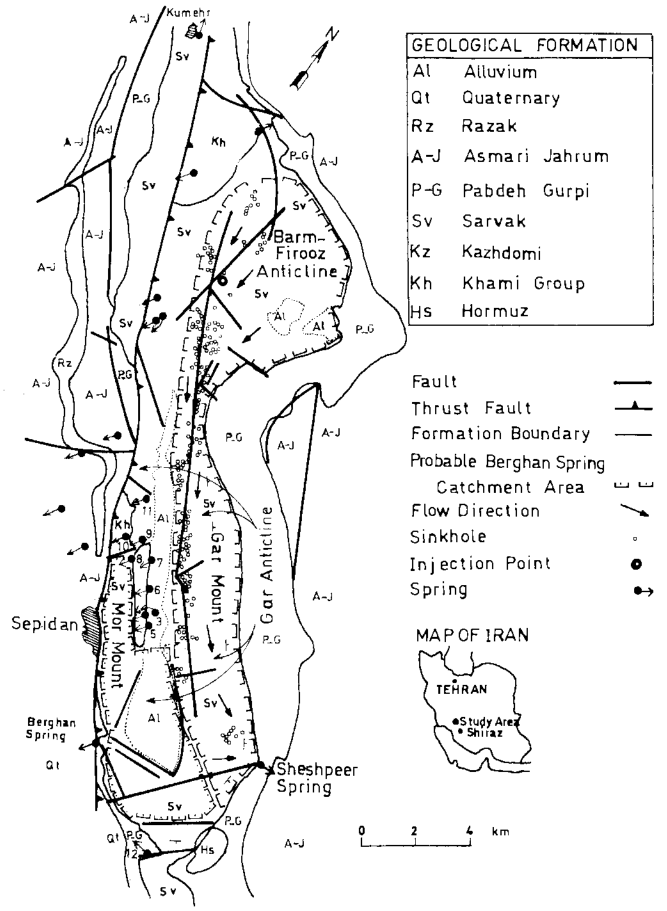

Figure 1. Hydrogeological map of the study area (after Raeisi & Karami, 1996). Razak (Early Miocene), Asmari-Jahrum (Paleocene-Miocene), Pabdeh-Gurpi (Santonian-Oligocene), Sarvak (Albian-Turonian), Kazhdomi (Albian-Cenomanian), Khami Group (Lower Jurassic-Albian), Hormuz (Paleozoic).

(Santonian-Oligocene) Formations (Figure 1). The most important tectonic feature in the study area is a northwest trending thrust fault (Figure 1). The southern flank of the Gar anticline (Mor Mountain) has been completely crushed. A cross section (Figure 2) shows the geological setting of the study area. The hydrogeological relationship of northern flank and southern flank of both anticlines has been disconnected by the action of thrust fault and impermeable Kazhdomi Formation.

Groundwater from the Sarvak aquifer discharges from 12 small and large springs, 11 of which, including Berghan Spring, emerge from the southern flank of the anticline, and one large spring (Sheshpeer Spring) emerges from the northern flank. Table 1 shows the elevations, mean annual discharges, and specific conductance (Spc) of these springs. The mean annual discharge of Sheshpeer and Berghan Springs is 3247 L/sec and 632 L/sec respectively, while the mean annual discharge of the other springs ranges from 1.41 to 68.3 L/sec. The probable catchment area of Berghan Spring is about 19 km^2

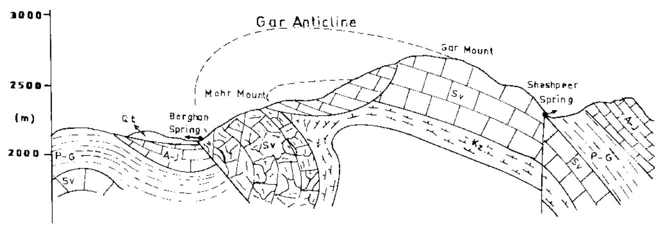

Figure 2. Geological cross section between Berghan and Sheshpeer Springs. Qt = Quaternary, A-J = Asmari-Jahrum Formations (Paleocene-Miocene), P-G = Pabdeh-Gurpi Formations (Santonian-Oligocene), Sv = Sarvak Formation (Albian-Turonian), Kz = Kazhdomi Formation (Albian-cenomanian). From Raeisi, et al., 1993.

(Pezeshkpoor, 1991). This catchment area is part of the southern flank of the Gar anticline (Figure 1). Dye-trace studies by Zare and Raeisi (1993) showed that water from the northern flank of Barm-Firooz anticline discharges only from Sheshpeer Spring, thus confirming the estimated boundaries of the Berghan Spring catchment area. Several normal faults and one thrust fault have resulted in an extensive brecciated zone in the catchment area of Berghan Spring (Figure 2). No sinkholes, pits, shafts, or caves are present in the catchment area of Berghan Spring. Forty percent of the catchment area is covered by soil (Karami, 1993).

Berghan Spring has one main, and two smaller resurgences, named the Eastern, Central, and Western emergences, respectively. The distance between the Central emergence and the Eastern and Western emergences is one and three meters respectively, and the elevation of the three emergences is almost the same. The Eastern, Western, and Central emergences discharge about 70, 25, and 5% of the total discharge, respectively. The average annual precipitation at Berghan Station, elevation of 2110 m, is 700 mm. The elevation of Berghan Spring is 2145 m and the catchment area is as high as 2500 m, thus precipitation in the catchment area is considerably greater. Precipitation occurs mostly in winter and in the form of snow, but most of the snow cover is melted by early April. There is no precipitation during late spring and summer.

Table 1. Elevation, mean annual discharge, and specific conductance of the karst springs of Sarvak aquifer (after Raeisi et al., 1993).

Spring Name	Number on Figure 1	Elevation meters	Mean Annual Discharge (liters/sec)	Specific conductance microsiemens/cm
Sheshpeer	1	2335	3247.00	268.60
Berghan	2	2145	632.00	254.45
Sib	3	2480	34.31	232.01
Saro	4	2427	39.89	263.64
Masjed	5	2415	3.48	275.55
Seileh	6	2492	2.25	191.61
Ghanat Sefid	7	2544	21.82	188.45
Targeh	8	2468	4.17	366.45
Baladan	9	2495	1.41	259.11
Pariz	10	2483	9.28	303.45
Dobardak	11	2714	35.70	247.36
Morikash	12	2120	68.34	278.36

METHOD OF STUDY

The specific conductance, water temperature, and pH of the three emergences of Berghan Spring were measured on site, and the major ions (calcium, magnesium, potassium, sodium, bicarbonate, sulfate, and chloride) were determined in the laboratory from samples collected once every twenty days from June 1991 to November 1992. Data obtained by Pezeshkpoor (1991) from March 1990 to June 1991 also were used. Calcium, sodium, and potassium concentrations were determined using flame photometric methods, bicarbonate by standard titration, chlorine by the Mohr volumetric method, and sulfate by turbidimetry in the hydrochemical laboratory of Geology Department, Shiraz University.

Carbon dioxide partial pressure (P_{CO_2}), calcite saturation index (SI_c), and dolomite saturation index (SI_d) were estimated using the WATEQF model (Plummer et al., 1976).

Spring flow rates were measured daily from March to September in 1990 and 1992, but only once every three weeks during the rest of the study period. Discharge measurements were not possible in every emergence of Berghan Spring; therefore total discharge of the spring was determined.

RECESSION COEFFICIENTS OF THE AQUIFER

The hydrograph of Berghan Spring from June 1991 to November 1992, shown in Figure 3, may be divided into the first recession, the second recession, and the precipitation time periods. The first recession period starts with a decrease in discharge of the spring and coincides with the period when rainwater and snowmelt infiltrates into the aquifer. During this period, the groundwater level is relatively high, and due to the steep hydraulic gradient, water discharges at a higher rate. The second recession period coincides with the dry season when no recharge from rain or snowmelt occurs. The precipitation period starts with the beginning of rainfall and an increase in discharge.

The hydrograph data of Figure 3, were plotted on semi-logarithmic graph paper and the recession coefficients (α) were evaluated as:

(1)

$$\alpha = (\log Q_2 - \log Q_1)/0.434t$$

where Q_2 is the discharge in cubic meter per second ($m^3 s^{-1}$) at time t_2 (day); Q_1 is the previous discharge at time t_1; t is the time elapsed between Q_1 and Q_2. The recession coefficients of Berghan Spring are presented in Table 2. Because discharge was not measured daily in 1991, the recession coefficients were only estimated for 1990 and 1992 when daily data were

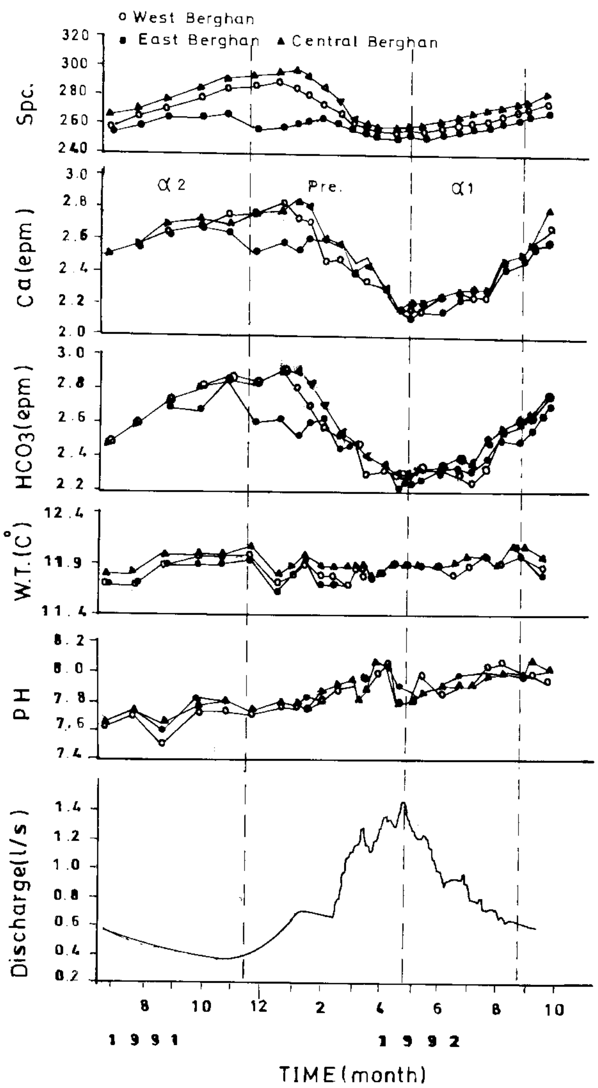

Figure 3. Hydrochemographs of Eastern, Western and Central emergences of Berghan Spring from June 1991 to November 1992 (Spc. = Specific conductance in microsiemens/cm, epm = equivalent per million, W.T. = Water Temperature in degrees Celsius, l/s = liters per second, α_1 = first recession period, α_2 = second recession period, Pre. = Precipitation period.

available. The first and second recession periods almost coincide with the elapsed time (t) of recession coefficients a_1 and a_2 respectively, considering the delay time between recharge and discharge. Even though the recession coefficients are smaller for the second recession period than the first recession period, the differences are not significant. The small values result from the delayed or prolonged response of the spring due to the crushing action of several normal faults and a thrust fault in the Berghan aquifer. Evidence for this also is indicated by the extensive breccia observed on the surface of the Berghan Spring catchment area. The crushing of limestone layers has resulted in a dense network of pores, small fissures, and joints that have inhibited the development of large conduits. Using the Berghan Spring hydrograph, the percentages of base flow and quick flow were determined by hydrograph separation techniques for the precipitation, first and second recession periods (Table 2). Base flow makes up at least 66.2%, 70.1% and 100% of the total flow in the precipitation, first recession and second recession periods, indicating that a diffuse flow system characterizes the Berghan Spring aquifer.

The small differences between the first and second recession coefficients could be related to the hydraulic behavior of the aquifer system and the ability of the porous media to retain water. Three different hydrologic zones are recognized in karst aquifers (Ford & Williams, 1989). Zone 1 (phreatic) is located beneath the low water table, and feeds the spring throughout the year. Zone 2 (shallow phreatic) is restricted to the lowest and highest fluctuation levels of the water table. The contribution of this zone to spring discharge is dominant during the precipitation and first recession periods. Zone 3 (subcutaneous or epikarst) is the vadose zone above the water table level. The thickness of this zone is dependent on water table fluctuations. Water from rain and snowmelt stored in this zone gradually percolates to the phreatic zones below (zones 1 and 2). As mentioned previously, small differences in the first and second recession coefficients (α_1 and α_2) are not due to the type of flow. The slightly higher discharge gradient during the a_1 period is caused by the slower rate of water table level drop. This slower drop during the first recession period may be explained by: first, a continuous recharge from rainfall and snowmelt; second, rapid drainage through larger fissures and pores of the vadose zone.

Table 2. Recession coefficients and percentage of base flow and quick flow of Bergham Spring.

Year	Period	Recession coefficient	Base Flow %	Quick Flow %
1990	1st recession α_1	.0056	72.9	27.1
	2nd recession α_2	.0041	100.0	00.0
	precipitation		66.2	33.8
1992	1st recession α_1	.0064	70.1	29.9
	2nd recession α_2	.0032	100.0	00.0

HYDROCHEMISTRY OF THE SPRING

Table 3 shows the minimum, maximum, and average physicochemical properties of Berghan Spring in the Eastern, Central and Western emergences. The average specific conductance, and calcium and bicarbonate concentrations increase in the Eastern, Western and Central emergences, respectively, suggesting that these emergences have three different flow routes. This has been confirmed by the geoelectrical studies of Nakhei (1993). The Eastern Spring, with its high flow rate, is probably fed by larger fissures and pores. Because of the short

Table 3. Physicochemical properties of the Eastern, Central and Western emergences of Bergham Spring. (Spc = specific conductance in microsiemens/cm, W.T. = Water Temperature in degrees Celsius, T.D.S. = total dissolved solids in milligrams/liter, epm = equivalents per million, SI_c = calcite saturation index, SI_d = dolomite saturation inex, P_{CO_2} = carbon dioxide partial pressure).

Spring Parameters	Western Emergence 25 % of total discharge			Central Emergence 5 % of total discharge			Eastern Emergence 70 % of total discharge		
	mean	max.	min.	mean	max.	min.	mean	max.	min.
Spc.	268	289	256	273	295	256	259	266	252
W. T.	11.9	12.1	11.7	11.9	12.1	11.8	11.8	12.0	11.6
T. D. S.	143	159	127	145	162	128	138	153	118
pH	7.85	8.06	7.52	7.87	8.08	7.64	7.87	8.04	7.60
Ca (epm)	2.482	2.831	2.168	2.517	2.831	2.179	2.446	2.681	2.119
Mg (epm)	0.230	0.292	.185	.233	.315	.185	0.230	0.330	0.185
Na (epm)	0.056	0.065	.044	.058	.070	.049	0.051	.064	0.043
K (epm)	0.007	0.014	.004	.007	.014	.005	0.007	.011	0.004
HCO_3 (epm)	2.544	2.900	2.250	2.581	2.900	2.275	2.497	2.850	2.225
Cl (epm)	0.191	0.300	.125	.205	.325	.125	0.190	.300	0.113
SO_4 (epm)	0.064	0.088	.040	.067	.086	.043	0.060	.081	0.038
NO_3 (epm)	0.031	0.048	.022	.035	.068	.022	0.028	.048	0.017
Ca/Mg	10.9	12.6	9.5	10.9	12.8	8.8	10.7	13.0	7.7
SI_c	0.131	.334	-.136	.164	.393	-.008	0.139	.325	-.086
SI_d	-.850	-.460	-1.43	-.771	-.324	-1.18	-.812	-.004	-1.30
log P_{CO_2}	-2.74	-2.38	-2.99	-2.75	-2.50	-2.96	-2.77	-2.46	-2.93

residence time, specific conductance, and calcium and bicarbonate concentrations have lower values. The specific conductance, and calcium and bicarbonate concentrations of the emergences do not remain constant throughout the year. As can be seen in Figure 3, the differences in the above-mentioned properties between each of the emergences are more apparent in the dry season. These differences tend to diminish as the precipitation season begins and flow rates increase. Reasons for these differences may include: at low flow rates, water flows through three different routes, but with an increase in flow rate, the water table level rises causing intermixing of the three spring waters; or, infiltrated precipitation and snowmelt near the emergences contribute more to the spring discharge and due to the shorter residence time, chemical properties tend to become more similar.

The chemical and physical properties of the Eastern emergence (main emergence) of Berghan Spring were determined for a period of 32 months, longer than that of any of the other emergences; therefore, the hydrochemical behavior of this emergence has been analyzed in greater detail (Figure 4). In this figure, time has been divided into the same three periods mentioned previously; the precipitation, first and second recession periods. The variation of specific conductance, calcium and bicarbonate concentrations and calcite saturation indices are not significant. For example, the minimum and maximum values of specific conductance were 252 and 266 microsiemens/cm during the study period. This implies that aquifer characteristics control the chemical behavior of the spring. The extensive network of fissures and pores in the three hydrologic zones increases the residence time, and potentially averages these chemical properties. The slight differences in chemical behavior between the three periods could be interpreted as follows: specific conductance, calcium and bicarbonate concentrations, and calcite and dolomite saturation indices are relatively low in the first recession period. This is due to melting of snow near the emergence, which quickly reaches the spring and has little time for dissolution. In addition, Raeisi and Karami (1996) showed that snowmelt in the first recession period contains insignificant amounts of dissolved ions. In winter, major cations and anions (except chloride ions) migrate from the upper layers of the snowpack to the bottom layers and ultimately reach the soil or rock underlying the snow. This results in a reduction of dissolved solids in the snowmelt during the spring, which in turn decreases the specific conductance of the first recession period. Ion migration in snowpack is in agreement with the results of Jeffries and Synder (1981). In addition, the rapid drainage of the vadose zone during the first recession period decreases the residence time, and thus results in a lower concentration of dissolved ions.

In the second recession period, specific conductance increases as there is no dilution by recharge water, and flow from smaller pores with longer residence time contributes to the spring discharge. In the precipitation period however, the specific conductance is relatively high and contradicts the expected higher flow rates. Three reasons are presented for this reverse anomaly:

1. Ashton (1966) explained that the increase in calcium and bicarbonate concentrations at the start of precipitation in winter is due to flushing of water with a long residence time in the deeper phreatic zone; recharge forces water out by a piston-like process. The removal of old water in storage being pushed out by new recharge water was confirmed by the work of Bakalowicz et al. (1974).

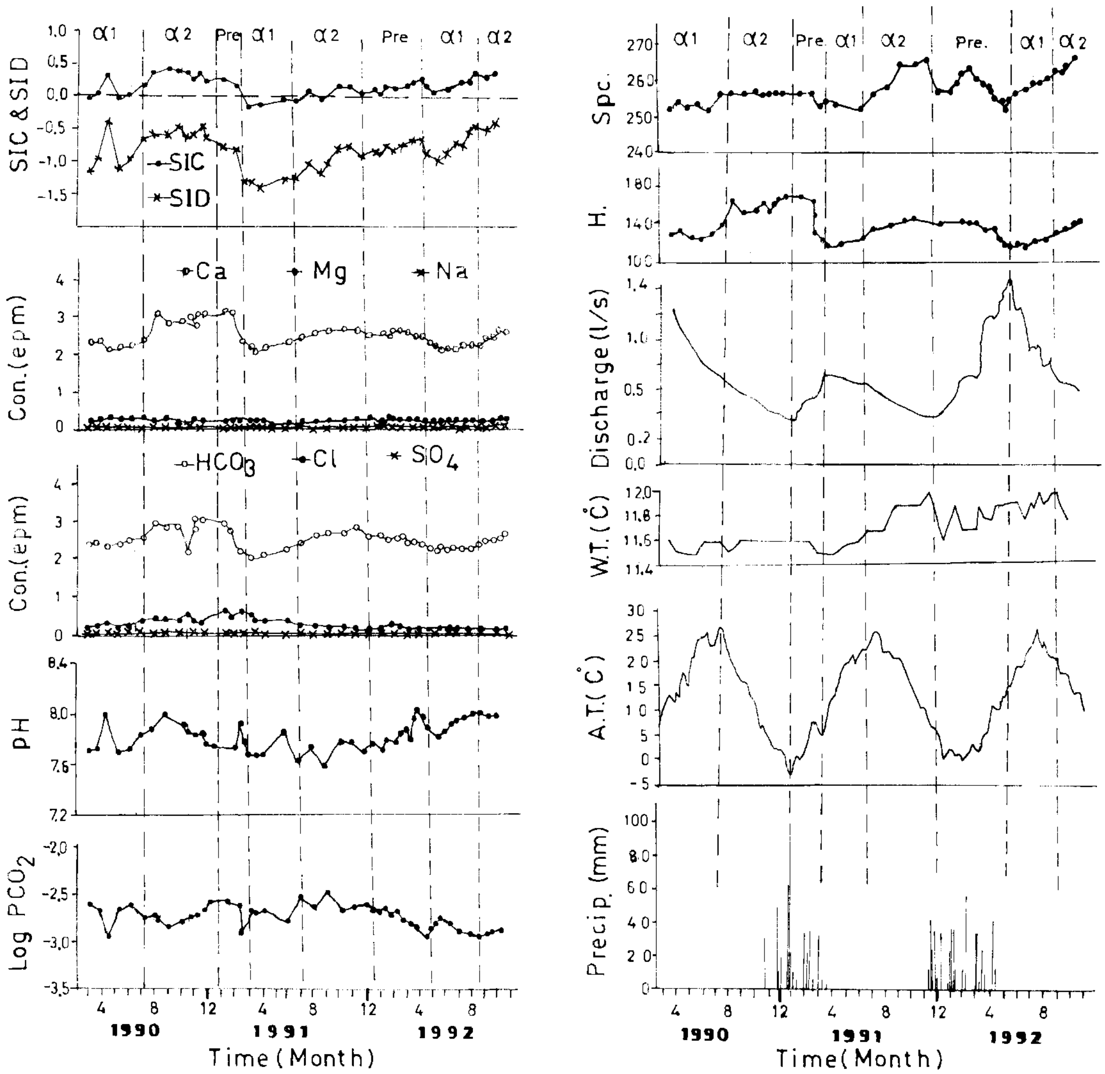

Figure 4. Time variations of physical and chemical parameters of Berghan Spring from March 1990 to November 1992 (SI_c = calcite saturation index, SI_d = dolomite saturation index, Con. = Concentration, epm = equivalents per million, Spc. = specific conductance in microsiemens/cm, H. = Hardness in milligrams per liter as $CaCO_3$, l/s = liters per second, W.T. = Water Temperature in degrees Celsius, A.T. = Air Temperature in degrees Celsius, Precip. = Precipitation in millimeters, α_1 = first recession period, α_2 = second recession period, Pre. = Precipitation period.

2. As mentioned earlier, 40% of the Berghan Spring catchment area is covered by soil. Evapotranspiration losses from the soil during the second recession period tend to increase chloride concentration in the soil water and hence in the underlying epikarstic zone (Ford & Williams, 1989). During the precipitation period, infiltrated water displaces water with a high chloride concentration which is observed as a small chloride peak in the Berghan karst spring (Figure 4).

3. Downward ion migration causes initial winter snowmelt to have higher amounts of dissolved ions.

The calcite saturation index (SI_c) shows that the spring water is almost supersaturated during the three time periods, which suggests a diffuse flow system. The dolomite saturation index indicates undersaturation as would be expected, because the aquifer is calcareous. The average water temperature and the temperature variation during the study period was 11.72ºC and 0.6ºC, respectively. Thus, it can be concluded that the spring water discharges from depths that are not affected by ambient temperature fluctuations and reaches equilibrium with surrounding rock. This also suggests diffuse flow in the Berghan Spring drainage basin.

The variation coefficients of flow rate, water temperature, specific conductance, hardness, and bicarbonate and calcium concentration were used to determine the type of flow in Berghan Spring aquifer. Although contradictory results were obtained from the criteria proposed by various authors, the overall results of this study suggest diffuse flow to Berghan Spring.

CONCLUSION

Morphological and geological characteristics of the Berghan Spring study area suggest a diffuse type aquifer. The catchment area of the spring has no sinkholes, pits, or shafts and 40% of the area is covered by soil. Recharge is by autogenic water from precipitation and snowmelt. The aquifer has been brecciated by one thrust fault and several normal faults, as evidenced by extensive breccia in the catchment area of Berghan Spring. Karstification has resulted in a network of interconnected fissures and pores. Recharge water stored in the vadose zone gradually percolates into the phreatic zone, through a diffuse flow system.

The hydrographs and chemographs of Berghan Spring reinforce and complement the conclusions drawn above. The recession coefficients derived for the first and second recession periods are small and almost equal, indicating slow drainage from an extensive dense network of fissures and pores. Specific conductance and calcium and bicarbonate concentrations, did not vary greatly during the precipitation or first and second recession periods, also implying that the Berghan Spring aquifer is dominated by diffuse flow. The chemical and physical properties of Berghan Spring are controlled primarily by the aquifer. The small differences in some of the chemical parameters during the three time periods, and in the recession coefficients are primarily related to the input water characteristics, the ability of the brecciated limestone to retain water, the hydraulic behavior of the aquifer, and to differences in residence time.

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John E. Cooper & Martha Riser Cooper-New Troglobitic Crayfish of the Genus *Orconectes*, Subgenus *Orconectes* (Decapoda: Cambaridae), Endemic to Shelta Cave, Huntsville, Alabama. *Journal of Cave and Karst Studies 59*(3): 119-127.

NEW TROGLOBITIC CRAYFISH OF THE GENUS *ORCONECTES*, SUBGENUS *ORCONECTES* (DECAPODA: CAMBARIDAE), ENDEMIC TO SHELTA CAVE, HUNTSVILLE, ALABAMA

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Orconectes *(*Orconectes*)* sheltae *is a new species of troglobitic crayfish endemic to Shelta Cave, Huntsville, Alabama, where it is the smallest and rarest member of a subterranean crayfish triad that includes* O. *(*O.*)* a. australis *and* Cambarus *(*A.*)* jonesi. *The new species may be distinguished from all other members of the subgenus by a combination of: (1) the absence of first pleopods in the female, (2) a broad median trough in the annulus, (3) the narrow, elongate chela of the cheliped, with its very long palm and subvertical orientation, (4) the length, conformation, and orientation of the terminal elements of the form I male gonopod (first pleopod), and (5) the lack of prominent spines on the mesial margin of the carpus. The mature oocytes of* O. sheltae *are large and few (8-12), and the young at recruitment may be larger than those of* O. a. australis *and* C. jonesi.

The first troglobitic crayfish reported in the literature was *Astacus pellucidus* [= *Orconectes* (*Orconectes*) *pellucidus* (Tellkampf)], described in 1844 from Mammoth Cave, Kentucky. Since then, 35 additional troglobitic taxa have been described, 5 of them in the genus *Orconectes*: *Orconectes* (*Orconectes*) *australis australis* (Rhoades), *Orconectes* (*Orconectes*) *australis packardi* Rhoades, *Orconectes* (*Orconectes*) *incomptus* Hobbs and Barr, *Orconectes* (*Orconectes*) *inermis inermis* Cope, and *Orconectes* (*Orconectes) inermis testii* (Hay). Hobbs et al. (1977) provided an excellent review of all the species and subspecies of troglobitic decapods known from the Americas as of 1975 (8 of the 36 crayfishes were described between 1976 and 1993).

Within the genus *Orconectes*, 5 of the 6 troglobites variously have been treated as closely related species or as subspecies in one combination or another, making up a complex generally considered to display the most plesiomorphic characters seen in the genus. Hobbs and Barr (1972) provided the current nomenclature and classification, and erected a Pellucidus Section of the genus for all six taxa, then Fitzpatrick (1987) brought them together in the subgenus *Orconectes*. On the basis of the number of plesiomorphies displayed by the members of the subgenus, Fitzpatrick (1987: 63) expressed the opinion that it is "close to the stem population from which the genus descended." Monophyly of the genus *Orconectes* has recently been questioned (Crandall & Fitzpatrick, 1996; Fetzner, 1996), but no nomenclatorial changes have yet resulted from these studies.

Shelta Cave has long been known to harbor populations of two species of troglobitic crayfishes. It is the type locality of *O. a. australis*, described as *Cambarus* (*Faxonius*) *pellucidus australis* (Rhoades, 1941), and was the first reported locality for specimens of *Cambarus* (*Aviticambarus*) *jonesi* Hobbs and Barr, which Rhoades (1941: 148) tentatively had identified as "*?Cambarus* (*Cambarus*) *hamulatus* (Cope)." The surprising presence of a third species in the cave was discovered serendipitously on 24 August 1963 when we made a random collection of 7 crayfish for experimental studies that MRC was conducting in the laboratory of Thomas L. Poulson at Yale University. Four of the seven turned out to be specimens of this new species. In the light of our subsequent efforts to obtain more material for its description, and considering what we later discovered about the rarity of the animal, it is remarkable that this crayfish made up 57% of our initial collection. In 9 other trips to the cave between 22 December 1963 and 7 July 1968, usually involving up to 8 hours per visit spent in intensive searching, we collected only 15 additional specimens and observed 3 others. Seventeen of the collected specimens comprise the type series, but some data also were obtained from 97 other individuals that were examined, marked, and released during an ecological study of Shelta's crayfishes conducted between November 1968 and July 1975 (Cooper, 1975).

ORCONECTES (*ORCONECTES*) *SHELTAE*, NEW SPECIES

Figures 1, 2A; Table 1

Three new species. –Cooper and Cooper, 1966: 39 (in part); Cooper, 1967: 14 (in part).

Rare endemic form. –Cooper, 1968a: 34.

New *Orconectes*. –Cooper and Cooper, 1968: 23.

New species. –French, 1968: 31.

Undescribed *Orconectes*. –Hobbs, 1969: 130; Rheams et al., 1994: 65.

Troglobitic crayfishes. –Cooper and Cooper, 1971: 30 (in part); Cooper and Cooper, 1976: 52 (in part).

Orconectes? sp.; *O.* sp.; new species. –Cooper, 1974: 5.

Two smaller species. –Cooper and Cooper, 1976: 52 (in part).

Cambarus (*Aviticambarus*) sp. B. –Bouchard, 1976: 14, 17.

Two crayfishes of subgenus *Aviticambarus* (genus *Cambarus*). –Hobbs et al., 1977: 5 (in part).

Two undescribed troglobites. –Hobbs et al., 1977: 75 (in part).

Three troglobitic crayfishes. –Cooper and Cooper, 1977: 44 (in part).

Undescribed form. –Cooper and Cooper, 1977: 44.

Undescribed species. –Cooper and Cooper, 1978: 44.

Two *Aviticambarus*. –Culver, 1982: 51 (in part; incorrect usage of generic name from unpublished source).

Aviticambarus sheltae. –Culver, 1982: 65 (nomen nudum; incorrect usage of genus and species names from unpublished source).

C. (*A.*) sp. B. –Fitzpatrick, 1990: 78.

Orconectes sp. –Hobbs, 1992: 93.

The above is a selected synonymy, including only references that have appeared in the literature; no citations from dissertations, or from open-file and similar reports, are included.

Diagnosis–Albinistic; eyes reduced, unpigmented, recessed. Rostrum acarinate, with narrow, subparallel to moderately converging margins and strong marginal spines delimiting base of acumen; latter comprising 33.3 to 43.2 (mean = 39.0) percent of rostrum length, which constituting 22.8 to 26.1 (mean = 24.5) percent of total carapace length (TCL); floor (dorsal surface) of rostrum deeply excavate, margins elevated. Areola 3.5 to 7.0 (mean = 4.9) times as long as wide, constituting 39.6 to 42.4 (mean = 41.2) percent of TCL and 53.5 to 55.9 (mean = 54.4) percent of postorbital carapace length (PCL), with 5 to 8 (usually 6) punctations across narrowest part. Total carapace length 1.5 times length of cephalic section of cephalothorax. Cervical spines strong, 1 to 3 (usually 2) each side of carapace. Branchiostegal spine relatively strong, acute; hepatic area with small, scattered tubercles. Suborbital angle absent; portorbital ridge moderately strong, groove nearly obsolete, cephalic margin with strong spine. Antennal scale 2.2 times as long as wide, lateral margin thickened and terminating distally in long spine.

Chela of cheliped attenuated, nearly vertically oriented; palm subovate in cross-section, 2.8 to 3.6 (mean = 3.1) times as long as wide, length comprising 44.2 to 49.5 (mean = 46.7) percent of chela length, mesial margin with 2 to 3 rows of minute tubercles. Fingers not gaping, without tuft of plumose setae at base of opposable margin of fixed finger. Carpus of cheliped devoid of strong spines or tubercles on mesial surface.

Hook on ischium of third pereiopod of male, that of form I male slightly overreaching basioischial articulation, not opposed by tubercle on corresponding basis. Coxa of fourth pereiopod with prominent caudomesial boss. Gonopods (first pleopods) of form I male symmetrical, proximomesial apophyses separated; length of gonopod approximately 23% of TCL, tip reaching to about midlength of coxa of third pereiopod when abdomen flexed. Gonopod in lateral aspect without shoulder at base of central projection, but with pronounced, cephalomesially-folded convexity along cephalodistal margin near base of central projection; greatest cephalocaudal diameter of shaft more than twice that immediately proximal to base of central projection; terminal elements constituting approximately 12% of gonopod length, both inclined caudodistally, mesial process more strongly inclined of two; central projection corneous, subconical in lateral aspect, tip directed mesially at about 43° and caudally from 47 to 62°; axis of central projection twisted and element flattened in cephalocaudal plane, with lateral margin thickened and mesial portion a thin, transparent, winglike extension; distal margin symmetrically concave; mesial process noncorneous, robust, tapering from broad base to subacute tip, which directed caudally about 35° and laterally about 50°; process moderately constricted and more strongly tilted caudodistally at base of distal two-thirds and, in caudal aspect, obscuring proximolateral margin of central projection; in mesial aspect, bases of terminal elements separated by cleft, surface of gonopod without setae.

Female lacking first pleopod, position indicated by very slight thickening of sclerite on either side. Annulus ventralis with median one-third of cephalic margin arched, entire, usually clearly delimited but fused with preannular sternite; caudal margin slightly movable; annulus about 1.5 times wider than long, with longitudinal ridge on each side of midline, ridges separated by shallow median trough occupying cephalic four-fifths of annulus length and about one-fifth of annulus width; trough and ridges originating near cephalic margin, descending caudally with little or no curvature through cephalic three-fifths before gently curving caudodextrally. Arclike sinus originating near caudomedian margin and following oblique, curved path dextrally within caudal one-fifth of annulus, ending in small, deep fossa; indistinct continuation of sinus directed for short distance cephalosinistrally from dextral extremity of fossa, partly shielded by ridge forming dextral wall of trough; caudal margin of annulus on either side of sinus with narrow, slightly elevated rim. Postannular sclerite subovoid, with broad, transverse ventral ridge, sclerite about 4 times as wide as long, width 35.0% of annulus width. Preannular sternite with narrow, tapered mesial surfaces, subacute ventral angles, and broad, concave cephalolateral margins.

Measurements of type specimens provided in Table 1.

Holotypic male, form I–Albinistic; eyes reduced, recessed, without pigment. Cephalothorax (Figures 1A,D; 2A) subcylindrical, thoracic region slightly depressed dorsally; carapace 1.3 times wider than depth at caudodorsal margin of cervical groove, slightly wider than abdomen. Areola 5.2 times longer than wide, occupying 18.1% of carapace width at nar-

Table 1. Measurements (mm) of types, *Orconectes* (*O.*) *sheltae*, new species.

	Holotype	Allotype	Morphotype
Carapace			
Total length	16.1	17.1	19.7
Postorbital length	12.4	13.9	15.5
Length cephalic section	9.3	10.2	11.4
Width	7.2	7.8	8.5
Depth	5.5	6.1	6.5
Rostrum			
Length	4.2	4.4	4.5
Width at base	1.8	2.1	2.4
Length acumen	1.4	1.9	1.8
Areola			
Length	6.8	7.5	8.3
Width	1.3	1.4	1.9
Antennal scale			
Length	3.7	3.7	4.0
Width	1.7	1.7	1.8
Abdomen			
Length	20.1	20.2	22.1
Width	5.7	6.4	6.6
Cheliped			
Length lateral margin chela	11.5	9.3	10.9*
Length mesial margin palm	5.4	4.4	5.4*
Width palm	1.9	1.5	1.5*
Depth palm	1.7	1.3	1.3*
Length dactyl	6.0	5.1	5.6*
Length carpus	3.4	2.4	3.3*
Width carpus	1.6	1.3	1.5*
Length dorsal margin merus	8.0	7.3	7.9*
Depth merus	1.7	1.5	1.6*
Gonopod length	3.9		4.2

* Left cheliped; right regenerate.

rowest part, where with 7 punctations across; areola length 42.2% of TCL (54.8% of PCL). Cephalic section of cephalothorax comprising 57.8% of TCL. Rostrum constituting 26.1% of TCL, acarinate, margins narrow and slightly converging to bases of strong marginal spines; rostrum deeply excavate, margins well elevated and with rows of setae mesial and lateral to margin, mesial row continuing cephalically from marginal spines; floor of rostrum slightly concave, with scattered setiferous punctations; acumen slender, length 33.3% of rostrum length, distal one-fourth curving cephalodorsally in lateral aspect and apex extending nearly to distal margin of first article of antennular flagellum; subrostral ridges narrowly visible to bases of marginal spines. Postorbital ridge with nearly obsolete groove bearing setiferous punctations, cephalic margin with strong spine. Suborbital angle absent, margin of orbital rim oblique, somewhat uneven. Cervical spines strong, 2 each side, ventralmost largest. Branchiostegal spine small, acute; hepatic region with small, scattered tubercles. Carapace with fine, setiferous punctations dorsally, fine granules laterally; ventral margin of cephalic portion of cervical groove with small tubercles, groove continuous; cephalolateral branchiostegal region with small bulbous protrusion just ventral to cervical spine.

Antennal peduncle with strong cephalolateral spine on basis, weaker, semi-erect ventral spine on ischium, and rounded boss at ventromesial margin of coxa; antennular peduncle with small spine near mesial margin of ventral surface at base of distal one-fourth of proximal podomere, ventral and mesial margins of podomere devoid of setae. External flagellum of antennule longer and broader than internal one; antennal flagellum 44 mm long, tip extending well beyond caudal margin of telson when flagellum adpressed. Antennal scale (Figure 1L) 2.2 times longer than wide; lateral margin thickened, curved, and with long distal spine, tip of which reaching distal margin of first article of antennular flagellum; lamella of scale about twice as wide as thickened lateral portion; distal margin of lamella subtransverse, then curving to widest part just distal to midlength; mesial margin broadly rounded before tapering to base.

Abdomen longer than TCL, latter 80.1% of abdomen length; abdomen width 79.2% of carapace width; second through fifth abdominal pleura with curved cephaloventral margins, rectilinear caudoventral margins, and very acute caudoventral angles. Proximal podomere of uropod with small spine on lateral lobe, larger spine on mesial lobe; cephalic section of lateral ramus of uropod with broad, foreshortened median ridge devoid of caudal spine, mesial ramus with strong caudolateral spine, and low, foreshortened median ridge without distal spine. Cephalic section of telson with 2 strong spines each caudolateral corner, mesialmost one moveable; transverse suture of telson obsolete, caudal margin domelike. Dorsal surfaces of uropods and telson with sparse setae.

Epistome (Figure 1H) with cephalic lobe broader than long, cephalic and cephalolateral margins thickened, generally semicircular but somewhat undulant in outline, devoid of cephalomedian projection; caudolateral apices slightly thickened, not flared; floor (ventral surface) of cephalic lobe essentially flat, moderately punctate, caudal margin broadly V-shaped and apex penetrating fovea of body; lamellae mostly glabrous, strongly tapering and subacute laterally, with tubercle at caudolateral corner; lamellae with shallow sulcus and moundlike cephalomesial convexity on each side of midline; zygoma weakly arched.

Third maxilliped with tip reaching distal margin of ultimate podomere of antennal peduncle; tip of exopodite reaching midlength of merus of endopodite, and basal podomere of exopodite not hirsute; cephalolateral corner of ischium slightly produced; lateral ridge of ischium subtended mesially by row of minuscule punctations bearing sparse, short setae; ventrolateral half of ischium with row of punctations along mesial border and scattered punctations elsewhere, ventromesial half with long, dense setae, and mesial margin with about 23 (mostly minute) denticles on right. Mandible with 7 denticles on right incisor ridge, 6 on left.

Chela of cheliped (Figures 1M, 2A) attenuated, subvertically oriented, 6.1 times longer than wide, length 71.4% of

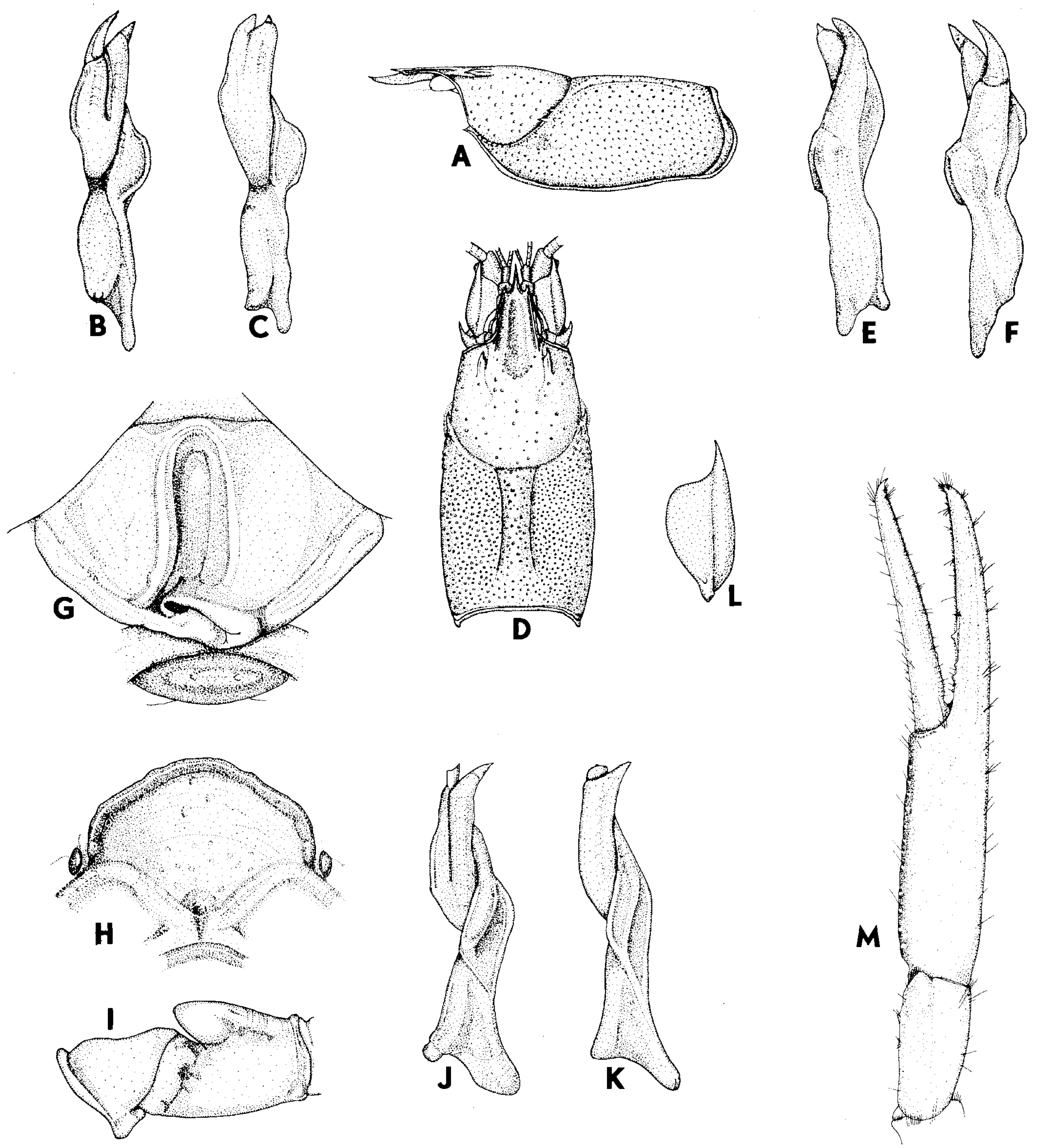

Figure 1. *Orconectes* (*Orconectes*) *sheltae*, new species (all from holotypic male, form I, except C, E, K, from morphotypic male, form II, and G from allotypic female; setae illustrated only in M): A, lateral aspect of carapace; B, C, mesial aspect of gonopod (first pleopod); D, dorsal aspect of carapace; E, F, lateral aspect of gonopod; G, annulus ventralis and postannular sclerite; H, epistome; I, basal podomeres of third pereiopod; J, K, caudal aspect of gonopod; L, antennal scale; M, distal podomeres of cheliped.

TCL; palm subovate, 1.1 times wider than deep; dorsal surface with small punctations, some minute squamous tubercles, short recumbent setae, and sparse tufts of long, erect setae; distal articular ridges of palm nearly obsolete dorsally and ventrally, with weak mesial eminence; ventrolateral eminence devoid of tubercle; lateral margin of palm rounded, punctate, with longer recumbent setae and several minuscule tubercles, each with 1 or 2 long setae; mesial margin of palm with row of about 12 minute tubercles, flanked each side by irregular row of minuscule tubercles. Fingers long, thin, curving slightly distoventrally, both subtriangular in cross-section. Fixed finger with moderate longitudinal ridges dorsally and ventrally, ridges flanked each side by row of punctations, surfaces covered with short, recumbent setae; lateral margin of finger punctate; opposable margin with prominent subconical tubercle ventral to denticles at base of distal two-thirds of finger, and 2 prominent tubercles proximal to subconical one; denticles in single row along entire opposable margin. Dactyl with moderate longitudinal ridges dorsally and ventrally, ridges flanked each side by row of punctations, surfaces covered with short, recumbent setae; rows of long, sparse, erect setae just dorsolateral and ventromesial to opposable margin, and along distal two-thirds of mesial margin; latter mostly punctate, but with some minute tubercles near base; opposable margin with subconical tubercle ventral to denticles near base, denticles in single row along entire margin.

Carpus of cheliped (Figure 1M) attenuated, 2.1 times longer than wide, length 29.6% of chela length and 21.1% of TCL, with very shallow dorsal sulcus and some minute tubercles distolaterally and distomesially; ventral margin with small distal spine, ventral surface with 9 or 10 small tubercles; mesial margin without spines, with 5 or 6 small, acute tubercles and 12 to 15 minute squamous tubercles; dorsolateral and lateral surfaces with scattered minute tubercles, other surfaces with setiferous punctations. Merus of cheliped 4.7 times longer than deep, depth fairly uniform throughout length, latter 69.7% of chela length and 49.7% of TCL; dorsal surface with single small subdistal spine, and many minute tubercles on dorsal ridge and mesial and lateral surfaces; ventrolateral ridge with large spine ventral to articular condyle, and numerous minuscule tubercles; ventromesial ridge with large distal spine, and numerous minuscule tubercles. Ischium with several minuscule tubercles ventrally; sufflamen obsolete.

Hook on ischium of third pereiopod (Figure 1I) simple, flattened on mesial surface and inflated on lateral surface, with tip overreaching basioischial articulation, not opposed by tubercle on basis. Coxae of all pereiopods, and sternites between them, with setae, which sparse cephalically, denser caudally. Coxa of fourth pereiopod with prominent, caudomesially disposed boss, caudal surface of which expanded into smooth horizontal arc; coxa of fifth pereiopod with narrow projection cephalic to penis papilla, tip of projection with tuft of long setae.

For description of gonopod (Figures 1B, F, J), see "Diagnosis."

Allotypic female–Exclusive of secondary sexual characters, differing from holotype in following respects: Areola 5.4 times longer than wide, occupying 17.9% of carapace width, with 6 punctations across narrowest part; areola length 42.4% of TCL (54.0% of PCL). Cephalic section of cephalothorax comprising 57.6% of TCL. Acumen length constituting 43.2% of rostrum length, which comprising 24.9% of TCL. Cervical spines 3 left, 2 right. Width of abdomen 82.1% of carapace width, TCL 87.6% of abdomen length. Transverse suture of telson complete but weak. Cephalic lobe of epistome with broadly rounded, semicircular margin. Chela of cheliped 6.2 times longer than wide, length 52.2% of TCL; palm 1.2 times wider than deep. Carpus of cheliped 1.8 times longer than wide, length 25.8% of chela length and 13.6% of TCL, with somewhat more obvious dorsal sulcus and lacking distinct distal spine on ventral margin. Merus of cheliped 4.9 times longer than deep, length 78.5% of chela length and 41.2 percent of TCL.

For description of annulus (Figure 1G), see "Diagnosis."

Morphotypic male, form II–Differing from holotype in following respects: Areola 4.4 times longer than wide, occupying 22.4% of carapace width at narrowest part; areola length 42.1% of TCL (53.5% of PCL). Acumen comprising 40.0% of rostrum length, which constituting 22.8% of TCL; acute tip of acumen directed cephalically. Width of abdomen 77.6% of carapace width; TCL 89.1% of abdomen length. Cervical spines 2 left, 3 right. Transverse suture of telson complete but weak. Right cheliped regenerate; chela of left cheliped 7.3 times longer than wide, length 55.3% of TCL; palm 1.2 times wider than deep. Carpus of cheliped 2.2 times longer than wide, length 30.3% of chela length and 16.7% of TCL. Merus of cheliped 4.9 times longer than deep, length 72.5% of chela length and 40.1% of TCL. Ischium of third pereiopod with reduced hook, tip not quite reaching basioischial articulation. Gonopods (Figures 1C, E, K) with proximomesial apophyses nearly abutted; central projection noncorneous, short, blunt; mesial process larger and longer than central projection; both terminal elements disposed approximately as in holotype.

Disposition of types–The holotype, allotype, and morphotype are in the crustacean collections of the North Carolina State Museum of Natural Sciences (NCSM), Raleigh (catalogue numbers NCSM C-3361, 3362, 3363, respectively), as are the following paratypes: 1 ♂ II (NCSM C-3364); 1 ♀ (NCSM C-3365); 1 j ♂, 2 ♀ (NCSM C-3366); 1 ♂ I, 1 ♀ (NCSM C-3367); 1 j ♀ (NCSM C-3368); 1 ♂ II, 1 j ♂, 2 ♀ (NCSM C-3371). Additional paratypes consisting of 1 ♂ I and 1 j ♀ have been deposited in the collections of the National Museum of Natural History (USNM), Smithsonian Institution, Washington, DC (USNM 131575, 131576, respectively).

Type locality–Alabama, Madison County, Huntsville, Shelta Cave (Meridianville 7.5' USGS Quadrangle, Sec. 27, T.3S, R.1W). Shelta Cave is designated AL4 in the cave cataloguing system of the Alabama Cave Survey, an official project of the National Speleological Society (NSS). The two pit entrances to the cave are located in a shallow wooded sink in northwest Huntsville, behind the headquarters of the NSS, which owns the entrance properties and controls general access to the cave. Research there is restricted by policies and guidelines of the NSS.

For a complete description of Shelta Cave, including its physical characteristics and fauna, see Cooper (1975), Hobbs III and Bagley (1989), McGregor et al. (1994), Moser and Rheams (1992) and Rheams et al. (1992, 1994).

Range and specimens examined–Endemic to the type locality, where we collected the following specimens (other collectors as noted): 1 ♂II, 1 j ♂, 2 ♀, 24 August 1963, with F.E. McKinney, T. Sawyer; 1 ♂ II, 1 ♀, 22 December 1963, with W. Sanborn; 1 ♂ II, 1 j ♀, 3 January 1964; 1 ♂ I, 2 ♀, 1 j ♀, 7 August 1965; 2 ♂ I, 11 April 1966, with J.E. Cooper, Jr.; 1 j ♂, 2 ♀, 20 November 1966, with J. Reddell; 1 ♂ II, 27 July 1968, L. Morin, R. Graham; 1 ♂ II, 10 April 1969; 1 ♀, 8 December 1968; 1 ♀, 12 August 1969; 1 ♂, II, 27 November 1970; 1 ♂ II, 14 July 1975; 1 ♂ I, 15 July 1975; 2 ♀, 16 July 1975. All specimens are catalogued at NCSM, except several that are catalogued at USNM.

As previously mentioned, some additional data were obtained from 97 other individuals that were examined and released. We also examined crayfishes of the appropriate sizes collected by Ronald A. Brandon and Ronald Altig in November 1964, as well as all Shelta crayfishes in the collections of the National Museum of Natural History and Tulane University (TU); all were either *C. jonesi* or juvenile *O. a. australis*.

Variations–Combining the data from the type series and specimens examined during the ecological study, most individuals have 2 cervical spines on each side of the carapace. However, 8 had 3 spines on one side and 2 on the other, 14 had a single spine on one side and 2 on the other, and 5 had but a single spine on each side. The dimensions of the areola vary within the limits provided in the "Diagnosis;" juveniles and subadults have somewhat shorter and broader areolae than adults. The cephalic lobe of the epistome of several specimens has a small cephalomedian projection instead of the usual, relatively featureless margin. Carapace width varies from 1.2 to 1.4 times carapace depth. Sexual dimorphism is evident in chela length, with the chelae of form I males averaging 75.5% of TCL, those of both females and form II males averaging 59.2% of TCL. Width of the palm varies from 1.1 to 1.3 times its depth, regardless of sex or male form. The carpus of females is shorter and somewhat narrower than that of all males. The merus of females and form II males is shorter than that of form I males, but the length of the podomere is about 4.9 times its depth in all specimens measured. The annulus shows some variation in dimensions and shape; width in adults ranges from 1.3 to 1.7 times length, but width is greater in juveniles. In addition, some specimens have a pair of broad tubercles at the cephalic margin of the median trough.

Size–The largest specimen in the type series is the morphotype, which has a TCL of 19.7 mm. The largest form I male has a TCL of 17.3 mm, and the smallest measures 16.1 mm TCL. During the mark-release phase of our study (Cooper, 1975), the smallest specimen we found was a juvenile male of about 9.2 mm TCL. Four others also had TCLs of less than 11.0 mm. The size ranges of adult males were 13.5 to 17.1 mm (mean = 15.4 mm, n = 8) for form I males and 13.5 to 17.6 mm (mean = 15.3 mm, n = 34) for males considered to be form II rather than juveniles. The range for adult females was 13.3 to 18.0 mm (mean = 15.2 mm, n = 42). Thus, we found no significant differences in mean TCL of mature animals of either sex or male sexual form (range for all adults 13.3 to 18.0, mean = 15.3, n = 84).

Life history notes–Form I males (numbers in parentheses) were found in April (2), July (3), August (5), September (5), October (12), November (6), and December (2), but were always a small percentage of the *O. sheltae* found during sampling in any time period. They may have been present in other months as well since very few individuals of this species were encountered during periods of elevated water levels.

Although no female bearing attached ova or young has ever been found, some reproductive data have been obtained. The annulus of the allotype, collected on 7 August 1965, contained the remnants of a sperm plug, indicating that mating had occurred, perhaps sometime near that date. A female of 16.8 mm TCL, with late-stage oocytes and weakly developed cement glands, and a form I male measuring 15.3 mm TCL, were observed in prolonged amplexus in a container within the cave on 18 October 1969. The smallest oocytes first appeared in females at about 13 mm TCL. Larger, late stage oocytes, often accompanied by fully developed cement glands, were seen in 9 females measuring 13.3 to 16.8 (mean = 15.0) mm TCL. Four of them were collected in July, and one each in August through December. One of these females collected on 10 July 1969 and measuring only 13.8 mm TCL had 8 very large oocytes (ca. 1.5-2.0 mm diameter) crowding the ovary, and all cement glands were highly developed. The number of oocytes observed in all females ranged from 8 to 12, which reflects a very low reproductive potential.

The young of *O. sheltae* at recruitment may be larger than the young of the other two, larger troglobitic crayfishes of Shelta Cave. The smallest individuals of *O. sheltae* ever found were two juvenile males, measuring 9.2 and 10.3 mm TCL that we examined and released. They were 2 to 3 times larger than the smallest *C. jonesi* (3-5 mm TCL), and twice the size of the smallest *O. a. australis* (5-6 mm TCL). A larger size at recruitment for young of this fragile species could give them a competitive edge by increasing their foraging efficiency, and by decreasing the probability of being eaten by the troglobitic fish, *Typhlichthys subterraneus* Girard. This fish is the most significant predator in the cave's aquatic community, where larger individuals, although not often observed in our study, are known to feed on the troglobitic shrimp, *Palaemonias alabamae* Smalley (Cooper & Cooper, 1974). We do not know for certain, however, if *O. sheltae* of 9 to 10 mm TCL are recently recruited juveniles, despite the fact that they are the smallest ever found in a number of years of intensive searching and trapping.

Relationships–We are in the process of evaluating the relationships among *O. sheltae* and a number of other crayfishes of the southern Cumberland Plateau, Sequatchie Valley, and Highland Rim. Since this evaluation includes species of other genera, extensive comments at this time would be inappropriate. However, based on the nature of the secondary sexual structures of form I males and females of taxa within the subgenus *Orconectes*, *O. sheltae* appears to be closer to the *O. inermis-australis-incomptus* line of descent than to that which led to *O. pelllucidus* (Hobbs & Barr, 1972). Within this group, the form I male gonopod of *O. sheltae* is most like that of *O. i. inermis*, as are several other features, including the percentage of areola length of TCL (<43%). The annulus, however, differs from that of *O. inermis* and *O. australis*, being more similar to that of *O. incomptus*.

In most respects, *O. sheltae* is quite different from the other troglobitic members of the genus, as limned by Hobbs and Barr (1972), Hobbs et al. (1977), and Fitzpatrick (1987), and is readily distinguished from them by (1) the absence of first pleopods in the female; (2) the broad median trough of the annulus; (3) the narrow, elongate chela, with its long palm and subvertical orientation; (4) the longer terminal elements of the form I male gonopod, their greater degree of curvature, and the cephalocaudal flattening of the central projection; (5) the great depth of the cephalocaudal axis of the shaft of the gonopod, immediately proximal to the base of the central projection; (6) the absence of prominent spines on the mesial margin of the carpus; and (7) the smaller size, with a maximum TCL of 19.7 mm, as compared to the maximum TCL range of from 24.3 mm for *O. incomptus* to 48.0 mm for *O. a. australis*.

Crayfish and other associates–In addition to *C. jonesi* and *O. a. australis* (Figure 2B, C, respectively), 6 specimens of a large, pigmented crayfish, referred to the common troglophile, *Cambarus* (*Erebicambarus*) *tenebrosus* Hay (s.l.), were found in Shelta Cave. Both of the troglobitic species far outnumbered *O. sheltae*. In 18 extended sampling periods we processed 1,314 individual crayfish: 959 *O. a. australis* (72.9%), 266 *C. jonesi* (20.2%), and 89 *O. sheltae* (6.8%). The only other decapod that we found in Shelta Cave was the atyid shrimp, *P. alabamae*.

Two troglobitic ectocommensals occur on the Shelta crayfishes, the entocytherid ostracod, *Sagittocythere barri* (Hart and Hobbs)(Hart & Hart, 1966; Hart & Hobbs, 1961), and the branchiobdellid worm, *Cambarincola sheltensis* Holt (Holt, 1973). Although we did not specifically search for them, we did note their presence when observed. No ostracods were recorded on any *O. sheltae*, and we noted branchiobdellids on only two of those handled. Both of the ectocommensals were commonly observed on *C. jonesi*, and far more frequently on *O. a. australis*. Other macroscopic troglobites found in the aquatic community are two species of amphipods of the genus *Stygobromus* (J.R. Holsinger, in litt.); a triclad turbellarian of the genus *Sphalloplana*; *T. subterraneus*; and a perennibranch salamander, *Gyrinophilus palleucus* subspecies, which was rarely encountered (Cooper, 1968b; Cooper & Cooper, 1968).

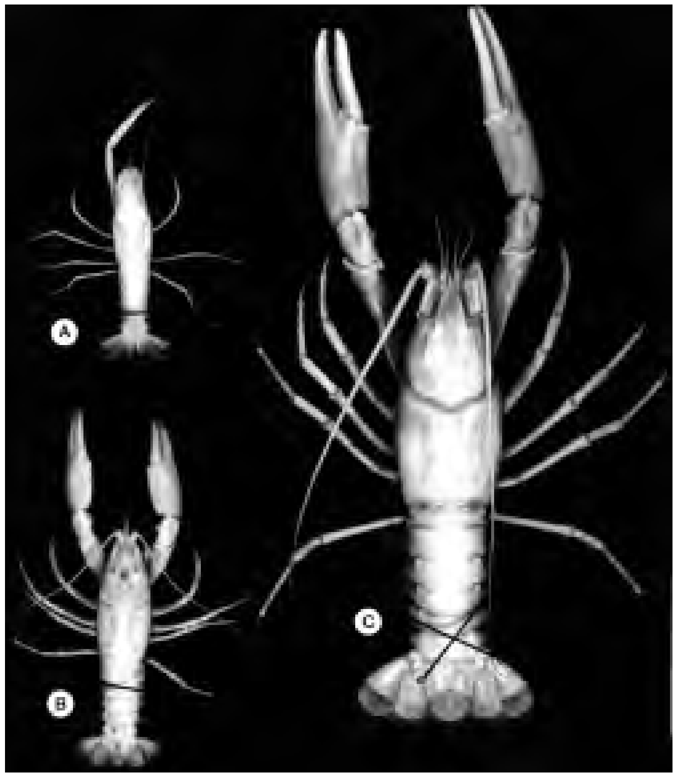

Figure 2. Comparative sizes and configurations (dorsal aspect) of form I males of the troglobitic crayfish triad that occurs in Shelta Cave. A, *Orconectes* (*O.*) *sheltae*, new species, 17.1 mm TCL; first and third right pereiopods missing. B, *Cambarus* (*A.*) *jonesi*, 21.0 mm TCL. C, *Orconectes* (*O.*) *a. australis*, 41.2 mm TCL; right cheliped regenerate.

Remarks–We know of only one other troglobitic crayfish triad whose members exist syntopically, or ostensibly so, in American caves. At least two sinkholes in Alachua County, Florida–Squirrel Chimney and Goat Sink–are occupied by *Procambarus* (*Ortmannicus*) *pallidus* (Hobbs), *Procambarus* (*Ortmannicus*) *lucifugus alachua* (Hobbs), and *Troglocambarus maclanei* Hobbs. Just as in the case of the three Shelta species, one of the Florida species, *P. l. alachua*, is very large, with a maximum TCL of 45.2 mm, which is closely comparable to *O. a. australis*; *P. pallidus* is intermediate in size, with a maximum reported TCL of 39.6 mm, which is larger than *C. jonesi*; and *T. maclanei* is a diminutive, fragile species, with a maximum reported TCL of 15.5 mm, which is close to *O. sheltae.*

Etymology–The species name, *sheltae*, is after Shelta Cave, the only known locality for the species. The name of the cave was at one time Bolen James' Cave, but in 1888 Henry M. Fuller purchased the land containing the entrances and renamed the cave Shelta, after his daughter (French, 1968). Suggested vernacular name: Shelta Cave Crayfish.

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Bogdan P. Onac, Rolf B. Pedersen and Magne Tysseland-Presence of Rare-Earth Elements in Black Ferromanganese Coatings from Vântului Cave. *Journal of Cave and Karst Studies 59*(3): 128-131.

PRESENCE OF RARE-EARTH ELEMENTS IN BLACK FERROMANGANESE COATINGS FROM VÂNTULUI CAVE (ROMANIA)

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This study examines the rare-earth elements (REEs) found in ferromanganese coatings covering both sandy alluvium and submerged boulders in an underground stream from Vântului Cave, Romania. The black ferromanganese sediments are mainly composed of birnessite and other poorly-crystallized manganese oxide and hydroxides (pyrolusite, romanechite, todorokite, rhodochrosite) as well as goethite and kaolinite. Scanning electron microscope and EDX analyses performed on the black ferromanganese sediments show the material to have concentrated considerable amounts of REEs (La, Ce, Sm, Nd) in iron-rich spheres that build up botryoidal-like aggregates. The correlation of $^{143}Nd/^{144}Nd$ ratio for 6 different samples indicates that the REEs were concentrated in the cave environment after being leached from bauxitic and red residual clays from above the cave. Based on our observations, we conclude that an increase in pH resulted in adsorption of REE onto the surface of ferromanganese minerals. This study demonstrates the potential of using Nd isotopes as a tool for paleochemistry studies of the cave environment.

The REEs have been used in several recent studies of oceanic manganiferous deposits in order to identify possible sources of the elements and, specifically, to assess seawater contributions of metal during their formation. So far, the presence of such elements in the cave environment has not been mentioned. However, REE and Nd isotopes may be useful tools with which to explore the paleochemistry of the waters and to reconstruct the redox chemistry of the waters in which they formed (Graf, 1978).

In this paper, we report the concentrations of Lanthanum (La), Cerium (Ce), Samarium (Sm), and Neodymium (Nd) in the black speleothems that were precipitated on both sandy alluvium, submerged boulders and on the cave walls. In addition, we have also made measurements of the $^{143}Nd/^{144}Nd$ isotopic ratios of black speleothems, and associated bauxitic and red residual clay. Because of the marked fractionation of Sm-Nd between continental and oceanic crust and the alpha decay of ^{147}Sm to ^{143}Nd, the source of the REE in the investigated ferromanganese speleothems from Vântului Cave and the genetic relationship between these elements in the black speleothems can be established using the $^{143}Nd/^{144}Nd$ ratios (Geyh & Schleicher, 1990).

Morphologic, mineralogic and genetic studies on manganese oxides in the cave environment have already been done by Crabtree (1962), Moore (1981), Gascoine (1982), Hill (1982), White et al. (1982), Kashima (1983), Peck (1986), Gradzinski et al. (1995), and Onac (1996).

GEOLOGICAL AND SPELEOLOGICAL SETTING

Karst near Suncuius, in the northwestern part of Padurea Craiului Mountains, Romania (Figure 1), is mostly developed in Lower and Middle Triassic limestones and dolomites. The upper sequence of Middle Triasic rock consists of white limestone of Ladinian age, with a thickness that sporadically reaches 180 m. After the deposition of this unit, an episode of continental evolution (uplift) generated the Ladinian paleokarst (Onac & Popescu, 1991). This paleokarst was subsequently

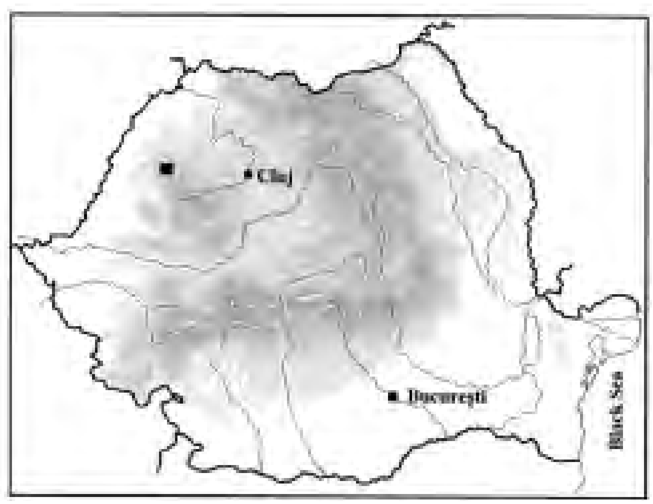

Figure 1. Map of Romania showing the Vântului Cave area (square).

covered by residual red clay and bauxite, sandstone, microconglomerate, refractory clay (exploited in mine and quarry in nearby Suncuius), and lenses of siderolithic clay that indicate continental alteration (Corvin-Papiu et al., 1988).

Vântului Cave is located 2.5 km upstream from Suncuius. It has a total length of about 45 km, and is the longest cave system in Romania. The cave is developed is on four levels, the lowest having an active stream (Szilagy et al., 1979). Tracer dye labeling has shown that the recharge area of the underground flow to Vântului Cave is linked to diffuse losses in the Recea Mining Brook basin (Oraseanu & Gaspar, 1980-1981). Decidous forests cover the entire basin, encouraging formation of organic acids derived from abundant decomposing vegetation.

There is also evidence that acid-mine waters (rich in aluminium, iron and silica) drain into the cave flow, having an impact on the cave environment (pollution, corrosion, speleothem deposition).

BLACK SPELEOTHEMS

The underground stream bed in Vântului Cave is covered by black jelly-like sediments. The thickness of these sediments changes as the distance from the sediment-water interface increases (Onac, 1996). The submerged boulders and cobbles can have layers up to 2.5-3 cm thick, while the sandy alluvium is covered with only 2 to 3 mm of this material. The black material will accumulate until a steady-state balance is reached between the deposition of the black speleothem coatings and the physical or chemical processes that remove these coatings. The cave walls alongside the stream are covered with black coatings of the same material, up to the highest level reached by the water. The very same black coatings, partly covered by recent calcite crusts, were observed on the walls in a few passages in the upper level of the cave.

Jet black flowstone and dripstone-like speleothems occur in many places along the active stream gallery.

ANALYTICAL METHODS

X-RAY FLUORESCENCE ANALYSIS

The major elements have been analyzed by X-ray fluorescence (XRF), with a Philips PW 1404 spectrometer, using glass beads prepared according to the method of Norrish and Hutton (1969). Twenty-five international standards were used, refined by least squares procedures, using Philips model PW 1492 software for calibration. Trace elements were determined by XRF, using pressed powder pellets. The standards and software used for the major elements were also used for the calibration of the trace elements.

Twelve samples collected from three different locations have given the following mean values shown in Table 1.

X-RAY DIFFRACTION ANALYSES

X-ray analysis was performed using a Philips powder diffractometer (PW 1710) with CuKa radiation. All specimens were continuously scanned from 10 to 60º 2θ in increments of 0.5º 2θ per minute. The digitized scans were then fitted with the PW-1877 curve program (version 3.6).

Diffractometer tracings from the fine-grained black sediments consist of broad diffraction bands with superimposed sharp peaks due primarily to detrital quartz. Minor amounts of birnessite, goethite, kaolinite, and possible romanechite, pyrolusite, todorokite, and hollandite were identified in most of the samples. In all cases, the broad but consistent character of the diffraction maximum indicates a material that is poorly crystallized but certainly not X-ray amorphous.

After heating the samples to 1000ºC and performing a new series of X-ray diffraction measurements, the spectra were better resolved. They showed sharp peaks due to Mn-Al-Fe rich spinels, pyrolusite, hausmanite, hematite and quartz. This mineral association revealed that the initial black sediments are composed of amorphous aluminium and silica gel-like material and poorly crystallized oxides and hydroxides of manganese and iron.

SCANNING ELECTRON MICROSCOPE ANALYSIS

Several perfectly rounded spheres with diameters ranging from 4 to 12.5 mm were observed when SEM analyses were carried-out (Figure 2). We also performed several energy dispersive secondary X-ray analyses (EDX) using Tracor NORTON's SQ program, which applies multiple least square analysis and ZAF matrix correction procedure to calculate elemental concentration using a library of references stored on disc. The EDX spectra of the spheres show that they are made

Table 1. Chemical Analyses of the Black Ferromanganese Coatings from Vântului Cave.

Component	Weight Percent	Parts per Million
SiO_2	28.35	
MnO_2	27.32	
Al_2O_3	19.80	
Fe_2O_3	4.02	
CaO	3.99	
K_2O	1.32	
MgO	0.74	
TiO_2	0.50	
Ni	0.45	
Ba	0.36	
S	0.29	
Co		860
V		219
La		762
Ce		938
Sm		93
Nd		448

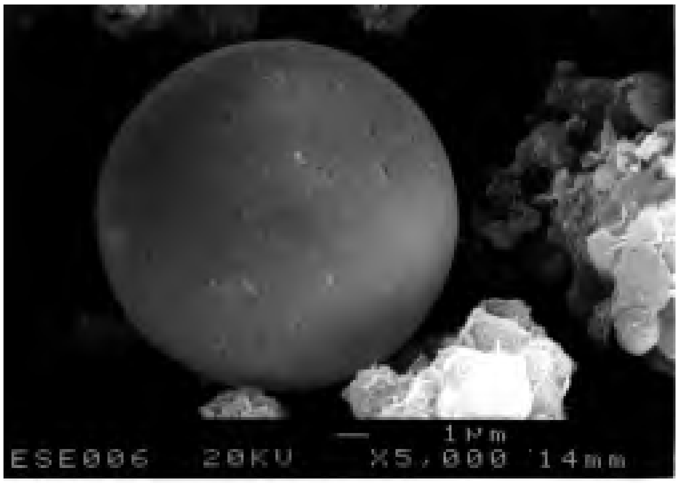

Figure 2. Uncovered sphere made up of iron and rare-earth elements.

up of iron and an association of rare-earth elements (REE), including Ce, La, Sm, and Nd (Figure 3).

SEM indicates the black precipitate is composed of welded botryoidal-like agglomerates covered by clusters of thin platy crystals with pseudo-hexagonal symmetry (kaolinite) (Figure 4).

THERMAL IONIZATION MASS SPECTROMETRY

Nd isotopic composition and Sm and Nd concentrations were measured at the Department of Geology, University of Bergen on a Finnigan 262 instrument. All chemical processing was carried out in a clean-room environment with HEPA filtered air supply and positive pressure. The reagents were either purified in two bottle teflon stills or passed through ion-exchange columns. Sample were dissolved in a mixture of HF and HNO_3.

Rare-earth elements were separated by specific extraction chromatography using the method described by Pin et al. (1994). Sm and Nd were subsequently separated using the method described by Richard et al. (1976). Sm and Nd were loaded on a double filament and analyzed in static mode. Nd isotopic ratios were corrected for mass fractionation using a $^{146}Nd/^{144}Nd$ ratio of 0.7219. Sm and Nd concentration were determined using a mixed $^{150}Nd/^{149}Sm$ spike. Repeated measurements of the Johnson Matthey Nd standard yielded an average $^{143}Nd/^{144}Nd$ ratio of 0.511113 ± 15 (2s) (n=62).

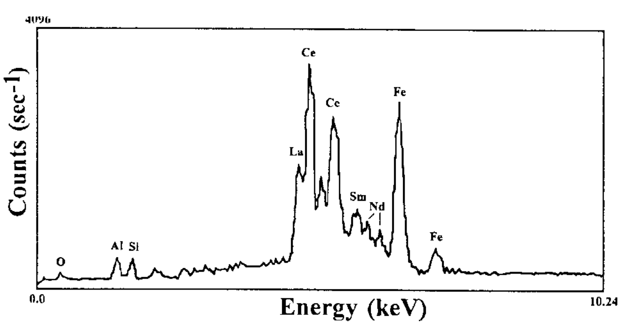

Figure 3. Energy dispersive X-ray spectrum for an uncovered sphere.

The $^{143}Nd/^{144}Nd$ ratio measured for 3 samples collected in the lower part of the cave stream shows very similar values (Table 2). These values are extremely close or equal to those measured for the bauxitic clay from above the cave and red residual clay accumulated either in the cave environment or at the surface (Table 2).

Table 2. $^{143}Nd/^{144}Nd$ ratio measured for various samples.

Black Ferromanganese Sediment		
Sample I	**Sample II**	**Sample III**
0.512206	0.512209	0.512208
Bauxitic Clay		
0.512206		
Red Residual Clay		
Cave	**Surface**	
0.512207	0.512209	

DISCUSSION AND CONCLUSIONS

The various analyses to which the black sediments were subjected suggest they are composed of amorphous aluminium and silica gel-like material, birnessite and other poorly crystallized oxides and hydroxides of manganese and iron. Among the minerals ascribed to the later group are: romanechite, todorokite, pyrolusite, rhodochrosite, goethite and possible hollandite. The mechanism suggested for the deposition of the black coatings in Vântului Cave is one controlled by *E*h and pH (Onac et al., 1997). The role played by micro-organisms is not exactly known, but the analyses undertaken so far on these black speleothems suggest them as a potential factor in manganese and iron deposition.

In continental systems, percolation of rain water through the rocks will result in low-temperature chemical weathering reactions that will slowly break down the primary minerals, resulting in mobility of the REEs. The chemistry of groundwaters is dependent on the physicochemical environments through which it has passed. A higher content of HCO_3^- in natural waters will cause a higher solubility of the heavy REE compared with the light REE (Herrmann, 1978).

The behaviour of the REEs can be significantly influenced by pH. A decrease in pH will favor solution of the REEs and their transport either as complexes or as free ions. An increase in pH can result in one or all of the three processes: precipitation of the REEs as hydroxides or carbonates, exchange of the REEs for H^+ on accessible mineral exchange sites, and adsorption onto the surface of minerals (Balashov et al., 1964). We believe the third process is most likely occurring in Vântului Cave as we found the pH to vary downstream from 5.1 to 8.

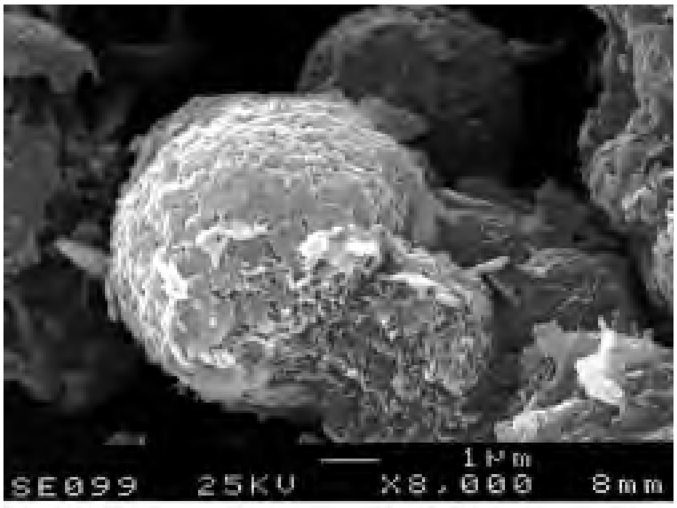

Figure 4. Botryoidal-shaped agglomerates covered by clusters of thin platy crystals.

The ferromanganese oxide surfaces have an ability to absorb appreciable quantities of ions from solution, particularly favoring the cations of transition metals and REEs.

The $^{143}Nd/^{144}Nd$ ratios in the black coatings are ~ 0.512207, an identical value to that found in two other samples from above the cave (bauxitic and red residual clay). The similarity of this ratio to that of karst-bauxite sediments suggests the REEs were readily removed from above the cave by percolating water and concentrated in the cave environment. The REEs were incorporated into the black ferromanganese coatings by coprecipitation with particulate iron colloids or other nodular phases.

The possible sources of the REEs (based on $^{143}Nd/^{144}Nd$ ratio) in the black coatings from Vântului Cave are dominated by continental input, the main source being an Upper Jurassic igneous rock (e_{Nd} (0) = -10.5). The e_{Nd} (0) of about -1.39 found in all samples suggests there is an additional source of Nd to this area with a higher e_{Nd} (0), possibly Nd released from weathering of some young rhyolitic rocks that outcrop in the central part of the Padurea Craiului Mountains.

The conclusions presented here will remain tentative until further work can establish more precisely the behavior of the REE and Nd isotopes in the black coatings from Vântului Cave. Nevertheless, they do provide an indication of the potential of Nd isotopes, in particular, as a tool with which to approach paleochemistry studies in the cave environment.

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Michael B. Barber and David A. Hubbard, Jr.-Overview of the Use of Caves in Virginia: A 10,500 Year History. *Journal of Cave and Karst Studies 59*(3): 132-136.

OVERVIEW OF THE HUMAN USE OF CAVES IN VIRGINIA: A 10,500 YEAR HISTORY

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The human utilization of caves within the Commonwealth of Virginia began early in prehistoric times and has extended to the present. Such use often has focused on the exploitation of removable resources; knappable lithic materials for the production of stone tools is an important prehistoric example. During historic times, the mining of saltpetre dominates although other natural resources also were removed.

The human interaction with caves, however, extends well beyond raw material extraction into the realm of ceremonialism and supernaturalism. Within a Virginia context, Native American use of caves includes both human interments and the codification of symbols. Cave burials have long been known and appear to include attitudes of elaborate ceremonialism as well as less intricate body disposal systems. The mud glyph cave phenomenon has been recorded in Virginia with incised designs and anthropomorphic figures apparently mediating between the sacred and the mundane. Such symbols have roles in rites of passage.

Historic use usually is framed in a more functional light. While resource extraction is an obvious utilization realm, the historic use of caves for other purposes is prevalent and includes resort recreation, scientific study, aesthetics, and general exploration. Caves can be discussed in terms of modern symbols and ceremonialism.

North America was devoid of humankind for the vast majority of its evolution. Although several archaeological resources show promise of an earlier occupation of the New World, current scientific evidence strongly confirms dates in the range of 9500 BC. As this migration of the new species came across the Bering Strait Land Bridge, which was exposed at the end of the Late Pleistocene, it was likely not until circa 9200 BC. that the first human set foot within the Commonwealth of Virginia (Gardner, 1989). In a turbulent period of climatic change and species extinctions, the Paleoindians (as they are called) focused their concerns on subsistence activities and the procurement of lithic resources for stone tool production that led to settlement patterns centered on the jasper of the Flint Run area of Shenandoah and Warren Counties, the cherts of the Williamson Site area in Dinwiddie County, and game rich areas such as Saltville in Smyth County and the Dismal Swamp in Virginia Beach. This early smattering of humans was busy in gathering food, dealing with the climatic and environmental changes of the end of the Ice Age, and producing the repertoire of tools necessary for such activities. No ties between Paleoindian peoples and cave resources has yet been established.

As the climate settled gradually into the warmer Holocene, and the human population during the Archaic Period (8500-1000 BC) increased, more extensive and intensive use of the environment was made (Barber, 1992). Caves were still not broadly sought out, but the use of rock shelters and cave entrances for shelter increased through the period. During the Woodland Period (1000 BC - AD 1650), people added intensive gardening to their repertoire of gathering and hunting, eventually resulting in increased sedentism, major village complexes, and the social stratification of some societies. More intensive use of caves developed during this period for the ceremonial pursuits of mediating with the spirits and\or the disposal of the dead, whether expedient or with more elaborate after-life concerns (Clark, 1978).

The Native American cultures of the Americas were subject to European impacts, which severely altered social trajectories, territories, material goods, health, and demographies. Cave utilization by these new emigrants from across the Atlantic included a plethora of historic uses such as onyx extraction, water sources, food storage, moonshine stills, transient hunting and gathering camps, and animal enclosures. Ironically, old graffiti are protected from new graffiti. The historic extractive industry focused on the removal of saltpetre.

As an overview document, this paper presents resource types with illustrative examples. Caves are discussed as prehistoric encampments including rock shelters, prehistoric burial caves, glyph caves, and historic saltpetre mines.

PREHISTORIC ENCAMPMENTS

Cave entrance ways and rock shelters provide protection from the elements in an energy cost-effective manner. This was not lost on the prehistoric Native Americans of Virginia, and these geomorphological features were occupied from Early Archaic times (ca. 8500 BC) to the European Contact Period (ca. AD 1650). Although there were disadvantages, such as the sharing of the occupiable space with other animals, and lessened mobility necessitating longer trips to water and other resources, the ease of occupation and protection from the elements apparently outweighed such inconvenience. From an archaeological standpoint, cave entrance ways and cliff-base rock shelters have unique attributes that make them particularly important in understanding the past. If they were continually occupied, they may preserve relatively undisturbed cultural deposition that can span thousands of years. In addition, due to the general protected nature and dryness, many botanical (plant) remains are preserved that would completely decompose in open-air sites. Although burials are sometimes included in the fill (e.g., Geier, 1980), these interments often derive from other habitation sites and do not necessarily involve the same activity sets as burial caves.

DAUGHERTY'S CAVE

The excavation of Daugherty's Cave is likely the most important contribution to understanding culture history in southwestern Virginia. Daugherty's Cave is a northeast-facing cave entrance with a high roof and accommodating space. In addition, a circa 50°F (10°C) air current continually moves through the cave, keeping it cool in summer and warm in winter. During excavation by Benthall (1990) in the late 1960s, 300 square feet of the cave entrance floor area was removed, including 44 cultural features. These included charcoal pits, refuse pits, hearths, ash pits, and stone-filled pits. The distribution of features included pits and hearths in the upper levels, and only hearths in the lower levels. Six hundred eighty-one pot sherds were recovered including Late Woodland shell-tempered ceramics (N=67), Late Woodland sand-tempered ceramics (N=17) and Early to Late Woodland limestone-tempered ceramics (N=697). Lithics included 9,256 artifacts of local cherts, rhyolite, ferruginous quartzite, silicified limestone, and steatite. Dominated by projectile points, 15 identified types were present from the Early Archaic Kirk corner-notched, through Middle Archaic Cedar Creek points, Late Archaic Savannah River points, and Late Woodland triangular arrow points. Other lithics included gravers, knives, scrapers, blanks, and flaking debitage. Faunal remains were dominated by white-tailed deer, black bear, and elk (as per estimated meat totals), but also included beaver, river otter, raccoon, turkey, passenger pigeon, and various other small mammals and birds, snakes, toads, and fish. Archeobotanical remains included corn, hickory nuts, walnuts, and hackberry seeds. Overall, Daugherty's Cave offers great insight into Native American lifeways.

The greatest contribution from the excavations of Daugherty's Cave, however, is the undisturbed stratigraphy, which allows the sorting of cultural activities by time period. Ten stratigraphic zones were noted within the circa 7.5 feet of natural and cultural deposition. At the bottom of the column were two sterile levels, one of brown sand and shell overlain by a level of rock fall. Above this sterile base were the following deposits (Benthall, 1990:92-96):

Zone J - 0.2 - 0.5' (6.096 - 15.24 cm) thick dark grey ashy level. One Kirk Corner-notched point and one unifacial side-scraper were recovered indicative of the Early Archaic with a radiocarbon date of 7840±400 BC obtained. Activities during this period included hunting, hide-working, and stone tool reduction. The occupation is seen as a short-term occupation, transient camp.

Zone I - 0.4 - 1.2' (12.192 - 36.576 cm) light yellow, tightly consolidated clay which contained no artifacts.

Zone H, G, and F - Zone H and F consisted of 0.5' to 1.0 - 1.1' (6.096 to 30.48 - 33.528 cm) of dark gray to black ashy fill interrupted by Zone G, a sterile stratum of yellow to brown fill. These occupation zones were marked by Middle Archaic Cedar Creek points. Activities during this period included hunting, gathering, and shell fish harvesting.

Zone E - 0.2' - 0.8' (6.096 - 19.507 cm) of sterile orange clay.

Zone D and C - Zone D was a 0.2' to 0.9' (6.096 - 27.432 cm) yellow-orange clay containing gravel under Zone C a 0.4' to 0.7' purplish-brown fill. Savannah River points of mostly grey silicified limestone were recovered from this level. Dating to the Late Archaic (3500 - 1000 BC), on-site activities included hunting, hide processing, woodworking, lithic reduction, and food processing.

Zone B - 0.5' to 1.0' (15.24 - 30.48 cm) of yellowish-orange clay with evidence of Early Woodland occupation of circa BC 500 to AD 1. With influences from East Tennessee, Long Branch fabric-impressed Long Branch Series pottery was recovered in this zone. Pits begin to appear and triangular and notched projectile points were collected. During this period the site functioned as a temporary food procurement camp.

Zone A - 1.5' to 3.0' (45.72 - 91.44 cm) of light to dark grey ashy fill with artifacts dating to the Middle and Late Woodland Period. Ceramics of the Wright Checked Stamped and Mulberry Creek Plain mark the Middle Woodland. Activities during this occupation included hunting, butchering of animals, hide working, general food processing, and lithic reduction sequences.

The Late Woodland Period was represented by a food procurement station. Seen as a support settlement for a large palisaded village, activities at Daugherty's Cave focused on the production of meat to augment the horticultural diet of corn, beans, and squash. Activities included hunting, food production, wood and bone working, butchering, and lithic reduction.

The stratigraphic sequence of the occupation of Daugherty's Cave allows for the understanding of cultural change through time. Beginning 10,500 years ago with an ephemeral hunting camp and ending possibly 350 years ago with a very different secondary camp focused on providing protein to a major village, the entrance deposits document evolving cultures of the area.

COEBURN EXCHANGE ROCK SHELTERS

Another study that lends insight into the understanding of the past is the study of the prehistoric occupation of rock shelters in Wise County, Virginia (Barber, 1980; 1985). The study area is a 1700 acre tract along the Guest River in Wise County under management by the USDA-Forest Service, that was proposed for exchange out of federal control. Under the National Historic Preservation Act of 1966 (as amended), such a transfer of potentially significant archaeological resources out of federal control would be seen as an adverse impact. In order to determine the cultural resource base, archaeologists undertook a Phase I archaeological survey in the late 1970s, with limited Phase II testing in 1981 and 1983 (Rogers, 1982; Barber, 1985).

Of interest here are the 34 prehistorically occupied rock shelters. Located along the tributaries of the Guest River in a dendritic drainage pattern, the Lee Conglomerate sandstone cliff line concavities proved attractive to both historic and prehistoric populations. Evaluation of the details of occupation for the shelters is based on examination of looters' backfill, limited subsurface testing, intensive Phase II evaluations, or some combination of these.

One of the more important aspects of the study relates to the change in land use through time. During the earliest occupation during Early Archaic times (8500 - 6500 BC), the shelters were sporadically used as transient camps with more complex base camps located elsewhere, probably along the more productive and varied flood plains and terraces of the Guest and Clinch River drainages. This pattern of limited use continued through the Middle Archaic (6500 - 3500 BC) and Late Archaic (3500 - 1000 BC) Periods, with a total absence of occupation during the Early Woodland Period (1000 BC - AD 500). A transient use of the area returns during the Middle Woodland Period (AD 500 - AD 1000).

The most frequent and complex use occurred during the Late Woodland Period (AD 1000 - AD 1650) when sites seem to have been both base camps and transient camps. During a period of major occupation in large villages on the flood plain, the rock shelter forays were likely aimed at the exploitation of game animals. Again, the acquisition of protein in the form of meat was needed to augment the horticultural diet. As village populations grew, environmental stress may have been brought to bear on the river systems, and the availability of prime food animals moved to the hinterlands. This would be reflected within the Coeburn Exchange by the presence of fragmented task force groups at both base camps and more satellite transient camps.

An alternative can be put forth for the added complexity of sites in the Coeburn area. This would relate to the establishment of a more complex, regional political system. If a chiefdom developed further to the south in Late Woodland times (or during the coeval Mississippian of that area), people in this headwater locale may have felt some direct or, more likely, indirect impacts. Based on the distribution of ceramics (Holland, 1970; Barber, 1985), it appears that Wise County was on the periphery of such developments. What may have developed in the area would have been a buffer zone or game reserve function where groups hunting deer may have exploited the area using the convenient rock shelters for camps.

Hence, the rock shelters occupied during prehistoric times offer a unique vehicle for understanding cultural change through time. Although disturbed by looting, the information they contain can be coupled with studies such as the excavation of Daugherty's Cave in order to develop an understanding more regional in scope. As a footnote, due to the significance of the cultural resources within the project area, the tract remains under federal control.

BURIAL CAVES

A number of caves in Virginia, particularly in the southwest corner along the Powell, Clinch, and Holston Rivers, have been used during prehistoric times for the disposal of the dead (e.g., Caldwell, 1951; Newman, 1951; Holland, 1970; Clark, 1978). Burial techniques in limestone caves vary across space and possibly across time. Interments run the gamut from disposal from above into relatively deep, vertical-drop caves to elaborate interments involving controlled placement with numerous and exotic grave goods. Scientific understanding of cave burials is severely impaired by the frenzy of uncontrolled looting of these resources. The condition of most of these cave burials at present consists of looters' pits and scattered human bones with any artifact contents removed for sale.

Although the burial cave phenomenon can be seen across southwestern Virginia, there do appear to be differences when moving from west to east. In the far southwest corner of Virginia, these natural burial chambers likely relate directly to the Dallas culture and people, who entered the area during Mississippian times. To the east, however, the cave interments of Smyth and Washington appear to be under Mississippian influence but not of Mississippian culture. In this area, cultural complexity may also have been at the chiefdom level with differential distribution of wealth items. Access to exotic and energy-expensive Mississippian trade items may have been tied to the exploitation and controlled distribution of Saltville salt (Barber & Barfield, 1991). In any case, the local populace adopted numerous traits from east Tennessee, among which may have been cave burial concepts. The intervening area may be transitional, involved with cave burial but lacking the wealth of the eastern group.

What is apparent is the geographic space between the burial cave in Page County and the remainder of cave interments. Located well over 200 miles northeast from its nearest counterpart, the 5+ burials at 44PA4 (Manson & MacCord, 1952) represent a cultural anomaly.

BULL THISTLE CAVE

Of the current total of 37 known burial caves in Virginia, only three remain relatively undisturbed by looters. Prime among these is Bull Thistle Cave, a vertical shaft pit cave (Willey & Crothers, 1986). The cave was first noted by a group of cavers in early 1985. The existence of the burial cave was reported to the local Crab Orchard Museum and subsequently the Virginia Department of Historic Resources, which, in turn, contracted with the Midsouth Anthropological Research Corporation of the University of Tennessee. Their task was to map the cave, determine the extent of surface material, identify human skeletal material and artifacts, and make management recommendations.

The cave is within the Ridge and Valley Province at the headwaters of the Clinch River. Entrance was limited to a 65-foot drop, and the cave proved to have a length of 575.2 feet (175.32 m) and a vertical extent of 119 feet (36.27 m) (Willey & Crothers 1986:1, 16). The cave was divided into a main room containing the talus slope of soil and debris from the entrance above, a smaller western alcove, and a lower eastern room containing a stream. Cultural material was confined to the main room and alcove. The distribution of skeletal material suggests that the corpses were cast down or lowered into the pit from above, with a likely original position just to the east and below the apex of the cave's talus slope. As decay of the flesh advanced, gravity moved the skulls downslope, with most crania moving to the base. Although some bones were moved up into the western alcove above the level of the talus, rodent activity is a likely explanation for this anti-gravity phenomenon. The skeletal material, however, remains *in situ* in the sense that only natural movement has occurred, with relatively little recent human alteration.

Due to the research design that specified only surface material was to be examined, and due to the nature of deposition on and within the talus slope, numerous human bones and individuals remain buried within the soil matrix. On the cave floor surface, ninety-one human elements were noted. These elements were from all parts of the body, with a minimum number of eleven individuals determined. The count included 2 children, 1 adolescent, and 8 adults. Of the adults for which sex could be determined, 2 males and 2 females were present. When statistically compared with the nearby skeletal sample from the Crab Orchard Village Site, there appears to be no difference in the age distributions. Hence, there was no age-determined preference towards cave burials (Willey & Crothers, 1986).

A single artifact was recovered from the Bull Thistle Cave by the initial cave group (Willey & Crothers 1986). This was the stem and part of the bowl of a smoking pipe tempered with crushed mussel shell. The bowl is set at an obtuse angle with the stem and resembles an alate-stemmed tube or modified tube pipe, a type common in southwestern Virginia (Willey & Crothers, 1986; Gunthe, 1965). This style of pipe dates to late prehistoric times and is probably the result of interaction with the Mississippian cultures of east Tennessee (Egloff & Reed, 1980; Holland, 1970). Willey and Crothers (1986) use the pipe's association with the skeletal material to date the cave burial period to between AD 1300 and AD 1600.

Willey and Crothers (1986:30) indicate that "Bull Thistle Cave is remarkable." If anything, this is an understatement. The cave contains human remains and fossilized behavior that lend insight into regional cultural patterns that have been lost on at least 36 other sites.

MUD GLYPH CAVES

Two mud glyph caves have been discovered in Virginia, both at the headwaters of the James River. Access to these resources is restricted, and locational data are protected by the owner and/or manager. In comparison to most of the burial caves, the glyph caves are horizontal features relatively easy to enter without the necessity of vertical techniques. The caves' histories involved previous flooding, mud deposition on the side walls, and finally stream migration where the water disappeared but the mud remained. The final element was discovery and use by Native American cavers, who took full advantage of the subterranean *tabula rasa* afforded by the mud-coated passage walls. A C14 date from one cave suggests an early Late Woodland use (ca. AD 900-1000), while the use of the second cave dates slightly later in the range of A.D. 1200 - 1450. All carbon samples were the result of charcoal collection from the remnants of pine torches used by the artists and possible entourage.

The glyphs are fairly extensive, overlapping in some cases. They are simple in execution in the sense that the mud was easily incised with either finger or sharp object. The artistic execution and symbolic messages, on the other hand, are highly complex. Included are renditions of 3 to 4 parallel serpentine lines, circle mazes, chevrons, relatively parallel straight lines, ovoid eye motifs, zigzags, meanders, anthropomorphic figures, torch jab marks, and gouge damage (Tolley, personal communication; Faulkner, 1994). Although some of the glyphs may date to the Late Archaic, most were likely initiated during the Late Woodland Period. Reminiscent of glyph caves in East Tennessee and the symbolic renditions in the Mississippian Southeast (Faulkner, Deane, & Earnest, 1984; Faulkner, 1986; Muller, 1986; Henson, 1986), the glyphs are absolutely out of place at the headwaters of the James River. Whether brought to the area by some wayward emissary, compassless wanderer, or powerful ideation, the symbols and messages are not consistent with the current understanding of the Late Woodland of the region.

HISTORIC SALTPETRE MINING

The removal of nitrates or saltpetre from cave deposits within the karst areas of the Ridge and Valley Province of Virginia has been important since colonial and national times. During the Revolution, War of 1812, and the Civil War, blockades hindered the importation of foreign gunpowder and spurred the acquisition of domestic saltpetre, which was processed and blended with charcoal and sulphur to produce gunpowder. The production of saltpetre from composted beds, from the walls of old cellars, from stables, and beneath houses and barns was important in colonial times, but production from cave deposits eclipsed the other sources in Virginia and other southern states by the time of the Civil War (Paepe & Hill, 1981). As outlined by Faust (1964), the saltpetre processing included mining the "cave earth" and placing it in vats, puddling it with fresh water for several days, and allowing it to drain. Potash salt was added to the leachate water exchanging potassium for calcium, and the amalgam underwent fractional crystallization yielding potassium nitrate. Further processing and blending with charcoal and sulphur produced gunpowder.

Saltpetre mining and processing left significant evidence of these historic events, with the identification of 88 saltpetre caves in the Commonwealth (Hubbard, 1995). Excavations, mattock marks, old sediment levels on walls, piles of hand-picked stone along passage walls and in alcoves, piles of sieved clay clasts and small stones, and tally marks quantifying production are some of the remaining evidence of mining. Path modifications include stone and cut clay steps, plank ramps and bridges, and demountable and notched log ladders. Tools left behind, including winches, scraping paddles, pry bars, bag-mouth-spreaders, grapples, torch stubs, vats and vat fragments, troughs and trough fragments, and kettles, are dwindling in numbers as visitors remove, trample, and burn these artifacts (Clark, 1978; Faust, 1964; Hubbard 1995).

CONCLUSION

Although this paper has been confined to resources found within a Virginia context, the potential archaeological significance of caves is global in nature. Cave resources are many, varied, significant to the understanding of the past, and extremely fragile. Education, preservation, and protection are concepts not limited to speleo-archaeological resources, but also apply to a plethora of cave phenomena that demand our work and attention.

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STABLE ISOTOPE ANALYSIS OF HUMAN REMAINS: A TOOL FOR CAVE ARCHAEOLOGY

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Stable isotope analysis of human remains is a research tool that can provide paleodiet information for archaeological sites, such as caves, where traditional evidence may be missing or out of context. Unlike other lines of evidence, the stable isotopes of carbon and nitrogen in human bone reflect the chemistry of the diet and therefore provide a direct measure of the foods consumed. As an example, the data from isotopic analyses of bone from the Mer site (44LE280), a cave in Lee County, Virginia, are presented. Although this site lacks faunal and floral remains to provide basic information about the availability and potential utilization of food resources, the stable isotope data from other sites throughout Virginia and North Carolina provide a basis for comparison. The $\delta^{13}C$ and $\delta^{15}N$ values for the cave burials suggest a diet composed of primarily C_4 plant proteins and some terrestrial animal proteins.

To understand a past civilization, knowledge about its subsistence strategy is necessary. Unlike other paleodietary indicators, the stable isotopes of carbon and nitrogen in human bone reflect the chemistry of the diet and therefore provide a direct measure of the foods consumed. Traditional methods of diet determination focus on an often incomplete and sometimes misleading archaeological record of faunal and floral remains, artifacts, or other cultural evidence associated with a site to provide information on available food resources, procurement strategies, and processing methods. However, population mobility and differential artifact preservation make quantification of the relative inputs of foods difficult. Ethnohistoric accounts generate a general outline of potential food items and their relative importance, but such accounts are usually biased by the observer and present an idealized view of past cultures. Observations of dental attrition, caries, and general health also provide information about what may have been consumed.

Stable isotope analysis of human remains is an especially valuable research tool in archaeological sites, such as caves, where traditional dietary evidence may be missing or out of context. For example, the Mer site, a cave in the extreme southwest corner of Virginia, lacks faunal and floral remains to provide basic information about the availability and potential utilization of food resources. Comparison of the stable isotope data for human bone recovered at the site with isotope data from other sites throughout Virginia and North Carolina provides specific information about the primary dietary components. The $\delta^{13}C$ and $\delta^{15}N$ values for the Mer site burials suggest a diet composed of primarily C_4 plant proteins and some terrestrial animal proteins.

In the first half of this paper we present stable isotope theory, interpretation, and methodology. Stable carbon and nitrogen isotope data for burials recovered from the Mer site are presented and discussed in the second half. Comparison to data from two other archaeological sites, Parker (31DV4) in Davidson County, North Carolina, and Shannon (44MY8) in Montgomery County, Virginia, facilitates interpretation of the Mer site data.

STABLE ISOTOPE THEORY AND INTERPRETATION

Isotopic compositions of carbon and nitrogen are expressed as

(1)

$$\delta^{13}C\ (^o/_{oo}) = [[(^{13}C/^{12}C_{sample})/(^{13}C/^{12}C_{standard})]-1] \times 1000$$

(2)

$$\delta^{15}N\ (^o/_{oo}) = [[(^{15}N/^{14}N_{sample})/(^{15}N/^{14}N_{standard})]-1] \times 1000$$

The $\delta^{13}C$ and $\delta^{15}N$ values are expressed relative to the international standards Pee Dee Belemnite (PDB) and atmospheric nitrogen (N_2), respectively. A substance with an isotope ratio less than that of the standard will have a negative δ value, and is said to be depleted in the heavy isotope relative to the standard. A substance that is enriched relative to the standard will have a positive δ value.

Isotopic fractionations that occur during the uptake and conversion of CO_2 into plant carbon influence the carbon isotope ratios of terrestrial plants. It is well established that C_4 plants have average $\delta^{13}C$ values around -12.5‰ relative to PDB, whereas C_3 plants have average $\delta^{13}C$ values around -26‰ (Bender, 1968; van der Merwe & Vogel, 1978; Vogel, 1980; van der Merwe, 1982; Matson and Chisholm, 1991). Most terrestrial plants are C_3 plants. Most of the edible C_4

plants in North America are species that have been domesticated, such as maize, sugar cane, sorghum, millet, some grains belonging to *Amaranthus* sp., and some members of the *Chenopodiaceae* family (e.g., *Atriplex* sp. and *Kochia* sp.). The domesticated *Chenopodium berlandieri* found at some archaeological sites is a C_3 plant (Smith, 1985; Spielmann, et al., 1990). Plants, such as succulents, that use the Crassulacean acid metabolism (CAM) photosynthetic pathway can have $\delta^{13}C$ values similar to either C_3 or C_4 plants, depending on environmental factors (O'Leary, 1981, 1988).

The observed isotopic fractionation that results from the assimilation of dietary carbon and nitrogen varies according to the tissue type sampled and the diet. Based on a study of mice and insects raised on known, monotonous diets, the $\delta^{13}C$ value for the homogenized whole body of a consumer is enriched by about 1‰ over the diet; bone collagen may be enriched by about 2.0‰ to 3.7‰ over a vegetarian diet (DeNiro & Epstein, 1978; Bender, et al., 1981). A study by Schoeninger and DeNiro (1984) of modern terrestrial and marine food webs showed an enrichment of about 5‰ between plants and the bone collagen of herbivores; the enrichment between the bone collagen of subsequent trophic levels (e.g., herbivore and carnivore) was only 0‰ to 1‰. Using an average collagen enrichment of about 2‰ for a consumer relative to the plant base, the bone protein of a terrestrial herbivore eating only C_3 plants should have $\delta^{13}C$ of about -26‰ plus 2‰, or about -24‰, whereas a consumer of only C_4 species should have a $\delta^{13}C$ of -12.5‰ plus 2‰, or -10.5‰. Intermediate $\delta^{13}C$ values for a vegetarian would indicate a mixed diet of C_3 and C_4 plants. The $\delta^{15}N$ values for bone protein consistently have been shown to be enriched about 3‰ relative to the food source (DeNiro & Epstein, 1981; Minagawa & Wada, 1984; Schoeninger & DeNiro, 1984). Terrestrial herbivores and carnivores have average $\delta^{15}N$ values of 5.3‰ and 8.0‰, respectively.

It has been demonstrated that the combination of stable carbon and nitrogen isotopes can be used to distinguish between terrestrial and marine food sources (DeNiro & Epstein 1978, 1981). Marine plants use dissolved bicarbonate, rather than atmospheric CO_2, during photosynthesis. Bicarbonate is about 8.5‰ more enriched in ^{13}C than atmospheric CO_2 (Schoeninger & DeNiro, 1984). Marine plants utilize dissolved nitrate and ammonium and are about 7‰ to 10‰ more enriched in ^{15}N than terrestrial plants. Thus, the $\delta^{15}N$ value for marine animals feeding on fish is 16.5‰, and the $\delta^{15}N$ value for marine animals feeding on invertebrates is 13.3‰ (Schoeninger & DeNiro, 1984). It follows that marine animals have higher $\delta^{15}N$ and $\delta^{13}C$ values than terrestrial animals, owing to the more positive $\delta^{15}N$ and $\delta^{13}C$ of marine plants. This difference will be passed on to human consumers of marine foods (Norr, 1981; Tauber, 1981; Chisholm, et al., 1982, 1983; Schoeninger, et al., 1983; Hobson & Collier, 1984).

Isotopic studies of paleodiet are based on the observation that the stable carbon and nitrogen isotopes of an organism appear to be maintained in its bone following death (DeNiro & Epstein, 1978, 1981). The earliest applications of stable isotope analysis to human dietary research utilized stable carbon isotopes and focused on the timing of the introduction of maize agriculture to various regions throughout North America. For example, isotopic analyses of human bones from archaeological sites in Ohio, Illinois, New York, and West Virginia revealed a gradual shift in diet from the Late Archaic period (around 2000 BC) to the Upper Mississippian period (around AD 1300). The $\delta^{13}C$ values (-21.9‰ to -21.1‰) for human bone collagen from 37 individuals from seven sites suggested a lack of C_4 plants (presumably maize) in the diet in that area prior to the Late Woodland period (Vogel & Van der Merwe, 1977; van der Merwe & Vogel, 1978; Bender et al., 1981). The $\delta^{13}C$ values for 72 individuals from 17 sites increase from -20.0‰ for the Late Woodland period to -9.1‰ for the Upper Mississippian period (around AD 1300) (Vogel & Van der Merwe, 1977; van der Merwe & Vogel, 1978; Bender et al., 1981; Farrow, 1986; Buikstra & Milner, 1991). It appears that reliance on C_4 plants increased steadily through this period. A similar shift in $\delta^{13}C$ values was seen in southeast Missouri and northeast Arkansas around AD 1000 (Lynott, et al., 1986). Late Archaic, Woodland, and early Mississippian bone samples from ten individuals from eight sites had $\delta^{13}C$ values of -21.7‰ to -19.9‰, whereas ten later Mississippian and Euro-American samples from seven sites had $\delta^{13}C$ values of -15.8‰ to -10.4‰.

In the American Southwest, faunal and floral samples of potential food items from archaeological sites in Cedar Mesa, Utah, provided baseline $\delta^{13}C$ values of -9.9‰ for maize, -23.8‰ for pine nuts and rice grass, -17.0‰ for mountain sheep, and -20.6‰ for deer (Matson & Chisholm, 1991). All of the Anasazi Indian bone samples had $\delta^{13}C$ values ranging between -7.1‰ and -7.9‰, clearly indicating a heavy reliance on a C_4 plant such as maize. There was no evidence of other C_4 plants or CAM plants in the coprolite (paleofecal) and floral samples from these sites that could account for the high $\delta^{13}C$ values.

Other studies have focused on differentiating between the resources exploited by coastal and interior populations. For example, populations subsisting on a marine economy (Alaskan Eskimos and Northwest Coast Indians) had $\delta^{15}N$ values ranging from 17‰ to 20‰, whereas populations with an agricultural economy (manioc farmers from Columbia, South America; Mesoamerican maize agriculturalists; and grain growers from the Neolithic period in Europe) had $\delta^{15}N$ values ranging from 6‰ to 12‰. Groups utilizing a mixture of marine and terrestrial foods had intermediate $\delta^{15}N$ values (Schoeninger, et al., 1983).

Although most stable isotope studies isolate bone collagen for analysis, it is not clear that true bone collagen survives post mortem deposition (DeNiro, 1985; Masters, 1987; Tuross, et al., 1988). The organic fraction of fresh bone consists of 90% collagen, 5% noncollagenous proteins, and 5% lipids and carbohydrates. Lipids and carbohydrates leach rapidly from bone after burial. Collagen is relatively insoluble, owing to linkages between its triple helix polypeptide chains, and is not strongly bound to the inorganic matrix of the bone. Noncollagenous proteins are acidic polypeptides that adsorb strongly to the bone mineral matrix of hydroxyapatite. As bone degrades, the adsorbed acidic proteins and peptide fragments are preferentially retained, whereas the collagen is lost (Masters, 1987). Therefore, fossil bone most likely contains noncollagenous proteins and collagen in proportions different from fresh bone; highly degraded bone may contain only traces of collagen. As suggested by Masters (1987), the composition of these two proteins in the organic fraction of bone or dentin should not affect the isotopic ratios of carbon and nitrogen.

The most common method of sample preparation to isolate organic matter from bones is the method of DeNiro and Epstein (1981) as modified by Schoeninger and DeNiro (1984). Briefly, powdered bone is demineralized by soaking in 1 M HCl for 20 minutes, washed with distilled water, soaked in 0.125 M NaOH for 20 hours, washed, hydrolyzed by placing it in 0.001 M HCl at 90ºC for 10 hours, filtered, and freeze dried. This process results in a gelatinous material that is equated with collagen. However, the amino acid profile of this material differs from true collagen standards and more closely resembles that of noncollagenous proteins (Tuross, et al., 1988; Schoeninger, et al., 1989; Weiner & Bar-Yosef, 1990). Interpretations of paleodiet based on samples prepared by this method may therefore be based on noncollagenous proteins, not collagen. Collagen from modern bone is characterized by high concentrations of the amino acids glycine and proline and the presence of hydroxyproline and hydroxylysine; noncollagenous proteins are characterized by high concentrations of glutamic acid and aspartic acid and little hydroxylysine (Wycoff, 1972; Hare, 1980).

The process used in this research isolates the high molecular weight (HMW), organic fraction from the bone or tooth, without discriminating against any specific protein (Ostrom, et al., 1990). This method requires less sample material and results in a greater yield of organic matter than the hydrolysis procedure (Schoeninger, et al., 1989). The amino acid profiles of modern HMW extracts are similar to collagen (Hare, 1980); the profiles for highly degraded bone, although consistent with a collagenous origin, are most likely derived from both collagenous and noncollagenous proteins (Schoeninger, et al, 1989; Ostrom, et al., 1990). As suggested by Masters (1987), the composition of these proteins in the organic fraction of bone or dentin should not affect the isotopic ratios of carbon and nitrogen. Although the amino acid compositions for collagen and noncollagenous proteins differ, the averaged isotopic contributions of the major amino acids in each protein to the total isotopic composition of the protein are the same. Therefore, an enrichment of 3‰ for nitrogen is expected per trophic level for the HMW extracts from bones and teeth; for carbon, an enrichment of about 2‰ between plants and herbivores and 1‰ between subsequent trophic levels is expected for the HMW fractions.

METHODS

Dialysis was used to collect the HMW organic fraction of each bone sample. First, each bone sample was washed in distilled water, scrubbed with a soft brush, if necessary, and scoured to remove surficial contaminants. The sample was then etched in 30% cold HCl, rinsed thoroughly in distilled water, dried, and powdered. A portion of the cleaned, powdered bone was dissolved in cold 6 N HCl, placed in dialysis tubing (molecular weight cut off of 8000), and dialyzed at low temperature (2º to 5º C) against distilled water to separate the HMW fraction from the low molecular weight fraction. The HMW material was lyophilized prior to analysis. Floral samples were cleaned surficially, acid etched in 10% cold HCl, rinsed thoroughly in distilled water, dried, and powdered.

Each sample was combusted in the presence of copper and copper oxide while under vacuum. The resulting gases were cryogenically separated; carbon dioxide and nitrogen were analyzed on a V.G. PRISM isotope ratio mass spectrometer for the $\delta^{13}C$ and $\delta^{15}N$ values, respectively. Approximately every fourth sample was replicated to verify the reproducibility of the measurements.

SITES

The Mer site (44LE280) is a cave located in a limestone hillside near a tributary of Indian Creek in Lee County, Virginia. A looted site reconnaissance survey in May 1993 by Dave Hubbard for the Marginella Burial Cave Project revealed disturbed human skeletal material under a rock ledge. The burials were approximately 15-18 m from the cave entrance. The location of this material in the dark zone and under a ledge suggests that the burials were intentionally placed and not the result of an accident or carnivore activity. Osteological analysis by Donna and Cliff Boyd, Radford University, identified a minimum of eight individuals: three male adults, three female adults, one subadult of undetermined sex, and one child aged 2½ to 4 years (Boyd & Boyd, 1997, Table 2).

The Shannon site (44MY8) is located on a ridge overlooking the floodplain of the North Fork of the Roanoke River approximately five miles east of Blacksburg in Montgomery County, Virginia. This site was excavated by Joseph Benthall in 1966 and 1967 (Benthall, 1969). The postmold pattern showed a 98 m (322 ft) by 64 m (210 ft) palisaded village comprised of a central plaza and 11 circular houses 2.5-7 m (8-23 ft) in diameter. Fire and refuse pits were associated with each house. Artifacts associated with these pits included ceramics, projectile points, refuse animal bone, bone tools (awls, fish hook, and chisel), turtle shells, mussel shells, shell and bone beads, and charred corn. Nearly all of the 100 human burials were individual burials in the flexed position. Grave goods included shell and turkey bone beads, mussel shells, turtle shell containers, bone tools (awls, chisels, fish hooks, flakers, hairpin, projectile points), stone tools (celts, drills, hammerstone, knife, projectile points), animal teeth (bear, eagle, elk, wolf), animal claws (mountain lion), ceramics (sherds, pipes), copper fragments (of native copper), and burned corn and hickory nuts.

Based on the ceramics (New River, Clarksville, and Radford) and projectile points (Caraway, Peedee, and Randolph), the Shannon site was occupied most intensively during the Late Prehistoric around A.D. 1400 to A.D. 1600. An absence of European artifacts suggests that occupation probably did not continue into the Historical Period. The presence of Palmer, Big Sandy, and Savannah River projectile points indicate that the site may have been occupied periodically during the Archaic Period.

The Parker site (31DV4) is located on Horseshoe Bend of the Yadkin River in Davidson County, North Carolina. The site was excavated in 1971 and 1972 by J. Ned Woodall of Wake Forest University (Newkirk, 1978). Numerous trash deposits, artifacts, human burials, and evidence of one substantial structure were observed in this small village. Lithics include triangular projectile points, drills, scrapers, blades, and cores. Other artifacts recovered were bone fish hooks, shell disks, worked antler, and worked turtle shell. The 25 burials were all primary burials in the flexed or semi-flexed position. Only one burial pit contained more than one individual. There were no definite grave goods associated with the burials.

The primary occupation of Parker was earlier than that at Shannon. Radiocarbon dates of A.D. 960 ±86 and A.D. 634 ±64 were obtained from two charcoal samples. Dan River ceramics recovered from the site suggest that it may have been reoccupied as late as A.D. 1600 (Egloff, 1992).

Results and Discussion

The Mer site has not been excavated. All that is available to investigate the activities at this site and the people who participated in them are disturbed human remains recovered from the surface of the cave floor and information about the site's location. With the exception of a 6 inch "spear point" reportedly removed from the cave by a looter, there are no artifacts from which to infer any cultural activities. There are no floral or faunal remains to aid in diet determination. Osteological analysis of the bone material provides information about the age, sex, number of individuals, physical trauma, disease, and health of the population. Stable isotope analysis provides information about their diet.

Bone samples from the femur shafts of four individuals from the Mer site were analyzed for their stable carbon and nitrogen isotope composition. The HMW organic fraction was isolated from each bone. The $\delta^{13}C$ values range from -12.7‰ to -9.2‰ (mean -11.0‰) and the $\delta^{15}N$ values range from 6.9‰ to 8.2‰ (mean 7.5‰) (Table 1).

To assess the diet, the isotopic compositions of several potential dietary sources must be determined. In the absence of faunal and floral remains from this site, a food web was constructed using data from other sites in Virginia and North Carolina. Ecological resources that may have been exploited by the individuals interred at the Mer site can be divided into three isotopically distinct categories: C_3 plant based, C_4 plant based, and aquatic. The isotopic values for carbon and nitrogen for food resources from these three categories plus an appropriate trophic level shift related to the isotopic fractionation for metabolism can be compared to the isotopic compositions of the bones recovered to assess the probable composition of the diet. No CAM plants were available in the study area in sufficient quantity to be considered a significant dietary component.

Table 1. Summary of Stable Isotope Data for Each Site.

Site	No. individuals sampled	mean $\delta^{13}C$	mean $\delta^{15}N$
Mer	4	-11.0‰	7.5‰
Shannon	16	-11.0‰	9.3‰
Parker	10	-18.8‰	9.3‰

A sample of maize (*Zea mays*) from Governor's Land (44JC308) was representative of C_4 cultigens, and has a $\delta^{13}C$ value of -9.8‰ and a $\delta^{15}N$ value of 4.8‰ (Trimble & Macko, 1994). A diet consisting solely of this C_4 plant would result in $\delta^{13}C$ value of -7.8‰ and a $\delta^{15}N$ value of 7.8‰ for the HMW extract of human bone. Hickory and walnut, C_3 species recovered from several sites in the Virginia Piedmont, had an average $\delta^{13}C$ value of -25.7‰ and $\delta^{15}N$ value of 3.0‰. The bone protein of herbivores such as deer, beaver, squirrel, and rabbit subsisting on C_3 plants would have a $\delta^{13}C$ of -23.7‰ and a $\delta^{15}N$ of 6.0‰; the HMW fraction of bones from humans eating these herbivores exclusively should have a $\delta^{13}C$ of -22.7‰ and a $\delta^{15}N$ of 9.0‰. The aquatic component might contain fish such as sunfish, bass, and sturgeon. Although the aquatic component could have $\delta^{13}C$ values similar to the C_3 plant based component, aquatic protein is more enriched in ^{15}N. Largemouth bass from the James River have an average $\delta^{13}C$ of -23.5‰ and $\delta^{15}N$ of 15.0‰ (Garman & Macko, in press). Consumers of aquatic protein exclusively might have a $\delta^{13}C$ of -22.5‰ and a $\delta^{15}N$ of 18.0‰. A mixed diet would result in intermediate values.

When compared to this compiled food web, the $\delta^{13}C$ values for the individuals buried at the Mer site appear similar to the range expected for consumers of C_4 plants. The $\delta^{15}N$ values are between those expected for terrestrial herbivores and carnivores. These values strongly suggest that C_4 plants were a key component of the subsistence economy. Marine foods could have contributed to the $\delta^{13}C$ values observed, but the associated $\delta^{15}N$ values expected for marine resources are lacking in the Mer site samples. In fact, the $\delta^{15}N$ values are quite low, suggesting that the people themselves were primarily plant eaters and consumers of other grazers such as rabbit and deer. Although freshwater fish and mussels may have had a role in their diet, the isotopic evidence for this being a major component is also lacking.

The Mer site is an anomaly with respect to other sites with-

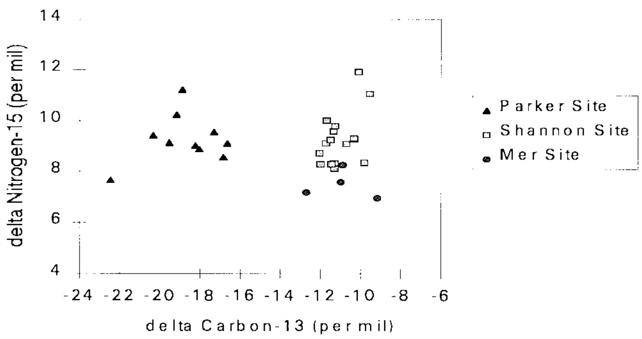

Figure 1. Stable carbon and nitrogen isotope values for the HMW fraction of human bone from the Mer, Shannon, and Parker sites.

in the Valley and Ridge physiographic province in terms of the stable isotope compositions. Out of over 20 sites in Virginia and North Carolina (Trimble, 1996), this site has the strongest evidence for C_4 plant consumption. Of those 20 sites, the Shannon site is the most similar.

Like the Mer site, bone protein from 16 individuals at Shannon has a mean δ^{13}C value of -11.0‰ (Figure 1). The mean δ^{15}N value, 9.3‰, is higher than at the Mer site. This suggests that terrestrial animals may have been consumed in greater quantities at Shannon, or that more aquatic resources may have been utilized. The faunal and floral assemblages from Shannon provide evidence for a varied diet (Table 2). Plant remains included maize, beans, and nuts. Animal remains included mammals, birds, reptiles, mussels, snails, and fish.

In contrast, isotopic analysis of 10 individuals from the Parker site yielded mean δ^{13}C and δ^{15}N values of -18.8‰ and 9.3‰, respectively (Figure 2). Fauna identified at Parker include deer, raccoon, fox, beaver, groundhog, squirrel, rabbit, wild turkey, gar, catfish, box turtle, and mussel. Flora identified include maize (*Zea mays*), hazel (*Corylus sp.*), hickory (*Carya sp.*), and a few other single seeds. The stable isotope compositions for the individuals at Parker are clearly within the range expected for consumers of C_3 plants. However, the presence of maize in the floral assemblage suggests that either maize agriculture was practiced at some time during the occupation of the site or contemporaneous trade networks existed to provide this resource. Alternatively, the maize may reflect a later occupation of Parker that is not associated with the burials examined.

Although it is unknown whether Shannon and Mer were contemporaneous, it seems that they shared a similar subsistence base. This information comes directly from the bones themselves and is independent of cultural or chronological affiliation. Given the small sample size for Mer, it is unclear whether the individuals recovered are representative of a specific social subset of a larger community or of the community at large.

Table 2. Faunal and floral remains recovered from the Shannon site.

Common name	Scientific name
Maize	*Zea mays*
Beans	*Prosopis sp*
Black walnut	*Juglans nigra*
Hickory nuts	*Carya glabra*
Virginia white tailed deer	*Odocoileus virginiana*
Elk	*Cervus canadensis*
Beaver	*Castor canadensis*
Groundhog	*Marmota monax*
Gray squirrel	*Sciurus carolina*
Black bear	*Ursus americanus*
Rabbit	*Sylvilagus floridana*
Muskrat	*Ondatra zibethicus*
Dog	*Canis familiaris*
Raccoon	*Procyon lotor*
Gray fox	*Urocyon cinereoargenteus*
Skunk	*Mephitis mephitis*
Bobcat	*Lynx rufus*
Mountain lion	*Felis concolor*
Turkey	*Meleagris gallopavo*
Bald eagle	*Haliaetus leucocephalus*
Canada goose	*Branta canadensis*
Ruffed grouse	*Bonasa umbellus*
Bobwhite	*Colinus virginianus*
Passenger pigeon	*Ectopistes migratorius*
Terrapin	*Terrapene carolina*
Mussels	*Elliptio complanatus* (Roanoke River)
	Villosa constricta conrad (Roanoke River)
	Cyclonaias turbiculata Rafinesque (New River)
Snails	*Mudalia carinata variabilis* lea
	Oxytrema symmetrica Haldeman

Further research at the Mer site is necessary. It is imperative that the chronological affiliation of the site be determined. This will enable comparison with other sites of the same period. The date will also aid in tracing the rise and spread of maize agriculture. Archaeological excavation within the cave could reveal the extent of the burial location, the types of burials, associated grave goods, or other artifacts related to cultural activity. Additionally, the remains of contemporaneous plants and animals may be recovered. Isotopic analysis of such ecofacts would enable definition of a localized food web to use as the basis for diet determination at the Mer site and other nearby cave sites, such as Indian Burial Cave (44LE11) and Bone Cave (44LE169).

Stable isotope analysis is particularly useful for cave sites because, as demonstrated for the Mer site, it provides information about the subsistence economy of the occupants, even in the absence of all other traditional archaeological data. Furthermore, the information generated by isotope analysis may elucidate culturally or archaeologically significant facets of a given site and may provide the impetus for further research.

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SCIENCE VERSUS GRAVE DESECRATION: THE SAGA OF LAKE HOLE CAVE

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In the spring of 1990, a prehistoric burial site in a small cave in Cherokee National Forest, Johnson County, Tennessee was almost completely destroyed by artifact collectors. Archaeological investigation of the disturbed deposits, conducted with the consent of the Eastern Band of Cherokee, yielded thousands of human skeletal remains, faunal remains, and artifacts. There may be hundreds of similar sites yet undiscovered within limestone and dolomite rocks of the southern Appalachian region. Efforts should be made by scientists and government agencies to discover prehistoric burial caves and to protect them, as American natives consider them sacred places.

Lake Hole Cave (40JN159) is situated on a south-facing hillside on the north side of Watauga Lake in Cherokee National Forest, northeastern Tennessee. The cave is a small solution cavity in the Shady Dolomite which forms the easternmost carbonate rock in the Valley and Ridge physiographic province. Unfortunately, Lake Hole Cave was discovered by individuals whose primary interest was the acquisition and selling of Native American artifacts and skulls. Sometime prior to March 26, 1990, at least one group of vandals dug in the cave (Jefferson, 1992). On March 26, 1990, a Cherokee National Forest employee saw the cave entrance, with a large pile of loose dirt, rocks, bones, and modern litter extending down slope. The District Ranger was alerted and immediately coordinated communications with the forest archaeologists, special agents, and other forest service law enforcement officers. The cave was visited by this group the same afternoon. Upon entering, they found digging equipment, scattered human skeletal remains, bags of human skulls, and a bag of marijuana. Within one day, Lake Hole Cave was placed under 24 hour surveillance.

On March 29th, three individuals were observed to enter the cave with shovels and were arrested after it was evident that they had commenced digging. All three pled guilty to formal charges of ARPA (Archaeological Resources Protection Act of 1979) violations for unauthorized excavation, removal of items, damage, or attempting to do such to an archaeological resource located on public lands of the United States. After one of the defendants was contacted by a local collector, who wanted to sell Indian artifacts reportedly from the cave, the federal agent asked the individual to wear a hidden recording device and meet the collector. Two subsequently taped conversations implicated the collector and other individuals. The group of defendants in the Lake Hole ARPA case grew to a total of nine, based upon the recorded evidence and subsequent testimony from four of the looters. Among the defendants charged were the Greene County assistant tax assessor and a local felon with a reputation for violence. In addition, the father of one defendant was arrested for felony jury tampering and felony obstruction of justice when it was discovered that he had attempted to persuade a jury member not to find his son guilty (Jefferson, 1992).

Two separate trials ensued in October of 1990 with eight of the nine pleading guilty. The jury trial found one individual guilty of all three felony counts. Five of the nine received ARPA felony convictions; and four received convictions of ARPA misdemeanors. The imposed sentences varied dramatically, from two years probation plus $499 fine, to a 22 month prison sentence (the local felon was given six months imprisonment for the ARPA misdemeanor and 16 months imprisonment for a felony weapons violation when it was discovered that he possessed 18 firearms while on probation for a prior felony).

Because Native American burials were desecrated, the Tennessee State Historic Preservation Office and the Regional Forest Service Committee for the Treatment of Human Remains were consulted. It was decided that the human remains would be delivered to the neighboring Eastern Band of Cherokee for reburial in a traditional manner. The Tribal Council of the Eastern Band of Cherokee sent an official delegation to the sentencing of the defendants. The Tribal Council Chair, Dan McCoy, read into the court record (Jefferson, 1992) a very strongly worded condemnation of the actions of the looters and:

"prayed for the imposition of the maximum penalties allowed by law upon these nine defendants, it being the strong feeling of the Tribal Council that such penalties are proper and deserved because of the actions of these defendants and their past history of Indian depredations and are further justified in order to discourage other persons from continual or similar depredations against the remains and spirit of the Cherokee people."

LAKE HOLE CAVE ARCHAEOLOGY

In the spring of 1991, Appalachian State University (ASU) was contacted by the U.S. Forest Service and the Eastern Band of Cherokee Indians, and a Challenger Cost Share Agreement was negotiated to conduct archaeological investigations at Lake Hole Cave (Whyte & Kimball, 1992). The purposes of these investigations were to recover human remains and artifacts from the disturbed contexts for reburial and to assess the informational damage done to the site. In the process, it was hoped that some knowledge of the nature and human use of the cave would be obtained. This project was directed by Dr. Thomas R. Whyte and Dr. Larry R. Kimball, of the Department of Anthropology at ASU, in cooperation with Cherokee National Forest archaeologists Quentin R. Bass and Norman D. Jefferson. The excavations were undertaken by students from ASU and a Cherokee tribal member who, at that time, was an Anthropology major at Western Carolina University. Dr. Ellen Cowan, of the Department of Geology at ASU, was responsible for geological investigations of the cave. Dr. Donna C. Boyd and Dr. C. Clifford Boyd of the Department of Anthropology at Radford University, undertook the identification and analysis of human skeletal remains recovered from the cave. Fieldwork was conducted from May 20 through July 12, 1991. Over 200 volunteers contributed roughly 1500 hours to the recovery and processing of materials from the site.

The cave consists of two small chambers. One extends horizontally more than 11 m to the right of the entrance (Figure 1). The left chamber extends over 6 m to the left and down slope from the cave entrance. Prior to the excavations, a person could stand erect only in the middle of the right chamber. The original entrance was probably no more than a half meter in diameter and may have been deliberately sealed with large dolomite slabs in prehistoric times. A locked iron gate framed in concrete now protects the cave.

After a lighting system powered by a generator was installed, the cave's interior was subdivided into horizontal excavation units, normally one meter long by the width of the cave (less than 3 m). Eighteen such units were excavated in the areas observed to have been disturbed (Figure 1). Undisturbed deposits were documented in the far reaches of the left chamber and the rear third of the right chamber. Each unit was excavated by natural strata, if observable, or arbitrary levels. These "strata" however, turned out to be loads of variably colored sediment moved from one place to another during the episodes of looting. Vertical control was maintained by reference to datum points fixed along the cave walls. Sediment was troweled into provenience-labeled polypropylene feed bags for transport to the screening site. All excavated sediments (over 20,000 kg) from approximately 24 m^3 of disturbed contexts were wet-screened through nested 0.64 and 0.32 cm mesh.

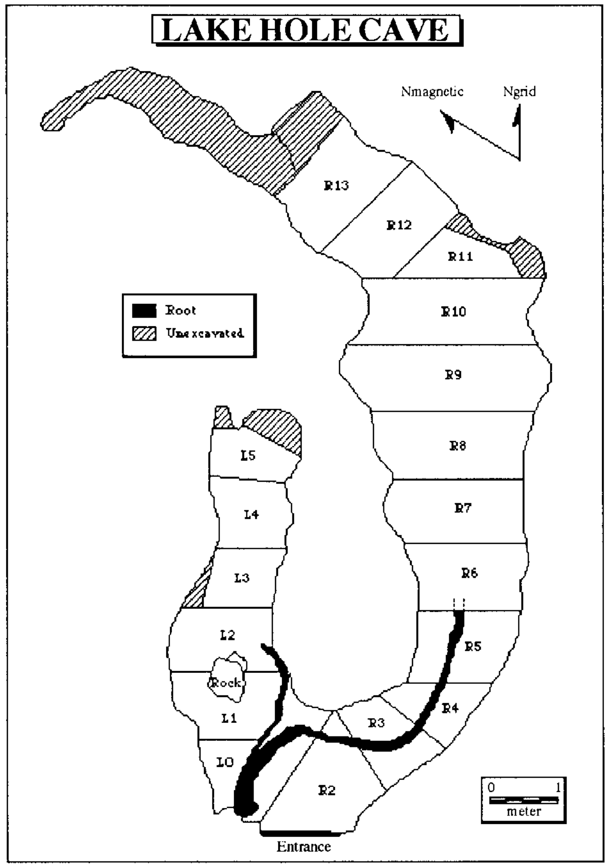

Figure 1. Plan view of the ground surface and excavation units within Lake Hole Cave, Johnson County, Tennessee.

RESULTS OF THE INVESTIGATION

The cave's deposits had undergone considerable damage as a result of vandalism and bioturbation. No completely intact burials were observed, although a few may remain preserved in undisturbed contexts. In addition to thousands of scattered and broken human elements, over 6,000 marine shell beads, 25 triangular arrowpoints, five stone tools, 67 pieces of stone debitage, eight bone and antler tools, 17 bone beads, 136 pottery sherds, and many thousands of animal and plant remains were recovered. It is likely that items of copper (copper staining occurred on a few human elements), pipes, pots, shell beads, arrowpoints, and human remains (especially skulls) were removed by the vandals. No evidence of prehistoric human use of the cave, for any other purpose than burial, was found. Although the deposits investigated had been severely vandalized, all of the prehistoric artifacts recovered appear to have been associated with human interments.

The human remains and artifacts recovered from Lake Hole Cave are much older than had originally been assumed. The recovery of smoothed-over rectilinear complicated stamped and net-impressed pottery with Woodland period rim treatments, the base of a Uwharrie vessel, and Hamilton incurvate-type triangular arrowpoints suggest a Late Woodland to Early Mississippian period (ca. A.D. 800-1200) association. Unfortunately, no torches of prehistoric origin were recovered for ^{14}C dating. A wood charcoal sample from a thin, amorphous area of burned soil discovered at a depth of over one meter below present ground surface, at the contact between the disturbed and undisturbed deposits, was submitted for radiocarbon dating. This burning appeared to have resulted from a natural fire within the cave sometime prior to the use of the cave as a burial site. The sample (Beta-51201) assayed to A.D. 249 ±80 (uncorrected). This date verifies what was already known based upon typological analyses, that the human use of the cave occurred sometime in the last 1,700 years. Subsequently, permission was obtained from the Eastern Band of Cherokee to submit a bone tool (an assumed burial association) for radiocarbon dating. The adjusted date assay for this sample (Beta-57966) is A.D. 1160 ±60 and the dendro-calibrated age (see Stuiver & Reimer, 1993) is A.D. 1260, which fits with the kinds of artifacts recovered from the cave.

GEOLOGY AND SEDIMENTOLOGY

Over many thousands of years, fine sediment has filtered in through sinks and crevasses in the jointed dolomite (Cowan, 1992). The extent of the cave system is unknown, because only the disturbed fill was excavated, but the presence of dripstone on the cave roof and walls indicates that the open area of the right chamber was up to two meters in height. Dripstone could not have formed beneath the sediment levels along the walls. The color mottling and particle size distributions in the three intact sediment profiles are the result of a long period of groundwater movement through these fine grained sediments.

The mean particle size is slightly coarser in the left chamber than the right in both the undisturbed and disturbed samples. This relationship suggests that the sediment and the artifacts buried within it were not transferred between chambers during digging by the vandals.

HUMAN REMAINS

Human skeletal remains were recovered from both chambers and from the exterior of the cave where vandals had deposited their backdirt (Boyd & Boyd, 1992). In certain instances, miscellaneous human bones had been placed in piles within the cave by these excavations. Most, however, were discovered as isolated fragments. The 12,841 human bones and teeth recovered represent a minimum of 99 individuals, including 50 subadults and 49 adults. Males and females and individuals of all ages, from fetal to older adults, were represented (Boyd & Boyd, 1997). Adult crania, however, were under-represented, probably due to their evident removal from the cave by the vandals.

The most common pathologies observed were degenerative arthritis, non-specific infection (periostitis, osteoporosis, and osteomyelitis), and dental disease. Minor evidence of periodic nutritional stress among subadults also was noted. Ten frontal bone fragments showed clear evidence of cribra orbitalia, suggesting a condition of iron deficiency. Other signs of nutritional stress noted were enamel hypoplasia (on 17 teeth) and considerable bowing of three tibias and a femur (possibly indicating rickets). Very few of the bones showed signs of traumatic injury (Boyd & Boyd, 1997).

The fact that all portions of the skeleton, including several hyoids and numerous small infant bones, were represented by the fragments recovered, indicates that at least some individuals were placed to rest in Lake Hole Cave as primary (articulated) burials. This also is indicated by the frequent incidences of carnivore chewing of the ends of long bones and phalanges. It is possible, however, that some individuals were brought to the cave as secondary (bundle) burials.

MARINE SHELL BEADS

The 6,029 marine shell beads recovered from Lake Hole Cave include ones manufactured from the shells of olivella (genus *Olivella*) snails (71%), olives (genus *Oliva*) (<1%), marginellas (genus *Prunum*) (3.5%), and whelks (genus *Busycon*) (Keller & Evans 1992). The latter include disk (25%), and columella (<1%) beads. A comparison of this sample with published counts from other sites in the region shows that Lake Hole and the Hamilton (Late Woodland-Early Mississippian) mortuary contexts have considerably fewer disk beads (25% at Lake Hole and <1% at Hamilton) than the later prehistoric and historic contexts (93 - 95%). For these same two groups (Lake Hole and Hamilton versus late prehistoric/historic), olivella beads are more abundant than marginella in earlier versus later contexts (Keller & Evans 1992). Thus, while artifact collectors may have removed more of the larger (more visible) disk beads than the smaller olivella and marginella beads, the Lake Hole sample is still quite similar to that of the Hamilton mortuary pattern.

BONE AND ANTLER ARTIFACTS

Artifacts of bone or antler recovered from Lake Hole Cave include 17 bone beads, one bone beamer, one scraped box turtle carapace fragment, two antler pressure flakers, and six fragmentary pointed bone tools (Kimball & Whyte, 1992). The beads all appear to have been grooved and snapped from the diaphyses of medium to large bird limb bones. Aside from these bone artifacts and the shell beads, no animal remains showed evidence of human modification or use, such as butchery marks. Furthermore a considerable percentage of the thousands of animal bones recovered exhibit evidence of chewing and breakage by carnivores, suggesting that humans were not responsible for their deposition in the cave.

PREHISTORIC CERAMICS

The 136 prehistoric pottery sherds recovered have been described by Kimball (1992a). Rim sherds were conspicuously under-represented, possibly indicating that the vandals collected rim sherds and perhaps whole vessels. The sherds are representative of a minimum of four vessels and exhibit smoothed-over rectilinear complicated stamped, smoothed-over simple stamped, smoothed plain, or indeterminate surface treatments. None of these designs is distinct enough to describe in great detail, but they do not appear to be smoothed-over versions of complicated stampings from Woodland, Pisgah, or Qualla assemblages for the region. The sherds from Lake Hole Cave exhibit tempering with coarsely crushed chalcedony or quartz, both of which are immediately available. The use of this tempering is a relatively local phenomenon in the southern Appalachians–possibly restricted to areas of the Shady Dolomite formation in northeastern Tennessee and southwestern Virginia.

Each of the rim sherds recovered is straight to slightly incurved. The lips are decorated with simple diagonal incisions. These ceramic types are more typical of a Woodland, rather than Mississippian period assemblage for the region, but the ceramic technologies from this portion of the western boundary of the southern Appalachians are very poorly known.

One vessel base from a probable Uwharrie series vessel was unexpectedly recovered. The Uwharrie series dates to approximately A.D. 1000 and is most abundant in the upper Piedmont and eastern edge of the Blue Ridge escarpment, minimally 50 miles to the east of Lake Hole Cave.

ARROWPOINTS

Twenty-five arrowpoints recovered from the cave deposits were compared with a sample of 175 small triangular arrowpoints, from Late Woodland through Historic Cherokee contexts from eastern Tennessee, using cluster analysis for five metric characteristics (length, width, thickness, lateral edge curvature, and basal curvature) (Kimball, 1992b). All the 25 clustered with points from Emergent Mississippian Martin Farm and Early Mississippian Hiwassee Island contexts, but never with points from later Dallas, Pisgah, or Historic Cherokee contexts.

The Lake Hole sample is made from the locally available Shady Dolomite chalcedony, near-local Knox Group black chert, and nonlocal jaspers and cherts (possibly from as far away as West Virginia and southeastern Kentucky). Many of the arrowpoints recovered are broken.

Given the variety of lithic raw materials and the broken condition of many of these points, it is suspected that some of these arrowpoints may have been in Lake Hole Cave because they had been brought there in the bodies of individuals buried there and not interred as grave offerings. This is not an unreasonable suggestion given the observations of embedded points and the positions of points documented for Late Woodland and Early Mississippian burials in the region, especially by Lewis and Lewis (1946) from Hamilton burial mound contexts.

To investigate this interpretation, we undertook a microwear analysis of these arrowpoints following the approach developed by Lawrence Keeley (1980). Using an incident-light microscope at magnifications of 50, 100, and 200 powers, microwear polishes due to use, hafting, and alteration can be determined by comparison to microwear polishes on experimentally employed tools. These polishes vary according to the material worked and the motion of the tools during work.

Excavation damage was first assessed for the sample. In only two cases is there clear evidence of microwear traces due to impact with metal tools. This means that the breakage of the other arrowpoints is probably due to other causes. Two arrowpoints exhibit “linear traces” which have been observed in projection experiments by several microwear analysts (Fischer, et al., 1984; Geneste & Plisson, 1993; Kimball, 1994). A linear trace is caused by the movement of a microflake across the point surface at the instant of impact. Hafting traces were observed on 12 examples. It is apparent that a somewhat loose hafting method was involved, possibly with vegetal cordage rather than mastic, although experimentation is needed to support this interpretation. Meat polish was observed at seven locations, and bone polish was recorded at the most distal portion on two distally broken points. Major distal fractures, micro-impact fractures, proximal fractures, and proximal burinations were all observed in the sample. These observations suggest that several of the arrowpoints had been used and were possibly embedded in the bodies of individuals buried there.

NON-HUMAN VERTEBRATE REMAINS

Tens of thousands of vertebrate and molluscan remains deposited by natural agencies were recovered by the archaeological excavations at Lake Hole Cave (Whyte, 1992). These faunal remains document a long history of the use of the cave by animals since the Late Pleistocene. Of particular interest was the recovery of remains of fisher (*Martes pennanti*), extinct horse (*Equus* sp.), and giant armadillo (*Dasypus bellus*). The fisher was last seen in the southern Appalachians in the 1830s (Powell, 1991) while the horse was probably extinct by 8,500 B.P. (Woodward, 1991) and the giant armadillo was probably extinct by 10,000 B.P. (Klippel & Parmalee, 1984).

CONCLUSION

Lake Hole Cave is a desecrated Native American cemetery and a vandalized archaeological site. It is one of several known and one of probably hundreds of existing prehistoric burial caves within the Shady Dolomite of the southern Appalachians. Entrances to burial caves, yet undiscovered, may have been artificially sealed with stone slabs and presently remain unknown. In addition to human and archaeological remains, these caves are expected to contain rich Pleistocene and Holocene faunal and botanical assemblages that have obvious scientific value. Most importantly, however, they represent cemeteries that are sacred to contemporary native Americans and must be protected from the destructive endeavors of artifact collectors and the seemingly innocent pursuits of recreational spelunkers and seekers of knowledge.

Out of respect for native peoples and their burial places, prehistoric burial caves, upon their discovery, should be reported to appropriate tribal representatives of Native American groups currently and/or historically resident within the region, so that they may be given the opportunity for a direct role in their protection, management, and if necessary, their scientific exploration. Many burial caves, such as Lake Hole Cave, are located on public lands and are therefore legally provided some protection. An even greater number of them are doubtless on private properties and are more vulnerable to the pursuits of artifact collectors and private land modification projects. One means of protecting privately owned burial caves would be for scientists, Native Americans, and concerned individuals to urge landowners to prevent the intrusion into such sites and to educate the public about the rights and concerns of native peoples with regard to prehistoric Native American burial places and skeletal remains.

Despite the unfortunate disturbance of human skeletal remains and archaeological and paleontological deposits within Lake Hole Cave, much information about the natural and cultural history of the cave and the region was obtained. While it may be in the interest of archaeology, speleology, paleontology, and other sciences to discover and explore caves in the southern Appalachians, exploration of a burial cave should be conducted only with the consent of native peoples and according to their desires.

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Charles H. Faulkner-Four Thousand Years of Native American Cave Art in the Southern Appalachians. *Journal of Cave and Karst Studies 59*(3): 148-153.

FOUR THOUSAND YEARS OF NATIVE AMERICAN CAVE ART IN THE SOUTHERN APPALACHIANS

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The seminal work of archaeologists in Mammoth and Salts caves, Kentucky, in the 1960s, revealed that prehistoric Native Americans not only buried their dead in these caverns, but also intensively explored and mined the "dark zones" beginning 4,000 years ago. When the glyph caves of Tennessee and Virginia were studied in the 1980s, research revealed these underground sanctuaries were also sacred areas of non-mortuary ritual. It was concluded at that time that Native American cave use during the past 4,000 years probably shifted from exploration to intensive mining of cave minerals. At about the beginning of the common era, the increasing use of caves as burial places eventually led to their abandonment as sources for minerals. By circa 1,000 years ago only a few of these caves continued to be used for ceremonial purposes. The recent discoveries of two additional glyph caves in Tennessee, one in Virginia, and two in Kentucky, have resulted in a reassessment of this chronological sequence of prehistoric cave use, and have also underscored the fact that southern Appalachian caves still contain important undiscovered archaeological remains.

If there is a universal truth in the study of prehistory it is that theories about cultural development are constantly being revised as archaeologists uncover new evidence about our past. The story of North American prehistory still has many missing chapters, but our efforts to plug these gaps are constantly rewarded as previously unknown archaeological sites are discovered and studied. Some of the most exciting and potentially informative of these newly discovered archaeological sites are in the dark zones of caves in the southeastern United States, mysterious places that were explored, mined, and venerated by Native American cavers for several thousand years.

The knowledge that Native Americans in the Eastern Woodlands were our first and perhaps most daring cavers is not new, however. Early in the 19th century several so-called "mummies," desiccated bodies of prehistoric Native Americans, were discovered in the deep inner passages of caves in Kentucky (Meloy, 1971; Robbins, 1971). After the turn of the century, Colonel Bennett Young described the prehistoric archaeological remains in the vestibule of Salts Cave (Young, 1910), and Nels C. Nelson conducted the first excavation of the entry chamber of Mammoth Cave (Nelson, 1917). These studies laid the groundwork for later systematic archaeological research in the deep inner galleries of these same Kentucky caves by Patty Jo Watson in the 1960s (Watson, 1969, 1974). Watson's research in Salts Cave revealed the diet of the Native American cavers who intensively exploited the dark zone for minerals more than 2,000 years ago, and her archaeological study of Mammoth Cave indicated these redoubtable miners were exploring remote passages more than two kilometers from the entrance.

Although Native American drawings in soft mud ("mud glyphs") had been reported on the walls of Williams Cave in Virginia as early as 1979 (Bunnell, 1979), it was the exploration and study of Mud Glyph Cave in East Tennessee in the early 1980s that first revealed the dark zone to be the scene of prehistoric ceremonial activity (Faulkner et al. 1984; Faulkner, 1986). One hundred and twenty meters from the entrance of this small cave is the 96 m long "glyph gallery," a narrow walking passage decorated by a palimpsest of trailed and incised glyphs on the clay-covered walls and banks. Abstract meanders or "macaroni," cross-hatching, and lattice-work con-

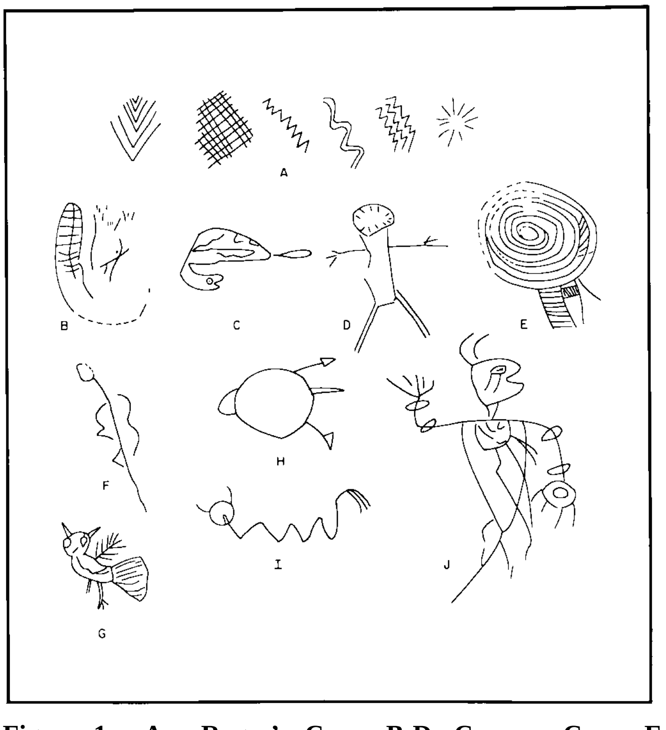

Figure 1. A. Roger's Cave; B-D. Crumps Cave; E. Williams Cave; F-J. Mud Glyph Cave. (A) Abstract/Geometric Forms; (B) Serpent; (C) Turtle; (D) Anthropomorphic Figure; (E) Spiral; (F) Mace; (G) Owl; (H) Turtle; (I) Serpent; (J) Anthropomorphic Figure (not to scale.

stitute the majority of the abstract designs. Renderings identified as late prehistoric Mississippian period, Southeastern Ceremonial Complex motifs include the forked or "weeping" eye, mace, concentric circles, and round suns with rays (Figure 1, F). During the Mississippian period, the southeastern Native Americans were intensive farmers who lived in large villages often containing public and sacred buildings constructed on flat-topped mounds. They had an elaborate religious art produced on shell, copper, and ceramic artifacts reflecting the "Southern Cult" or Southeastern Ceremonial Complex (SECC). Zoomorphic forms in Mud Glyph Cave are represented by horned serpents, turtles, owls, and woodpeckers (Figure 1, G-I). The human figures are the most numerous of the naturalistic drawings in the cave and range from very detailed SECC "eagle beings" or "falcon dancers" to a detailed stick figure of a running ball player holding a ball stick, to simplistic caricatures with finger-poked eyes and pinched noses (Figure 1, J; Figure 2). Cane torch charcoal associated with the glyphs dates from A.D. 465 to A.D. 1760 with five of the eight dates falling between the 12th and 14th centuries (Faulkner et al., 1986: Table 1).

During the National Geographic Society (NGS) funded research in Mud Glyph Cave, other cave surveys and information provided by sport cavers indicated that Mud Glyph Cave was not an isolated example of subterranean ceremonialism. In 1984, the NGS funded a study of seven additional decorated caves in the southeastern United States (Faulkner, 1988). Since that time, an additional five caves containing glyphs have been reported and described in this region.

The NGS project provided the initial data base for an assessment of the age, cultural association, and function/meaning of the glyphs in these caves. Williams is the only one of the seven containing mud glyphs, the most striking glyph being a large spiral with an attached lattice design (Fig. 1, E) (Faulkner, 1988). Three other caves contain significant groups of petroglyphs and pictographs in deep inner passages. Petroglyphs are incised or pecked into the cave wall; pictographs are drawn on the wall, usually with charcoal.

Figure 2. Bird man or falcon dancer, Mud Glyph Cave. Note gorget on chest and bracelets and armlets on arms.

Table 1. Glyph Cave Radiocarbon Dates.

Cave	Uncalibrated Date	Source
Adair Glyph Cave	1610 BC ± 100 yrs.	DiBlasi 1996
Third Unnamed, TN	1243 BC (av of 5 dates)	(per. communication)
Crumps, KY	30 BC ± 60 yrs.	(per. communication)
Mud Glyph, TN	AD 465 ± 60 yrs.	(Faulkner, et al. 1986)
Devil Step Hollow, TN	AD 920 ± 90 yrs.	(Faulkner 1988)
Little Mountain, VA	AD 975 ± 120 yrs.	(per. communication)
Second Unnamed, TN	AD 980 ± 60 yrs.	(Faulkner 1995)
Williams, VA	AD 995 ± 75 yrs.	(Faulkner 1988)
Indian, TN	AD 1010 ± 60 yrs.	(Faulkner 1988)
Little Mountain, VA	AD 1030 ± 120 yrs.	(per. communication)
Williams, VA	AD 1030 ± 65 yrs.	(Faulkner 1988)
Williams, VA	AD 1060 ± 70 yrs.	(Faulkner 1988)
Mud Glyph, TN	AD 1155 ± 60 yrs.	(Faulkner, et al. 1986)
Mud Glyph, TN	AD 1200 ± 45 yrs.	(Faulkner, et al. 1986)
Mud Glyph, TN	AD 1235 ± 60 yrs.	(Faulkner, et al. 1986)
Little Mountain, VA	AD 1235 ± 110 yrs.	(per. communication)
Mud Glyph, TN	AD 1315 ± 50 yrs.	(Faulkner, et al. 1986)
Devil Step Hollow, TN	AD 1330 ± 150 yrs.	(Faulkner 1988)
Mud Glyph, TN	AD 1335 ± 60 yrs.	(Faulkner, et al. 1986)
Indian, TN	AD 1360 ± 80 yrs.	(Faulkner 1988)
Little Mountain, VA	AD 1425 ± 90 yrs.	(per. communication)
Mud Glyph, TN	AD 1605 ± 65 yrs.	(Faulkner, et al. 1986)
First Unnamed, TN	AD 1690 ± 50 yrs.	(Faulkner & Simek 1996)
Mud Glyph, TN	AD 1760 ± 80 yrs.	(Faulkner, et al. 1986)

The most significant cave from the standpoint of naturalistic SECC figures incised into the walls is Devil Step Hollow in the Cumberland Plateau escarpment of middle Tennessee. The petroglyphs are all found on the low ceiling of a large chamber reached by a crawl and stoop passageway. These include two woodpeckers, a monolithic axe/warrior with roach and beaded forelock, an eagle being with weeping eye holding a mace in each hand (Figure 3); a monolithic axe with human face characteristics; a mace superimposed over or part of an eagle being's tail; a cross-in-circle; and a toothed mask with weeping eye (Faulkner, 1988). Beyond the petroglyph chamber are two pictographs drawn in charcoal on the ceiling: a dog or wolf and another woodpecker.

Indian Cave on the Eastern Highland Rim of Middle Tennessee contains a large number of petroglyphs scattered over the walls from the mouth to about 100 m from the

Figure 3. Eagle being holding maces, Devil Step Hollow Cave.

entrance. Many of these glyphs also appear to be SECC in their inspiration, but unlike those in Mud Glyph and Devil Step Hollow caves, they are more crudely and/or abstractly rendered. They include several abstract bird/human "falcon or eagle dancers" with little V-shaped heads and possible plumage indicated by chevron designs (Figure 4). Other petroglyphs are a sun symbol near the cave mouth and a serpent with an embellishment on the tail that could be rattles, and branch-like antlers on a small oval head.

The major prehistoric activity in Third Unnamed Cave on the Cumberland Plateau in Tennessee was the mining of chert nodules in a large room over 1000 m from the entrance. While this chert quarry and workshop area was being studied by archaeologists in 1981, petroglyphs were noticed on the low ceiling of the quarry chamber. These include a lightly incised "sun," nested circle or spiral, a serpentine line, possibly a snake, an "arrow", and several groups of cross-hatched, wavy, and parallel lines (Faulkner, 1988).

In addition to recording the glyphs found in these caves, the NGS project also focused on collecting torch charcoal for radiocarbon dating of the activity in the glyph caves. It is important to remember that in none of these caves, including Mud Glyph, was this charcoal directly associated with these drawings. Thus it could be reasonably argued that the activity associated with the deposition of the torch charcoal had nothing to do with the drawing of the glyphs. However, in Mud Glyph and Williams caves, the torch charcoal was heavily concentrated under the glyphs and because the production of these drawings appears to be the only prehistoric activity that is presently recognized in most of these caves, it is assumed that these torches provided the light for the prehistoric artists.

At the completion of the NGS project, a total of 21 radiocarbon dates had been obtained from charcoal believed to have been deposited when the glyphs were drawn (Table 1). Some of this charcoal from torches and fires in Mud Glyph and Williams Caves was in close association with the glyphs, other samples such as those from Third Unnamed and Indian Caves dated other activity, but it was presumed that the walls were decorated at the same time. If we exclude these two caves from consideration for the moment, it can be seen that the remaining 13 dates, except the sixth century date from Mud Glyph, range from A.D. 920 in Devil Step Hollow Cave to A.D. 1760 in Mud Glyph Cave. This approximate 800 year range falls squarely within the Mississippian period, and the association of these dates with the glyphs is strengthened by the SECC motifs in Mud Glyph and Devil Step Hollow.

While the earlier dates were generally ignored, it was conceded that Late Archaic cave explorers and miners may have occasionally decorated the walls with simple abstract or geometric designs. Virtually all of the dark zone art work, however, was believed to be the result of Mississippian period artists who drew the naturalistic/realistic figures that also decorated ceremonial artifacts. This apparent sudden or at least prolific appearance of ceremonial cave art suggested a major shift in the utilization of caves between the Archaic and Mississippian periods. Patty Jo Watson envisioned an early period (from Late Archaic to early Middle Woodland; circa 2000 B.C. to A.D. 300-400) when caves were intensively mined for minerals and a later period (later Middle Woodland to Mississippian; circa A.D. 300 or 400 to A.D. 1500) when caves were used as burial sites or contact points with the supernatural (Watson, 1986). Expanding on this interpretation, we suggested that this shift in cave function signaled a cognitive change in the Native American's conceptualization of caves: what had formerly been a prosaic part of their natural world now became an awesome place, perhaps the entrance to the underworld (Faulkner et al., 1984). This is heady stuff, to venture beyond function and actually interpret meaning in the archaeological record. The working hypothesis of changing activities in caves was further tested by George Crothers, who used a number of "fixed split" hypotheses to test whether the combined radiocarbon ages between deep cave sites exhibiting similar activities were effectively estimating the same date. His statistical data supported a consistent diachronic pattern of deep cave utilization (Crothers, 1987).

Figure 4. Abstract bird/human figure, Indian Cave.

Because of the NGS funded glyph cave projects in the early 1980s, five additional decorated caves have been found and studied in Tennessee, Kentucky, and Virginia. Research in these caves is still on-going, but enough data have been collected to submit three additional conclusions about the art in these caves. One is that these decorated caves are more numerous than was first thought. Another is that a diachronic change from early resource extraction to later ceremonialism in the dark zone may be more complex than previously suggested. And finally, the art forms on the walls do not necessarily evolve from simple abstract designs in the Archaic and Woodland periods to naturalistic expressions in the Mississippian, and certain motifs may even be associated with specific activities such as burial of the dead.

Adair Glyph Cave in Adair County, Kentucky contains mud glyphs on the floor of a remote passage more than one kilometer from the entrance (DiBlasi, 1996). The glyphs appear to be like those in Third Unnamed Cave: "geometric" symbols including trailed lines, zig-zags, hatching and cross-hatching, and chevrons (Figure 1, A). Torch charcoal on the floor of the glyph passage has been dated at 1610 B.C. ± 100 years (DiBlasi, 1996).

Crumps Cave is a large cavern in Warren County, Kentucky that contains glyphs on the clay banks of a passage 1000 m from the entrance. First reported in 1989, a majority of the glyphs are trailed meanders and clusters of short, straight lines; however, some crudely executed naturalistic figures have also been identified (Davis & Haskins, 1993). These include a horned serpent with rattlesnake tail and possible wings, a turtle, and eight human figures, some with scooped-out heads and abdomens; two of these figures exhibit nipples and are thought to be pregnant females (Figure 1, B-D) (Haskins, 1992, personal communication). Bark from a deep incision in one of these figures produced a radiocarbon date of 30 B.C. ± 60 years (Haskins, 1994 personal communication). This date is especially significant because it is the only charcoal actually retrieved from within a glyph.

Prehistoric rock art, also possibly attributable to Late Archaic-Early Woodland cavers, has been recently recognized on the walls of Salts and Mammoth Caves in Kentucky. In the former cavern, a set of glyphs 841 m from the entrance include zoomorphic and possibly anthropomorphic pictographs in charcoal and incised crosshatched petroglyphs. Mammoth Cave also contains geometric charcoal drawings that may be prehistoric in age (DiBlasi, 1996).

Another important recent discovery is the apparent association of some cave glyphs with prehistoric burials. In 1987, cavers discovered vandalized human skeletal remains in a shallow pit cave in White County, Tennessee. The main burial chamber in the twilight zone of Officer Cave contains four human head/face petroglyphs scratched on a limestone wall (Willey et al., 1988). Two of the glyphs have weeping eyes, a toothy "grinning" mouth, and wavy lines extending downward from the chin (Figure 5). These are very similar to the so-called toothed mask in Devil Step Hollow Cave. That this burial association is not fortuitous is indicated by the discovery in 1991 of another pit burial cave only 100 m from Officer Cave, this latter cave also containing a crude human figure and a "grinning" mouth scratched on the wall of the main burial chamber (Faulkner & Grant, n.d.).

Within the past two years three additional mud glyph caves have been discovered in Tennessee and Virginia. While the archaeological research in these caves is in various stages of completion, a preliminary summary of our findings should be presented here because it bears on our changing interpretations of the ceremonial use of these underground sites. The amount of drawing varies from decoration of a single chamber to more extensive renderings through the main passage. All seem to be characterized by a preponderance of abstract designs: curvilinear meanders or zig-zags drawn with the fingers or a stick, although a more detailed study of the glyphs will probably reveal more crudely executed naturalistic figures. One cave, First Unnamed in East Tennessee, has several crude naturalistic figures within the palimpsest of meanders, including the human effigy, serpent, bird, and bird/man (Faulkner & Simek, 1996). Little Mountain Cave in southwestern Virginia has a combination of trailed lines that might represent an anthropomorph or bird (?), and the barred oval motif may also be present there. Preliminary reports have been written on the mud glyphs in Second Unnamed Cave on the Eastern Highland Rim in middle Tennessee (Faulkner, 1994, 1995). The glyphs consist of three groups of meanders on the mud-coated ceiling and on a narrow rock ledge. On one area of the ceiling, a possible human or bird figure was incised within the meanders.

Torch charcoal was collected for dating from these three glyph caves. Radiocarbon dates from the two Tennessee caves have been recently received, courtesy of the University of Arizona Radiocarbon Dating Laboratory and the Tennessee Valley Authority. The First Unnamed sample was collected from the floor of the passage in an area of intensive artistic activity. The date is 260 ± 50 B.P. (A.D. 1690) (Simek et al., 1995). The end of a cane torch had been stuck into the ceiling

Figure 5. Human head/face petroglyphs, Officer Cave.

mud of Second Unnamed Cave, a sample of this charcoal gave a date of 970 ± 60 B.P. (A.D. 980) (Faulkner 1995). Four radiocarbon dates are available from Little Mountain Cave; two are Emergent Mississippian dates (A.D. 975 and A.D. 1030) and two are later in the Mississippian period (A.D. 1235 and A.D. 1425) (G. Tolley, personal communication). Like the seven dates from Mud Glyph Cave, these dates bracket the span of Mississippian occupation in the eastern Tennessee Valley.

CONCLUSIONS

The recent discovery of additional mud glyph caves in the southeastern United States has prompted a reassessment of what at first appeared to be a consistent diachronic pattern of prehistoric cave utilization from earlier resource exploitation to later ritual activity. The similarity of the Late Archaic drawings in Adair Glyph Cave to those in Third Unnamed Cave suggest that these early cavers may have already been venerating elements in the underworld as well as exploring and mining it. The direct date from the human figure in Crumps Cave is additional evidence that such ritual activity continued into the Middle Woodland period. This gives more credence to the A.D. 465 date from Mud Glyph Cave. The similarity of some of the crude stick figures in Mud Glyph to the anthropomorphs in Crumps might also suggest that Middle Woodland cavers were embellishing the walls of the former cave as well. The crude, abstract drawings in Second Unnamed Cave are a caveat to the simple assumption that Mississippian period cave art can always be distinguished by identifiable naturalistic figures. That this art did not simply evolve from the abstract and geometric to the naturalistic is also indicated by the crude First Unnamed drawings that appear to date as late as the 17th century. This late date for activity in First Unnamed also supports the evidence for 17th and 18th century traffic in Mud Glyph Cave, and thus makes a case that some of the drawings in the latter may be early historic in age. Taking all of the radiocarbon dates that have thus far been obtained for the glyph caves at face value, it is probable that the ceremonial decoration of cave walls in the southeastern United States was practiced for several thousand years, from the Late Archaic through the early historic periods, with an intensification of this activity after A.D. 900.

Before we can accurately determine when and how these caves were utilized by Native American cavers, we must have an adequate sample of these sites for study. Presently we are aware of only a few tantalizing caves that contain evidence of prehistoric ritual activity. Based on the discovery of new glyph caves during the past couple of years, however, there is every reason to believe that more of these glyph caves will be identified in the future. This optimism is based on the fact that modern cavers are increasingly aware of the presence and importance of these archaeological remains. We must not forget that it was the discovery and reporting of glyph caves by NSS members that first alerted archaeologists to the existence of these fascinating underground sites.

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VIRGINIA BURIAL CAVES: AN INVENTORY OF A DESECRATED RESOURCE

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In an ongoing inventory of Virginia cave resources, 23 burial caves have been field documented by the Marginella Burial Cave Project (MBCP). All but one site have been vandalized to varying degrees. In addition to the burial resource inventory, goals of the MBCP include measures for site protection and education. Problems have been encountered by the MBCP in attaining these goals. The sensitive and sacred nature of these cave resources, however, warrant limiting site specific discussions to protected sites. One burial cave in Montgomery County and two in Lee County are protected by gates because of recent disturbances. Adams Cave (44MY482) served as a party cave, but was not known as a burial site until a student brought a human mandible and two long bone fragments to a college professor and an investigation ensued. Indian Burial Cave (44LE11) was known locally as a burial cave and has suffered desecration for decades. Bone Cave (44LE169) was known locally as a burial site, mistakenly attributed to black slaves, but MBCP and Phase II archaeological investigations documented this Native American burial site and provided information that helped to alter the path of a road realignment through the cave. The examination and analysis of these and other Virginia caves by the MBCP has resulted in significant new knowledge about the use and distribution of caves as Native American burial sites.

The Commonwealth of Virginia is rich in natural resources. Among these resources are more than 3400 caves. To most of our contemporary humankind, shelter and natural resources are not the primary images generated by the sight of a cave entrance. Rather than as resources, most of our peers perceive caves as portals to the unknown-an unknown in which resource opportunity is overshadowed by manifestations of our personal fears. But has this always been the case? There is substantial evidence that some caves in Virginia and adjacent states were utilized by Native Americans for their resources (in this volume: Faulkner: 148-153; Barber & Hubbard: 132-136) as well as portals to the unknown in ceremonial context (Faulkner, 1986; in this volume: Faulkner: 148-153) and later mortuary contexts.

Of the Native American burial caves examined by the Marginella Burial Cave Project (MBCP) between its inception in 1992 and the initial preparation of this presentation in 1995, only three are discussed in detail in this paper. These were selected because they are gated and visitation is restricted, so discussion of these sites will not likely result in additional unintentional or intentional visitor impacts. As a limited sample, however, they provide a representation of the cave environments and settings used by Native Americans for burial purposes. A discussion of this specialized use of caves is important to inform the caving community about the significance of these extremely sensitive resources. Cave burial sites, as any other burial site, must be treated with the utmost respect. They are regarded as sacred by Native Americans, a perspective the caving community would do well to acknowledge. Most of these sites were first recognized by cavers rather than professional archaeologists. Unfortunately, the majority of these caves were disturbed by looters prior to their documentation. The disturbance of mortuary sites, even casually, is a felony violation of the Commonwealth of Virginia and federal laws.

THE MARGINELLA BURIAL CAVE PROJECT

The Marginella Burial Cave Project (MBCP), a project to document the extent of Native American burial caves in Virginia, was initiated in February of 1992. Between September 1992 and June 1995, the MBCP had expanded in scope to include the study of exposed and disturbed human skeletal remains and associated artifacts in Virginia caves, munder permits issued by the Department of Conservation and Recreation (DCR) and the Department of Historic Resources (DHR) of the Commonwealth of Virginia. The existence of this project was first revealed to cavers in the 1993 NSS Members Manual.

The project missions can be summarized as data collection, site protection, and education. The goals have been progressively implemented since the project's inception and include: the inventory of mortuary caves; education of cave owners about resource sensitivity and protection by law; education of state and federal law enforcement agents about cave resource sensitivity and protection by law; education of cavers about mortuary caves and protection by law.

The inventory has resulted in field visits to 23 Virginia burial caves, of which only eight were known previously to the archaeological community. All but one of these sites had been vandalized. Disturbance ranged from extensive digging and looting, potentially destroying the evidence of mortuary context, to unintentional damage by cavers handling what was discovered to be a calvarium (partial skull). The absolute degree of disturbance at each site was indeterminate because excavations have not been made during MBCP inventories. One site contained evidence of erosion by dripping water, gravity movement, and rodent activity, but there was no visible evidence of looting.

Exposed, disturbed skeletal material was removed from 12 caves. Two previously existing collections of human skeletal material also were recovered. One of these collections was retrieved from the State Police and is also a site sampled by the MBCP. The other recovered collection was made during 1955. All collections of removed and retrieved skeletal material were submitted for osteological study (Boyd & Boyd, this volume: 160-165). Stable isotope analysis of skeletal materials has been conducted on material from one site and is discussed by Trimble and Macko (this volume: 137-142).

The education of owners about the sensitivity of burial caves and their protection by law has been approached from two different perspectives. The first of these is a moral perspective, wherein mortuary caves and the human interments they contain should be attributed the same status and respect given burials in any community cemetery. The second is to convey information on existing laws that protect cave resources and cave burials. It is emphasized that the laws enable landowners to protect these important resources in their caves. In the few instances, where local contacts indicated that owners had allowed collectors to loot their mortuary caves, particular care was taken in discussing implications of the scope of the law and that a protection strategy minimizes the possibility of being implicated as an accessory to the felonious exploitation of a burial site. A primary tool in these communications was a supply of back copies of a Virginia Cave Owner's Newsletter containing two articles on cave resources and their protection. This newsletter was previously distributed to all known cave owners in Virginia during the spring of 1993. One article (Hubbard, 1993a) discusses a range of cave resources, including burial caves, while the second article (Hubbard, 1993b) presents information on the laws protecting burial caves in a question and answer format. A copy of this issue has been left with the owners of burial caves inventoried by the MBCP.

Significant problems have been encountered in working with local law enforcement agents and state agencies with respect to the protection of Virginia's mortuary caves. A solution to logistical problems with local law enforcement programs has recently evolved with the advent of the Virginia Department of Criminal Justice Services developing a curriculum on "Theft of Historic Resources" for the training of law enforcement agents within the Commonwealth of Virginia.

Problems with state agencies with respect to the protection of Virginia's caves generally center on a lack of knowledge of the Virginia Cave Protection Act and the extent of the range of

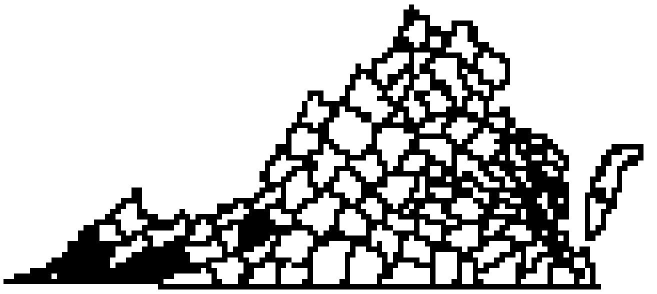

Figure 1. Shaded Virginia counties contained one or more burial caves examined by the Marginella Burial Cave Project. 1. One of the burial caves discussed is in Montgomery County; 2. Two of the burial caves discussed are in Lee County.

resources present and protected by the statutes. An example of a more serious state agency problem with mortuary cave protection is discussed in the following section.

The education of the general public about Virginia's mortuary cave resources is a desirable goal that may not be implemented, due to the jeopardy such information creates for our inadequately protected cave resources.

THE MORTUARY CAVES

Only three of the 23 mortuary caves studied are discussed in this paper (Figure 1). Each of the three sites is gated and visitation is restricted. Adams, Indian Burial, and Bone caves were found to contain disturbed and exposed human skeletal elements indicating they were used as mortuary sites by Native American peoples.

ADAMS CAVE

Adams Cave (44MY482) is located in Montgomery County, Virginia, well beyond the historically known geographic extent of mortuary cave use in southwest Virginia (Boyd & Boyd, this volume: Figure 1, western most area). It is a small cave, containing 96 meters of passage, developed in dolostone of the Cambrian-aged Elbrook Formation. The cave was previously reported to contain 18 meters of passage and to attain a depth of 3.6 meters (Douglas 1964).

Long known to area youth, the cave contains considerable evidence of misuse and vandalism including litter and graffiti. The caving community has traditionally regarded this cave as insignificant. Serious attention was directed to this site after a student brought two human long bones and a mandible to Radford University anthropologist C. Clifford Boyd. The initial MBCP inventory of the cave, in November 1993, revealed that it contained evidence of saltpetre mining, but no additional human bone material was found. A subsequent trip, in December 1993, with the student that had found the skeletal material yielded an additional 21 exposed human skeletal elements. Osteological analysis of the recovered bones indicates that the minimum number of individuals buried at this site is

Figure 2. Human remains in Adams Cave were found in the mining spoils behind the 0.3 by 0.4 m menu board, at the junction of floor and ceiling.

four (Boyd & Boyd, this volume).

The site of the osteological discoveries was beyond a crawl in the dark zone of the cave. The skeletal material was exposed in saltpetre mining spoil along a low margin of the cave where a sloping ceiling met the floor (Figure 2). Two rock slabs adjacent to the disturbed skeletal material may represent the original site of placement, prior to disturbance. The location of the disturbed skeletal material in mining spoil implies the burials were disturbed during mining. The age of this saltpetre mining is unknown. No associated wooden artifacts other than torch stubs were noted, but the degree of weathering of mattock marks imply that mining may predate the Civil War (1861-1865) and may date to the War of 1812. MBCP information and recommendations were instrumental in protection of this site by gating in September 1994.

INDIAN BURIAL CAVE

Indian Burial Cave (44LE11), in Lee County, Virginia, is within the established distribution of Native American mortuary caves in southwest Virginia. It is an intermediate-sized cave containing about 400 meters of passage developed in the upper Ordovician-aged Woodway Limestone. The speleological literature (Douglas 1964: 301) describes the cave to the burial chamber only and notes that "...this dirt slope [into the room] may have archaeological possibilities." This site has been locally known as a burial cave for decades. Local lore, related by a former owner of the cave, held that the Native American burials were first observed in extended positions on large flat rocks. The site was documented as a mortuary site in 1970 by C.G. Holland, who referred to the cave as Cedar Hill Cave and remarked that shell beads had been reportedly found with burials. Holland collected "...about 500 human bone fragments..." and a New River Series rimsherd from this site. The site had been "...ransacked by pothunters..." prior to his visit. Holland reported that a local collector, Morgan Edds, "...owns a small complete Dallas Culture jar found in..." this site (44LE11 Site Report). In a literature review of archaeological resources in Virginia caves, Clark (1978) listed this as a Late Woodland period (AD 1000 - AD 1650) site.

During the MBCP inventory, in January 1993, disturbed human skeletal material was removed from the Burial Chamber. This room is doughnut-shaped and isolated from the main entrance by a tight sloping crawl. The skylight entrance in the ceiling of the chamber provides partial lighting of the room. During subsequent visits to map the cave (November 1993) and to educate representatives of the new landowner about the cave's sensitivity and significance (February 1994), we noted new evidence of looting and newly dug piles of skeletal material (Figure 3). During the gating of this site in April 1994, two individuals visited the entrance equipped with flashlights and packs. The gaters reported that they suspected this pair were looters because they became quite agitated when they were informed the cave was being gated to protect it from misuse (Roy Powers, 1995, personal communication). A total of 98 exposed human skeletal fragments were recovered from this site during MBCP activities. Osteological analysis indi-

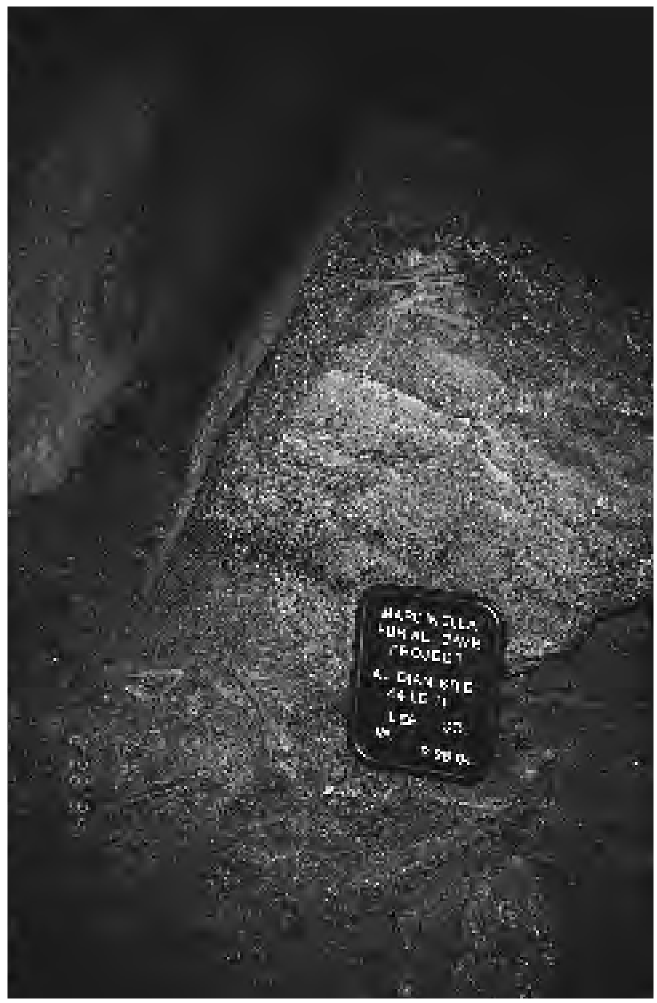

Figure 3. Evidence of looting consisting of newly dug human remains discovered in piles, to left and on edge of rock above the 0.3 by 0.4 m menu board, during an indoctrination tour for representatives of the new owners of Indian Burial Cave.

cates that the minimum number of individuals buried at this site is six (Boyd & Boyd, this volume). Based on the distribution of some of the disturbed skeletal fragments, two suspected burial sites are known within this chamber. One is a large rock slab, the other is a ledge in the passage through the pillar in the center of the chamber.

BONE CAVE

Bone Cave (44LE169) is located in Lee County, Virginia. It is a small cave containing about 15 meters of passage and is developed in the upper Ordovician-aged Woodway Limestone. The cave is described (Holsinger 1975: 118) as "...a single, dry passage trending to the west for 50 to 75 feet [15 to 23 meters]...." It is not the same site referred to as Bone Cave (44LE16) by Holland (1970).

This site is locally known as a human burial cave, but local lore held that it is the site where Art Faulkerson buried his slaves. A visit to the cave in March 1993 (Figure 4) established that the site contained disturbed human skeletal materials. Subsequently, it was learned that the site was within the realignment path of U.S. Highway 58. It was discovered that the Archaeological Survey for the realignment had not inventoried Bone Cave. Negotiations between the Virginia Cave Board (VCB) and representatives of the Virginia Department of Highways (VDOT) in January 1994 resulted in an agreement that a Phase II Investigation would be conducted in Bone Cave prior to any attempt to remove the ceiling of the cave for stabilization and grading. The Phase II Investigations involved the excavation of two test pits in the cave to determine the extent and significance of the human use of the site. The excavations yielded 1494 probable human skeletal fragments, prehistoric artifacts (marine shell beads, pottery, and cut mica), and thousands of other vertebrate and invertebrate remains (Kimball & Whyte, 1994). The dental characteristics and prehistoric artifacts examined in these excavations indicated that the skeletal remains in Bone Cave are of prehistoric Native Americans. The minimum number of individuals buried at this site is six (Boyd & Boyd, this volume). Kimball and Whyte (1994) reported that the pottery sherds indicate that Bone Cave was used by Middle and/or Late Woodland (AD 350 - AD 1000) peoples. They concluded from their excavations "...that Bone Cave is an extremely significant archaeological and biological resource." Following the Phase II investigation, a VDOT representative communicated to the VCB that the U.S. Highway 58 realignment would be altered to spare Bone Cave from destruction. Prior to the erection of a permanent gate in June 1994, it was learned that the Phase II investigators had left the human skeletal and artifactual material in plastic sample bags in the test pits. A letter from the VCB to DHR (14 October 1994) about concerns for the stability of these Native American materials in plastic bags resulted in no action.

Subsequent to the presentation of this paper in Blacksburg in July 1995, Bone Cave has been subjected to a number of violations. In August of 1995, rumors were circulating that someone had dug under the gate and plundered the cave and that the cave had been blown up during highway construction. A visit to the site in September 1995 revealed that a thin space had been excavated under the gate and one of the test pits had been disturbed. Additionally, about half a cubic meter of rock and soil rested beneath a new dome in the ceiling. Further investigation revealed fresh rock fragments distributed around the interior of the cave as well as many impact marks on the cave walls. The remains of a blasting cap were found within the cave, beyond the gate. A drill hole through the ceiling, from which water dripped, was located about five feet beyond the blast margin. Because of the unstable looking rock in the new dome in the ceiling, a VDOT representative subsequently was asked to have the loose rock removed from the excavations above the cave to determine the thickness of the remaining ceiling. A return visit in October 1995 revealed the cone of rock debris extended from the floor to the old ceiling level, obscuring the new dome (Figure 5). A quick level survey indicated an approximate remaining cave roof thickness of 0.8 meters of material beneath road excavation. Unfortunately, the floor of the surface excavation was not bedrock, but rock fragments and soil, so the intact thickness of the cave's structural ceiling could not be determined more precisely than less than 0.75 meters without excavation. This visit established that the cave ceiling had been breached at the new dome, because the unstable dome visible during the September visit had extended higher than 0.75 meters above the old level of the cave ceiling. Beyond the collapsed ceiling in the cave, two seeps of a dark viscous fluid were dripping from a fracture in the cave ceiling during the October 1995 visit and are believed to be motor oil or hydraulic fluid from construction equipment.

Figure 4. View of the area where disturbed human remains were found exposed in Bone Cave. The rock wall, on which the 0.3 by 0.4 m menu board rests, is believed to have been constructed by kids and/or hobos using the cave. It was subsequently dismantled by archaeologists during the Phase II investigation.

As of November 1995, the Bone Cave gate has been modified to prevent further undermining (Roy Powers, 1995, personal communication). As of this writing, the VCB is prepar-

Figure 5. Similar view of Bone Cave as Figure 4, but post Phase II and ceiling collapse. One rock and wood filled test pit is located diagonally to the left of the foreground strobe, while the second rock and wood filled test pit is located diagonally to the right of the distal strobe. The cone of blast and collapse debris extends to less than a meter to the right of the distal strobe. For a comparison of the blast and collapse damage, the location of the debris cone is just beyond the menu board in Figure 4 and occupies approximately a third of the area illuminated by the right portion of the distal strobe in Figure 4.

ing to negotiate repairs and safeguards to Bone Cave, but the desire of VDOT and its contractor to safeguard this sacred mortuary cave is in doubt. The human skeletal and artifactual materials that were not stolen when the gate was undermined, remain in plastic sample bags in the test pits.

COMPARISON AND DISCUSSION OF THE MORTUARY SITES

The three examples of Native American mortuary caves presented represent a range of the sites known in Virginia. Of the two Lee County examples, Indian Burial Cave was reported to have contained ceramics and shell beads, while Bone Cave was found to have ceramics, shell beads, and cut mica. Such artifactual associations in a mortuary context imply attitudes of elaborate ceremonialism typically linked to the Middle and Late Woodland period in the upper Tennessee River Basin.

The Montgomery County example, Adams Cave, did not yield any associated artifacts and is well outside the recognized area of mortuary use of caves. No information currently known about this site is useful in assigning any cultural affiliation. There was no local knowledge of this cave as a mortuary site, as in the cases of the other two caves. No artifacts were found at any of these three sites during the field investigations of the MBCP.

Both Lee County sites were within the twilight zone of their respective caves, but many of the burials in Lee and other southwestern Virginia counties were in the dark zones, as were those of Adams Cave.

In addition to the knowledge obtained from the exposed, disturbed skeletal and artifactual materials removed from inventoried burial caves, the study of these materials prior to reburial has provided additional benefit to the resources. Such recovered materials are no longer subjected to unintentional damage or casual disturbance and vandalism by cave visitors. At a number of inventoried sites, there was evidence of secondary and less systematic disturbance of burials. It is thought that these secondary disturbances were prompted by interest and curiosity in skeletal materials left exposed by earlier looting. The presentation of this work at the 1995 NSS Convention marked the end of the permitted removal of exposed and disturbed human skeletal remains from Virginia burial caves and their subsequent osteological analysis. Although the MBCP is continuing to document cave burial sites in the Commonwealth of Virginia, documentation no longer involves professional osteological analysis and MNI determinations.

Two potentially significant aspects of some Native American cave burial sites investigated by the MBCP were not reflected in the three examples. One aspect concerns the mode of placement, the second relates to the sealing of sites. Because most of the sites investigated were disturbed and no excavations were made, it was not determined whether individual burials were primary (whole person) or secondary (representative or significant bone bundles) interments, and in many cases the distribution of skeletal elements precludes a determination of where the original interment occurred. In most of the caves with relatively horizonal passage orientation, burials were assumed to have been placed at specific spots in the cave, as in the three examples. A number of burial sites were in caves with vertical entrances, where burial remains are spread along slopes at the base of vertical pitches. At some vertical sites, remains were found distally to the pitches, implying that the vertical pitches were successfully negotiated to enable interments to be placed within the cave. In a cave with a 25 foot pit entrance, an apparent burial chamber was located in an alcove 15 feet above the cave floor. Access to this virtually inaccessible chamber was accomplished by throwing a length of webbing over a thin arch above the passage entrance and scaling the overhung wall. Only four human teeth were found exposed, apparently by dripping water and gravity movement, in the alcove. This burial cave is believed to be relatively intact with no evidence of human disturbance observed during the MBCP inventory. The placement of human remains remote from entrance drops requiring at least technical descents, seems to indicate the use of ladders or other climbing aids at some burial sites.

Informant information about one investigated site indicates the cave's entrance was concealed by a rock pile at the time of its initial rediscovery. A number of other investigated burial cave sites have small entrances that could easily have been sealed after burials were interred. Although the entrances to these burial sites were open upon their discovery by cavers, many of these sites had been looted. Whether the looters dug open these caves, seals were eroded open, or entrances have remained open since interment is unknown. The authors have visited one remarkable cave that had obviously been sealed prior to its rediscovery. The non-caver who partially opened and resealed the cave invited the authors to investigate the site. Viewed from inside, the cave entrance had been nearly sealed by a stacked rock wall that had been constructed from within. Rock debris and slabs concealed the wall on the outside and were covered with soil and vegetation. The discoverer reported the cave was completely concealed, but he moved a couple of rocks and revealed the site on an impulse. The small portion of accessible cave did not contain any exposed evidence of human burials. An apparent passage was blocked by a rock dropped into a vertical slot and would require wedging the rock out and a minor bit of digging to enter. It was decided not to disturb the site further, however, and the cave was resealed. Although this sealed cave has not been documented to be an archaeological site, it is within the recognized area of mortuary caves and may be an intact burial site.

CONCLUSIONS

The Marginella Burial Cave Project has documented a significant number of previously unknown burial caves as well as a considerable volume of new data about previously recorded burial caves in Virginia. The use of caves as Native American burial sites is considerably more extensive and widespread than was previously known. Perhaps the most distressing discovery is that the looting of these sites is so extensive and is continuing. Cavers must learn to recognize burial caves, while minimizing their impacts to such sites. Suspected cave burial sites should be reported to cave archaeologists as soon as possible so that they can be verified and appropriately protected. Presently, there are very few resources available to protect archaeological sites in caves. Yet these highly sensitive and sacred sites need immediate protection to remain intact.

The termination of osteological analysis of the human skeletal materials left exposed by looting activities is believed to be very unfortunate. Not only is the fragmentary forensic knowledge about these destroyed archaeological sites being lost, but so is the opportunity for the legal systematic reburial of Native American remains disturbed by looting. Unfortunately, disturbed sacred cave sites will continue to undergo further casual destruction because of interest and curiosity in skeletal materials left exposed by looting, and because unintentional physical damage is done by visitors who accidentally tread upon these sacred materials.

ACKNOWLEDGMENTS

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OSTEOLOGICAL COMPARISON OF PREHISTORIC NATIVE AMERICANS FROM SOUTHWEST VIRGINIA AND EAST TENNESSEE MORTUARY CAVES

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The remains of at least 160 individuals from 15 burial caves in Southwest Virginia and East Tennessee are compared in terms of their temporal and spatial context, age and sex profiles, incidence of pathologies, and degree and type of postmortem alteration of bone. Individuals appear to have been interred predominantly as primary inhumations. Dental pathologies are frequent for these Late Woodland/Mississippian period interments, but overall levels of nutritional stress and trauma appear low. This suggests a generally good level of health for these prehistoric Native Americans.

Caves used as mortuary facilities for prehistoric Native Americans are known throughout the southeastern United States; investigations of them have provided a wealth of information about their inhabitants (e.g., Walthall & DeJarnette, 1974). There are two areas in the Southeast where prehistoric burial caves are especially common–northern Alabama and southwest Virginia. The Copena mortuary complex of the Middle Tennessee River valley of Alabama dates to the Middle Woodland period (ca. A.D. 0 - 500) (Walthall & DeJarnette, 1974; Willey et al., 1988). In addition to the distinctive Copena burial mounds, over 30 nearby caves were used as mortuary sites, containing both extended burials and cremations (Walthall & DeJarnette, 1974).

A cluster of mortuary caves is also documented in southwest Virginia along several tributaries of the Tennessee River (Clark, 1978; Willey & Crothers, 1986; Willey et al., 1988; Boyd & Boyd, 1992) and even extends into east Tennessee (Tucker, 1989; Whyte & Kimball, 1995). This cave region is our focus in this paper. At least 38 prehistoric mortuary caves have been identified in southwest Virginia and east Tennessee (Table 1). This number is a minimum estimate because there are probably many more undocumented mortuary caves in this region. Most of these caves are thought to date to the Late Woodland period in Virginia (ca. A.D. 900 - 1600), or anywhere from the Middle Woodland to Early Mississippian periods in Tennessee (ca. A.D. 350 - 1300) (Clark, 1978; Willey et al., 1988; Kimball & Whyte, 1994).

Over 520 prehistoric Native American individuals have been exhumed or identified from southwest Virginia and east Tennessee caves (Table 1). Many of these bones have never been fully analyzed by professional osteologists. Recently, skeletal remains of at least 160 individuals from 15 of these prehistoric burial caves have been intensively studied by the authors. Remains from two caves (44LE169 and 40JN159) were examined as part of professional archaeological salvage excavations. Collections from the other 13 caves were obtained and analyzed as part of the Marginella Burial Cave Project (MBCP) under the direction of David Hubbard and

Table 1. Recorded burial caves in southwest Virginia and east Tennessee (revised from Clark, 1978).

Site Number/Name	County	Number of Burials
44LE9	Lee	100
44LE11*	Lee	6
44LE15	Lee	+
44LE16	Lee	+
44LE28	Lee	+
44LE169*	Lee	6
44LE258*	Lee	1
44LE280*	Lee	8
44LE261*	Lee	4
44LE281*	Lee	1
44LE260*	Lee	3
44SC6	Scott	+
44SC10	Scott	+
44SC44	Scott	+
44SC140*	Scott	2
44RU6	Russell	113
44RU10	Russell	+
44RU12	Russell	+
44RU29	Russell	+
44TZ5	Tazewell	102
44TZ92	Tazewell	11
44WG3*	Washington	20
44WG14	Washinton	+
44WG397*	Washington	2
Nick Site*	Washington	2
44SM6	Smyth	1
44SM12	Smyth	1
44SM13*	Smyth	1
44SM24	Smyth	+
44SM28	Smyth	2
44SM34	Smyth	+
44SM48	Smyth	+
Cave 2	Smyth	+
Cave 3	Smyth	6
44MY482*	Montgomery	4
Long Cave*	Pulaski	1
40JN159*	Johnson (TN)	99
40CE20	Claiborne (TN)	25
Total		521+

Note: skeletal collections from cave sites with an asterisk (*) have been examined in detail by the authors; unless otherwise noted, all counties are located in southwest Virginia; a (+) indicates some human remains were noted.

Michael Barber (this volume). In this paper we present the results of that skeletal analysis, including information relating to demographic characteristics of the individuals represented (age at death, sex), health and disease indicators (infection, nutritional stress, oral health, arthritis), and lifestyle (trauma). In addition, examples of postmortem alteration of bone are discussed in terms of causative biological and cultural agents. A comparison of these sites with previously documented southwest Virginia and east Tennessee sites reveals biological, cultural, temporal, and postdepositional patterns. Our goals are twofold: 1) to present summary information about the biocultural characteristics of prehistoric Native Americans from cave sites of this region; and 2) to understand relationships among southwest Virginia and east Tennessee mortuary caves and their human interments.

ARCHAEOLOGICAL BACKGROUND

Table 1 presents site information for burial caves from southwest Virginia and east Tennessee. With the exception of one cave each in Montgomery and Pulaski Counties, all of the southwest Virginia cave sites discussed herein are found in the following counties: Lee, Russell, Scott, Smyth, Tazewell, and Washington (Figure 1). The two East Tennessee caves listed in Table 1–Lake Hole Cave (40JN159) in Johnson County and Ausmus Cave (40CE20) in Claiborne County–are located to the south of these southwest Virginia counties and are likely a part of this regional cluster.

The most intensively and extensively investigated burial cave in this region is Lake Hole Cave (Kimball et al., 1992; Boyd & Boyd, 1993; Whyte & Kimball, 1995; Whyte & Kimball, this volume). The cave, located in the Cherokee National Forest, had been extensively looted. After apprehension of the looters, the U.S. Forest Service (in consultation with the Eastern Band of the Cherokee) contracted with archaeologists at Appalachian State University, Boone, North Carolina, to excavate the disturbed portions of the cave. All sediments from these controlled excavations were removed from the cave and water screened through nested 0.64 cm and 0.32 cm mesh screen.

A bone awl produced an uncorrected Accelerator Mass Spectrometer date of 790 B.P. ± 60 years (Tom Whyte, 1995, personal communication). When corrected, using dendrocalibration formulae derived from Stuiver and Reimer (1993), this date calibrates to A.D. 1260 with a one sigma age range of A.D. 1210 - 1290. This date differs from the only other radiocarbon dated burial cave in this region. A sample of human bone from Higginbotham Cave (44TZ5) in Tazewell County, Virginia, produced an uncorrected date of 535 ± 65 years (Clark, 1978), calibrating to a corrected date of A.D. 1410 with a one sigma age range of A.D. 1390 - 1440. While both of these dates fall within the same general time period (Late Woodland of Virginia or Mississippian of east Tennessee), the Lake Hole Cave date of A.D. 1260 is considerably earlier than Higginbotham and reflects the time span over which these burial caves were used.

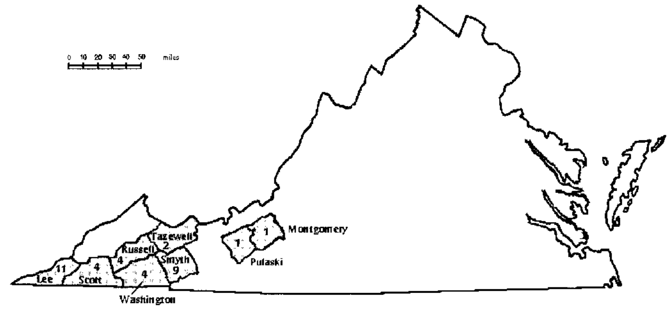

Figure 1. Map of Virginia showing locations and frequencies of southwest Virginia mortuary caves.

A total of 12,841 human bones, bone fragments, and teeth representing all skeletal elements (Whyte & Kimball, 1995; Whyte & Kimball, this volume) was recovered from Lake Hole Cave. This collection, although biased through the wishes of the Cherokee to excavate only the looter-disturbed deposits, represents the most complete and extensive skeletal database from any of the discussed burial caves.

The other skeletal collections from burial caves analyzed in this study are less complete and informative. For example, most of the Bone Cave (44LE169) skeletal sample is only from limited Phase II site testing (Kimball & Whyte, 1994). Collections from both the Ton (44WG3) and Mer (44LE280) sites were recovered by the Marginella Burial Cave Project (MBCP) from third party intermediaries after looting. Most of the other skeletal samples represent only surface collections by the MBCP from looter disturbed sites. More extensive test excavations were not permitted by state law. Controlled excavation of all of these sites would surely produce far greater amounts of bone and more secure information about these individuals. Even with these limitations and biases, biological and cultural characteristics of those interred in these caves can be compiled and compared.

RESULTS AND DISCUSSION

DEMOGRAPHIC PARAMETERS

Table 2 presents summary information for all human bone and teeth personally analyzed by the authors from the 15 burial caves. Calculations of Minimum Number of Individuals (MNI) are also provided. MNI estimates vary widely for the sites from as little as one or two individuals from the Mud (44LE258), Born (44WG397), Scott Born, (44SC140), Stead (44SM13), Burt, (44LE281), and Nick sites to a high of 99 individuals from Lake Hole Cave (40JN159). Of course, these estimations vary directly with the amount of bone obtained from each site. There is a clear pattern, however, of all ages and sexes being represented in the skeletal remains from these sites. This is also true of other recently studied burial caves in Virginia and Tennessee. Bull Thistle Cave (44TZ92) in Tazewell County, Virginia, contained the remains of at least 11

Table 2. Summary information on skeletal collections from 15 analyzed sites.

Site		Total Number of Bones	Teeth	MNI Adult Male	Female	Indeterminate	Subadult	Mode of Collection
44LE11	Indian Burial Cave	98	-	3	1	1	1	surface collection (a)
44 LE258	Mud Site	3	-	-	-	1	-	surface collection (a)
44LE280	Mer	144	16	3	3	-	2	surface collection (a) excavation by vandals
44LE261	Kull	65	-	-	2	1	1	surface collection (a)
44LE281	Burt	-	4	-	-	1	-	surface collection (e)
44le260	Curry	29	-	1	-	1	1	surface collection (a)
44LE169	Bone Cave	1650	39	1	-	2	3	surface collection (d) controlled excavation
44WG3	Ton Site	126	34	12	5	-	3	excavation by vandals
Nick		8	-	1	1	-	-	surface collection (a)
44SM13	Stead Site	-	2	-	-	1	-	surface collection (a)
44SC140	Scott Born	3	-	1	-	-	1	surface collection (c)
44MY482	Adam's Cave	24	8	1	1	-	2	surface collection (b)
Long Cave		2	-	1	-	-	-	surface collection (a)
44WG397	Born Site	7	-	1	-	-	1	surface collection (a)
40JN159	Lake Hole Cave	11,977	864	19	11	19	50	excavation by vandals controlled excavation
TOTALS		14,136	967	44	24	27	65	

Note: Collections from all sites except Lake Hole Cave were obtained as part of the Marginella Burial Cave Project.
(a) = surface collections from looted sites
(b) = surface collection from site historically disturbed by saltpeter mining
(c) = surface collection after minimal caver disturbance
(d) = surface collection after disturbance by local vagrants and children
(e) = surface collection from erosional disturbance

individuals, including 8 adults (2 males, 2 females, 4 indeterminate sex), one adolescent, and two young children (Willey & Crothers, 1986). Officer Cave (40WH98) in White County in middle Tennessee contained the remains of at least 15 individuals, including 9 adults (4 males, 4 females, 1 indeterminate sex) and 6 subadults (including two infants, three children, and one adolescent 12 - 14 years old) (Willey, et al., 1988). Finally, Ausmus burial Cave (40CE20) in east Tennessee contained a minimum of 25 individuals of all ages and both sexes (Tucker, 1989). The high number of young infants, one year old or less, from Lake Hole Cave (at least 17 of the 99 individuals) is the direct result of the use of water screening through small mesh as an excavation recovery technique (Whyte & Kimball, 1995). It is clear that, even for Lake Hole Cave, these are indeed *minimum* estimates of the numbers of individuals interred in these sites and that there is no interment bias by age or sex of the people buried in these caves.

PALEOPATHOLOGY

Table 3 summarizes the presence and frequency of major pathologies for the five sites analyzed with substantial sample sizes–Ton (44WG3), Mer (44LE280), Bone Cave (44LE169), Indian Burial Cave (44LE11), and Lake Hole Cave (40JN159). Identification of pathologies is based on descriptions and illustrations in Ortner and Putschar (1981), Ortner and Aufderheide (1991), and White (1991). The most common pathologies represented in the skeletal collections included dental disease (caries, abscesses, antemortem tooth loss), indicators of possible nutritional deficiencies, non-specific infection or generalized stress (porotic hyperostosis, enamel hypoplasia, osteitis, periostitis, osteomyelitis), trauma, and degenerative osteoarthritis.

Dental caries rates were high for all of the analyzed sites for which teeth were available (no teeth were collected from Indian Burial Cave), affecting between 13.5 and 50.0% of the total number of adult teeth examined from each site (Figure 2). These caries rates are well within the range of agricultural populations (Smith, 1983). A high percentage of adult mandible and maxilla (jaw) fragments manifested antemortem tooth loss, ranging between 25.0 and 61.5% of all fragments (Figure 2). This tooth loss surely occurred as a result of dental infection, abscess, and decay of the adult dentition and further sup-

Table 3. Pathologies of skeletal collections from selected cave sites.

Pathology	Ton		Mer		Indian Burial Cave		Bone Cave		Lake Hole	
dental caries	7/31	22.6%	8/16	50%	-	-	13/30	43.3%	83/614	13.5%
abscess	-	-	-	-	-	-	3/8	37.5%	2/45	4.4%
tooth loss	8/13	61.5%	2/5	40.0%	-	-	2/8	25.0%	26/45	57.8%
porotic hyperostosis	3/5	60.0%	-	-	-	-	-	-	21/43	57.8%
enamel hypoplasia	1/31	3.2%	1/16	6.3%	-	-	3/30	10.0%	17/614	2.8%
non-specific infection	5/121	4.1%	6/144	4.2%	-	-	2/326	0.6%	73/3349	2.2%
arthritis	-	-	3/120	2.5%	1/65	1.5%	4/254	1.6%	93/3576	2.6%
trauma	-	-	2/120	1.7%	2/65	3.1%	1/254	0.4%	25/3916	0.6%

Note: Dental caries and enamel hypoplasia percentages are based on total number of adult teeth; abscess and tooth loss percentages are based on total adult maxilla and mandible fragments. Bone Cave percentages are based on identifiable bone fragments only.

ports the contention that the individuals from these sites were part of an agricultural (maize-based) society. A high caries rate (23.5%) was also observed for Officer Cave but not Ausmus Cave (5.6%) (Willey, et al., 1988; Tucker, 1989).

Nutritional or disease stress was also indicated by the high percentage of frontal fragments with pitting in the eye orbits from the Ton site and Lake Hole Cave (Table 3 & Figure 3). This condition, called porotic hyperostosis or cribra orbitalia, has been linked to chronic iron-deficiency anemia in some subadults or to the secondary effects of chronic disease (Stuart-Macadam, 1991). Lowered iron levels in the blood of individuals may actually be a positive adaptive physiological response in regions with large numbers of pathogens, because pathogens are less likely to attack successfully or reproduce within such a host (Stuart-Macadam, 1992).

The occurrence of enamel hypoplasia (grooves or pits) (see Goodman & Rose, 1990) on some adult teeth suggests periodic stress during childhood. The frequency was overall very low for these sites. Finally, one adult tibia from the Ton site and three tibiae and one femur from Lake Hole Cave were bowed. Bowing of long bone shafts may be produced by a variety of factors (e.g., malnutrition, trauma, disease) (Ortner & Putschar, 1981).

Frequencies of non-specific infection were also low. Most included moderate osteoporotic pitting of the cranium (affecting 5% of the skull fragments at Lake Hole Cave) and periostitis (pitting and bone remodelling) on arm and, especially, leg bones. On at least six long bones from Lake Hole cave and one fibula from Bone cave, more advanced osteomyelitis was present. According to Ortner and Putschar (1981), this non-specific infectious state involves bone marrow and is often accompanied by a cloaca for pus drainage, which is often part of the

Figure 2. Mandibles from 44WG3 with extensive premortem tooth loss and caries.

Figure 3. Porotic hyperostosis on upper left eye orbit of cranial fragment from 44WG3 (near upper left corner of scale).

Figure 4. Arthritic lipping and abcess on right innominate (top), Arthritis on thoracic vertebra (bottom left), and 3 fused thoracic vertebrae (bottom right). All 44LE261.

reactive process to traumatic injury. At Lake Hole Cave, non-specific infection was most commonly seen on the leg bones. Over 7% of all leg bones (26/337 total femora, tibiae, patellae, and fibulae) were affected. This same pattern of periostitis distribution was observed by Willey and colleagues (1988) at Officer Cave. They (Willey, et al., 1988:64) note: “The tibia (lower leg) is a common location for infectious disease and trauma because it is vulnerable to blows, has a large subcutaneous area, few capillaries, and slow blood flow.”

Degenerative osteoarthritis was also commonly recorded from these skeletal samples (Figure 4). For example, at Lake Hole Cave, 8.96% of all vertebrae, 5.45% of all clavicles, 3.2% of all feet, and 2.15% of all elbow and wrist areas of the arms manifested osteoarthritis. This condition is particularly common in the vertebrae and long bone joints of older individuals and is indicated by the presence of osteophytes (bony lipping and spurs) and eburnation (wear and polishing) on joint surfaces (White, 1991).

A few traumatic injuries, predominantly in the form of healed postcranial fractures of the ribs, legs, and arms, were noted at Mer, Indian Burial Cave, and Bone Cave, and at Lake Hole Cave (Table 3). Of the 25 traumatic injuries noted for Lake Hole cave, most were healed fractures of the legs (7/25) or ribs (5/25). As stated previously, periostitis and osteomyelitis, infectious conditions often initiated by traumat-

Figure 5. Rodent-gnawed right humerus (top) and right tibia (bottom) shafts from 44LE261.

ic injury, were also most common on the leg bones of Lake Hole Cave individuals.

POSTMORTEM AND POSTDEPOSITIONAL ALTERATION OF BONE

The most dramatic post-depositional or post-mortem alteration of many of the bones from these caves has been produced by animals (Figure 5). Carnivore gnawing of the spongy ends of long bones and highly patterned rodent gnawing of bony projections (see White, 1991:363-365 for a discussion and illustrations) obliterated the external features of some bones. For example, over 49% of the 144 Mer site bones were rodent gnawed. At Indian Burial Cave, 29.7% of bones were rodent gnawed and 16.2% were carnivore chewed. All of these cave sites clearly suffered from extensive alteration and movement of bones by burrowing and denning animals.

Burned human bones were rare for all sites; however, 53 calcined bone fragments were recovered from two excavation units at Lake Hole Cave, suggesting the possibility that at least two cremations were placed in the cave. Evidence for cremations in burial caves has been noted by Clark (1978) for Higginbotham Cave and Willey, et al. (1988) for Officer Cave. This mode of post-mortem human alteration of the dead appears to be rare for these cave sites, however.

Some researchers (Boyd & Boyd, 1992; Kimball & Whyte, 1994) have suggested that the disarticulated human remains in these sites may represent the remnants of secondary bundle burials, in which the bones of individuals previously interred elsewhere were collected after decay. While this mode of interment may have been used by these prehistoric Indians, the extensive bioturbation, erosional processes, and human looting that have affected these sites could have easily produced the scattering or clustering of bones seen today. The recovery of numerous small bones (such as the hyoid, hand and feet bones, fetal, and infant bones) from Lake Hole Cave indicates that most individuals at this and possibly the other cave sites were placed in these sites shortly after death. The predominance of primary interment as a mode of burial is also supported by informants' comments suggesting the presence of articulated skeletons with artifacts in many southwest Virginia cave sites (David Hubbard, 1995, personal communication).

SUMMARY AND CONCLUSIONS

From a detailed review of the skeletal biology of human remains from 15 Southwest Virginia and East Tennessee prehistoric burial caves and a comparison with previously studied caves, several patterns emerge:

1. While burial caves may have been used for over 1000 years in this region (Wiley, et al., 1988; Boyd & Boyd, 1992; Kimball & Whyte, 1994), radiocarbon dates and artifact evidence suggest their most common use between circa A.D. 900 – 1400.
2. These caves were cemeteries, with all ages and sexes interred within them.
3. The skeletal remains predominantly represent primary burials, although other forms of interment (such as cremation and secondary burial) occurred in some cases.
4. High caries and antemortem tooth loss rates for nearly all sites indicate that the interred were from maize-based agricultural societies (although the low caries frequency at Ausmus Cave suggests greater variability in diet).
5. The overall low rates of non-specific infection on the skeletal remains suggest that, except for dental disease, the general level of health for individuals was good (i.e., they successfully met nutritional and pathogenic challenges).
6. Trauma frequencies suggest that the likelihood for injury to the skeleton was low.
7. Extensive natural and human disturbance to these sites have altered much of their contextual information, thus requiring careful investigation and stronger efforts at preservation of these sacred sites.

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SELECTED ABSTRACTS FROM THE 1997 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN SULLIVAN, MISSOURI

BIOLOGY SESSION

Cave Wildlife in Missouri's Big Spring Country–An Overview

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The watersheds of the Current and Eleven Point Rivers in the southeastern Missouri Ozarks form one of the most intensely karstic regions in the state. In a program that originated in 1990 with concern over the effects of mineral exploration, the Cave Research Foundation has been systematically mapping caves and performing macrofaunal surveys within the Eleven Point watershed on the Mark Twain National Forest. The caves range up to 1.6 km (1 mi.) in length and vary from small remnant channels to large base-level stream caves. About 160 caves have been examined. The habitat is very food limited, as recharge takes place through a thick mantle. Typical stream fauna includes low densities of troglobitic isopods (*Caecidotea antricola*) and two species of *Stygobromus* amphipods. Added to this may be troglobitic fish (*Typhlicthys subterraneus*) and crayfish (*Cambarus hubrichti*) and troglophilic snails. The amphibian fauna is relatively diverse. Cave, long-tailed and grotto salamanders are all common, frequently within the same cave. An unexpected factor is the use of stream caves by beavers, often an important source of nutrients. Gray bats colonize a dozen caves, including some newly recorded sites. Terrestrial invertebrates include widespread species such as the fungus beetle *Ptomophagus cavernicola,* and the flightless fly *Spelobia tenebrarum* as well as a diverse mixture of springtails, mites, rove beetles, etc. Several previously unrecorded species occur. This attempt to look comprehensively at all caves in a relatively large area is helping to build a broad overview of the regional cave fauna.

Heterotrophic Dominance Observed Among the Microorganisms of the Schermerhorn Park Cave in Cherokee County, Kansas

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Although the Schermerhorn Park Cave, in Cherokee County, is considered the most biologically diverse cave in Kansas, the microfauna of the cave does not diverge significantly from the nearby soil, and the cave's inhabitants rely primarily on the surface for their supply of organic nutrients. Analysis of water samples through bacteria density plate counts, metabolic and morphologic tests on isolated bacteria, and a quantitative water analysis provided by the Kansas Department of Health and Environment gave a preliminary survey of the underground bacteriology of the cave. The bacteriological tests revealed an abundance of heterotrophic bacteria in samples collected from the stream origin and an isolated pool. The water analysis showed levels of essential nutrients and toxins for iron oxidizing bacteria that diverge significantly from optimum conditions. Therefore, it seems that the Schermerhorn Park Cave is dominated by heterotrophic organisms, that the cave's microenvironment closely resembles the soil, and that large regions containing an abundance of chemolithoautotrophs do not exist.

Notes on Biogeography, Ecology and Behavior of Mexican Blind Catfish, Genus *Prietella* (Ictaluridae)

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The Mexican blind catfish *Prietella phreatophila Carranza* 1954, is an obligate troglobitic catfish, formerly thought endemic to springs adjacent to, or within about a 50 km radius of, the town of Muzquiz, in central Coahuila. Specimens have been rare, and generally little is known of the biology of the genus. Several characters, however, place the genus as the sister group to *Noturus,* indicating a probably ancient divergence from the common ancestor perhaps related to cave invasion. Recent discoveries of congeneric populations far to the northwest (near the Texas border) and southeast (in southernmost Tamaulipas) extend the range across more than 600 km, transecting many major surficial drainages and major mountain ranges. Preliminary morphological observations indicate that the northern population differs little from *P. phreatophila,* but the single specimen from the southernmost locality was recently described as *Prietella lundbergi* Walsh and Gilbert 1995.

Human Impact on the Microbial Communities of Lechuguilla Cave: Is Protection Possible During Active Exploration?

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In an effort to assess the impact of humans (explorers and scientists) on the microbial communities of Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico, the authors undertook a study of selected human indicator species of bacteria. We compared low impact (alcoves, off-trail sites) with high human impact areas (camps, trade routes, rocks that humans slither over, urine dumps, drinking water sources). Enrichment culture procedures targeted high-temperature *Bacillus* sp., *Escherichia coli,* and *Staphylococcus aureus* sampled from these sites. High-temperature *Bacillus* are bacteria that one would expect to find on the surface in high-temperature desert soils, but would not expect to find in the soils of the cave which remain at a stable 20°C. Results of these comparisons show that high human impact areas have significantly more of the human indicator species than do the low impact areas. Some recovery is seen in areas with *S. aureus* and *E. coli* if the areas are given a rest from human visitation, giving time for the human-associated bacteria to die off.

The Ecology of Texas Cave Crickets

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The rhaphidophorid genus *Ceuthophilus* has numerous described and undescribed species in Texas caves. Three species are sympatric in caves along the Balcones Fault Zone in Central Texas. *Ceuthophilus (C.) secretus* Scudder and C. (C.) new species "B" both roost on ceilings and forage outside, while *C. (Geotettix) cunicularis* Hubbell is a floor-dweller that rarely ventures outside. Crickets will emerge most evenings when the air is >16°C. The "cricket hop" usually starts within 15 to 45 minutes after sunset, and crickets scavenge for carrion at distances up to 30 m from the entrance. Crickets will occasionally feed on rich fruits, such as Texas Persimmon, or fungi. Adult crickets are more sensitive to light and cold than are nymphs, and on chilly evenings only the nymphs will venture outside. There is a large, annual crop of young crickets. Intense competition occurs at bait stations with the red imported fire ant *Solenopsis (Solenopsis) invicta* Buren. Fire ants invade Texas caves during the spring and summer, where they forage for water and attack cave crickets and other native fauna. These invaders threaten native soil and cave communities, which include endangered species. Several species of *Rhadine* beetles specialize in sniffing out and digging up cave cricket eggs laid in the cave.

THE CRYSTAL BEACH SPRING ECOSYSTEM

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The Crystal Beach Spring is a freshwater spring located in the Gulf of Mexico, approximately 300 m offshore from the community of Crystal Beach, Florida. The system is subject to tidal influences as the discharge may reach 280 L/sec at low tide and saltwater from the Gulf may siphon into the system at high tide. The cave system's fauna include five troglobitic crustaceans (two crayfish, *Procambarus* sp. and *Troglocambarus* sp., two amphipods, *Crangonyx hobbsi* and *Crangonyx grandimanus*, and an isopod, *Caecidotea* sp.), two species of mussels, a hydrobiid snail, a hydroid, *Eudendrium cf. carneum*, and several types of bacteria. The crustaceans are throughout the explored freshwater areas of the cave, including areas inundated by saltwater at high tide. The hydroid is only found within the part of the cave that is inundated by saltwater on a regular basis (a penetration of 580m and less). This may indicate that the hydroid depends on plankton brought into the cave system by the saltwater for a food source. The mussels are only found downstream from the Dragons Lair Tunnel. The Dragons Lair contains a distinct halocline/thermocline with freshwater flowing toward the cave entrance on top of stagnant saltwater. Orange bacteria colonies are in the saltwater and a white bacterial "cloud" sits on top of the interface. Bacteria identifications are currently in progress, but it appears that the bacteria in the Dragons Lair generate nutrients on which the mussels are dependent for a food source.

CHANGING INDIANA BAT SUMMER HABITAT AND DECLINING POPULATIONS

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The Indiana bat is in much of the eastern half of the United States, with large hibernating populations in Indiana, Kentucky and Missouri. An endangered species, its population is declining rapidly. The decline of this species is most prominent in Missouri, while population numbers are stable to increasing in Indiana. In Missouri, the Indiana bat overwinters in caves in the southern portion of the state, and spends its summers in forested riparian zones north of the Missouri River. Based on previous research, it does not appear that the decline of the species is due to perturbation while overwintering. If the Missouri population continues to decline at the present rate, it is estimated that the Indiana bat will become extinct in Missouri by the year 2023.

DIGGING SESSION

HELICTITE CAVE, VIRGINIA

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On March 16, 1996, a Virginia Cave was opened after several years of digging in the bottom of a surface fissure in the Burnsville Cove. The fissure walls contain so many chert stringers and pockets that it is not readily recognizable as limestone. There were two digs in the bottom of the 5.5 m deep fissure that encountered cave passage. The first dig yielded about 120 m of cave passage but was choked with breakdown in the direction that would lead back into the hillside. The second and more extensive digging project, on the uphill side of the fissure and three meters from the first, reached a depth of 7.3 m before breakthrough was achieved.

GEOLOGY AND GEOGRAPHY SESSION

GEOMORPHOLOGY OF FOUNTAIN CAVE, A PSEUDOKARSTIC SINKING STREAM SYSTEM AT ST. PAUL, MINNESOTA

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Fountain Cave is the longest natural sandstone cave (350 m) in Minnesota. During headward retreat of the falls of Glacial River Warren, which carved a segment of the Mississippi River gorge at St. Paul, Minnesota, the Platteville Formation's limestone caprock of the river terrace was fractured over the future site of the cave, allowing enhanced recharge to the underlying St. Peter sandstone at this point. The gorge provided a lower base-level, initiating piping along joints in the loosely consolidated sandstone. A tubular void propagated from the wall of the gorge toward the recharge point. The existence of rooms in the cave, which successively decrease in size upstream, suggests tributary piping at joint intersections. Collapse of the cave roof later created a ravine at the cave entrance. In historical times, a surface stream entered a sinkhole on the terrace and flowed through the cave and ravine to the river. The stream allowed the cave to remain open into postglacial times, whereas other sandstone caves in the gorge, without streams, sealed themselves. When expansion of the city of St. Paul dried up the surface stream, early in the present century, Fountain Cave, too, sealed itself.

MICROORGANISMS AND CONDENSATION CORROSION: A DISCUSSION OF DOLOMITE, ITS OCCURRENCE IN CAVES, AND POSSIBLE MICROBIAL MEDIATION

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Condensation corrosion is the preferential dissolution of a cave by aggressive condensate, controlled by three conditions: a high carbon dioxide concentration, a high air humidity, and a strong thermal gradient between cave passage levels. In Movile Cave, located in Southern Dobrogea, Romania, these conditions are met. Condensation corrosion, occurring in the upper level of the Movile, is linked closely to sulfuric acid speleogenesis in the lower level of the cave. While the bedrock in the vicinity of Movile Cave is limestone with high-magnesium calcite, the corroded rock walls in the cave have been dolomitized. Dolomitization is most evident at the surface of the corroded walls and corrosion residues. Microbes are found in abundance on and around dolomite crystals. Although corrosion residues in Lechuguilla Cave, New Mexico, are thought to be associated with biogenic processes, condensation corrosion is not active in Lechuguilla. Therefore, an opportunity exists to study the active corrosion, bacteria, and dolomite of the Movile. Although dolomite forms from a variety of inorganic mechanisms, this work proposes that the presence of microbes may not only contribute to dolomite formation, but might also accelerate and stabilize rates of mineral precipitation. The metabolic and biogeochemical processes of the bacteria, coupled with possible redox reactions in the condensation pore waters, all may work to enhance rock dolomitization.

Tumulus, Lava Tube, Lava Rise, Flow Lobe, and Drain Caves of Kilauea Volcano

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As a result of increasing cooperation between volcanologists and speleologists in Hawaii, the origins of certain puzzling caves of Kilauea Volcano now are better understood. In addition to classical lava tube caves and hollow tumuli, subsidence caves have been identified beneath and adjacent to boundary ridges of lava rises, and of flow lobes with sagged centers. At least two major caves underlie long, sinuous tumuli, and several caves contain remnants of horizontal and/or vertical partitions between drained flow lobes in sheet flows of fluid basalts. The longest cave found in the crater to date (about 500 m) is a two-level complex of drained flow lobes. Also, a single vertical drain cave has been found beneath the sunken center of a prominent lava rise.

Classification and Morphology of St. Peter Sandstone Piping Caves in Minnesota

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Piping caves result from mechanical erosion by water in poorly consolidated clastic materials. Hitherto, all natural caves formed by this process in the St. Peter Sandstone, an Ordovician cratonic sheet sand of the Upper Mississippi Valley, have been lumped together as “piping caves,” with no attempt made to distinguish among them. But in the state of Minnesota, at least, these caves fall into two distinct populations, tubular and maze caves. The tubular caves are single conduits up to 350 meters in length, wholly within the sandstone. They are graded to nearby river valleys to which they drain(ed). Among named caves, examples are Fountain, Carvers, Old Soldier, and Channel Rock Cavern. The maze caves are low, wide spaces with sandstone pillars supporting a ceiling formed by the base of the overlying Platteville limestone. These voids are related to the St. Peter–Platteville contact. Examples are Farmers & Mechanics Bank Cave, which underlies a whole city block in downtown Minneapolis, and Chutes Cave.

The Forgotten Karst of Northeastern Kentucky: a Model for Regional Speleogenesis, Carter County, Kentucky

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While numerous cave studies detail the features of large karst terrains, we suggest cavers and researchers not overlook smaller, but no less interesting, karst landscapes. Such a mecca exists in and around Carter Caves State Resort Park, Carter County, Kentucky. Previous attention has been given to the overlying coal-bearing, Pennsylvanian sandstones and to the sedimentology of the Mississippian, Newman Formation carbonates. However, the existing cave systems and their speleogenesis have been virtually ignored. These caves, when observed collectively, provide an excellent tool for regional speleogenetic and geomorphic interpretation. Based on observations in the multiple cave systems and drainage basins, we have developed a model of regional speleogenesis which incorporates three distinct phases. First, phreatic tube development initiated during a time when regional base level was still at elevations above the carbonate units. Second, surface streams cut through the sandstone and into the Newman Limestone, allowing for rapid down-cutting and lowering of regional base level. During this time, extensive vadose passage development, characterized by high, narrow canyons, occurred in caves throughout the region. Third, major streams quickly cut through the limestone units and into the underlying shale and sandstone of the Bordon Formation. Consequently, the lowest cave passages have lower gradients and greater horizontal passage development.

The Effect of Stream Piracy in the Delineation of the Dolan Springs Drainage Basin, Val Verde County, Texas

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The Dolan Springs Group, located in the western Edwards Plateau in Val Verde County, Texas, is comprised of seven springs within a 1.8-km-radius upstream of the confluence of the Devils River and Dolan Creek. Mean discharge of the individual springs ranges from 101-235 L/s. Some hydrologic inconsistencies are apparent upon initial examination: the springs’ drainage basin, as estimated by geochemical calculations, is 30% larger than the area determined by potentiometric mapping; water budget data for the potentiometric basin indicate a mean aquifer recharge rate double that of the surrounding area; and the springs’ sustained baseflow does not correlate to the low storage capacity of the limestone. These anomalies result from the subsurface piracy of streamflow from the Devils River for 30 km to the springs. Potentiometric mapping partially supports this hypothesis; more data points are needed south of the river for greater certainty. The piracy is strongly supported by the increase of total dissolved solids in groundwater with distance from the river and increased proximity to the springs, and also by spring hydrographs which show little response to local rainfall but rapid response to the river’s discharge. Most of the groundwater flows along the honeycombed contact of the Segovia and Ft. Terrett members of the Edwards Limestone. The lack of local significant cave development suggests the current flow regime is a relatively recent phenomenon along the contact, but the presence of at least one higher elevation and hydrologically abandoned cave may suggest the piracy pre-dates the modern springs.

Magnitude/Frequency Analysis of Cave Passage Development in the Central Kentucky Karst

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A quantitative evaluation of passage growth rates by dissolution has been undertaken within the Logsdon-Hawkins River of Mammoth Cave, Kentucky. Sampling and high resolution monitoring of chemical and flow conditions in the river through two 145m deep wells has allowed an estimate of passage growth during the warm-season months (May-October) of 1995. The surface area of water-wall contact in the passage cross section at the site was determined using stage data, and mineral dissolution rates were estimated using chemical data and several existing dissolution rate expressions, assuming reaction-limited kinetics. During the study period, storm events clearly dominated overall passage growth, with an estimated 70% of the dissolution occurring during the 7% of the time during which the cave was flooded completely to the ceiling. A single storm was responsible for nearly 30% of total passage growth during the 165 days of the study. Different kinetic rate laws resulted in similar relationships between stage and dissolution work, but different estimates of the total work done. Although the impact of siliceous sediment covering the floor and walls was not quantitatively evaluated, the presumed inhibition of dissolution by this sediment would additionally favor the large events, during which river waters are in contact with the relatively sediment-free rock of the cave ceiling. Further work is underway at the site to evaluate the impact of sediment masking, abrasion by suspended load, and our assumption of an independence between dissolution rates and water velocity which occurs with reaction-limited kinetics.

Mechanics of Clastic Sediment Transport in Karst

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Most caves contain a suite of clastic sediments ranging from varved clays to cobbles and boulders. In active stream passages, the clastic sediments move mainly under flood flow conditions. If the mechanism of sediment transport were understood, the transport model could be applied to sediment deposits in fossil passages as a means of interpreting past flow conditions. Sediment transport mechanisms also have implications for soil piping and resulting sinkhole formation, and for transport of solid waste and pollutants that have an affinity for siliciclastic sediments. Sediment transport theory for surface streams is well developed but its transfer to karst conduit systems is complicated by multiple inputs for water and sediment and by the presence of both pipe and channel flow regimes. Elevation differences between sinking streams and springs give an overall hydraulic gradient from which to estimate the energy line through the aquifer system. Sediment particle sizes are used to estimate boundary shear and therefore stream power. Two thresholds in boundary shear stress occur. The first is the shear stress needed to move sediment as bedload. Bedload movement is strongly a function of particle size, resulting in winnowing and differentiation of sediments. The second threshold is the shear stress required for complete entrainment of the sediment mass resulting in passage flushing and deposition of undifferentiated sediment deposits.

Bioerosion Notches versus Flank Margin Caves: Viability as Paleo Sea Level Indicators

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Recently, dramatic claims have been made regarding sea level conditions during the last interglacial sea level highstand (oxygen isotope substage 5e), based on the position of features interpreted to be fossil bioerosion notches in the Bahama islands. We believe that those interpretations are questionable, as the features described as fossil bioerosion notches may in fact be the eroded remnants of flank margin caves. The distinction is critical, as flank margin caves take much longer to develop than do bioerosion notches, and would require sea level to have been at +6 m for substantially longer than the <1,000 years that has been proposed. Flank margin caves are commonly found with all or portions of their outer wall removed by surficial erosion; this erosion is more than enough to remove fossil bioerosion notches. Erosion rates for Quaternary limestones quoted in the literature indicate a minimum denudation rate of 4 m/100 Ka, which is enough to have removed fossil bioerosion notches and breached into flank margin caves contained within a hillside. A preliminary comparison of eroded flank margin caves and modern bioerosion notches on San Salvador Island, Bahamas, indicates that morphological analysis can distinguish between fossil bioerosion notches and highly-eroded flank margin caves. This comparison showed that eroded flank margin caves typically contain phreatic dissolutional surfaces, speleothems, and have undulating floors and ceilings. On the other hand, modern bioerosion notches have very flat ceilings and floors at a consistent elevation, and evidence of bioerosion activity. As bioerosion notches form at the surface environment, fossil notches would not contain dense calcite speleothems.

The Freshwater/Saltwater Mixing Zone in the Waynes World Sink Cave System

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Waynes World Sink is located in Hudson, Florida. The Sink is approximately 450m (1500 ft) east of the head of Cow Creek (a saltwater, tide influenced creek) and approximately 900m (3000 ft) east of the Gulf of Mexico. The Sink leads to a complex, submerged, anchialine cave system primarily developed at a depth of ~30m (90 to 100 ft). The water in the cave system is usually brackish with a permanent halocline above a 43m (140-ft) deep saltwater tunnel. The deep saltwater tunnel is approximately 120m (400 ft) long and another brackish water tunnel is found at its opposite end. The Sink is tide-influenced. The Main Street Tunnel, which trends southwest toward the Gulf, is a strong siphon toward the Gulf at low tide and a strong spring inland at high tide. At low tide, a groundwater divide is created within the cave system with some water flowing toward the Gulf through the Main Street Tunnel and some water flowing toward a nearby spring. The complex interactions between brackish and saltwater in this cave system have created a unique environment where troglobitic crustaceans (crayfish, *Procambarus leitheuseri*, and isopod, *Caecidotea* sp.), which are generally considered freshwater organisms, are found in the same location as anemones and feather duster worms. The cave system environment has also changed significantly during the study period from February 1996 to January 1997, as below normal rainfall has caused the salinity in the system to increase from less than 5 parts per thousand to 15 parts per thousand.

Preliminary Results of Speleothem U/Th Dating From the Helderberg Plateau, New York

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The Helderberg Plateau consists of gently dipping Silurian-Devonian carbonates that outcrop across central New York state, supporting a well-developed, multiply-glaciated karst. Stalagmites and flowstone collected from five caves covering a 60 km Plateau traverse, WNW from Albany to Schoharie County, yielded 36 U/Th alpha count dates. Hollyhock Hollow, southern Albany County: two cave-fill samples yielded three dates of 56-70 Ka and four dates of 35-41 Ka. The mid-Wisconsin dates may reflect the cave's southerly position. Onesquethaw Cave, central Albany County: two stalagmites yielded five dates, all Holocene (<9 Ka) in age. The dates suggest that Onesquethaw Cave may be post-glacial in origin. Caboose Cave, eastern Schoharie County: five stalagmite and flowstone samples provided 13 dates, ranging from 56-207 Ka, with distinct clusters at 56-100 Ka and 172-207 Ka. The dates support the cave being older than the last glaciation. Schoharie Caverns, two km west of Caboose Cave: six samples from one flowstone all dated to >350 Ka. The dates indicate that the cave has survived more than one glaciation. Barrack Zourie Cave, western Schoharie County: two stalagmites yielded four dates, which cluster at 158-161 Ka, with a younger overgrowth at 61

Ka. Two previously reported dates were 165 Ka and 277 Ka. The dates support the cave being older than the last glaciation. The U/Th dates indicate that both pre- and post-glacial caves exist in New York. The dates cluster in the 56-100 Ka and 158-207 Ka range, and there are a surprising lack of dates from the last interglacial (120-130 Ka), possibly an artifact of the sampling regime.

Travertine Deposition from High-Sulfate Spring Water: a Clue for Secondary Porosity Development by Dedolomitization

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High-sulfate springs are the source of several travertine-depositing streams in central New York. Water chemistry of springs was compared and rates of travertine deposition were measured using artificial substrates. Water samples from springs were analyzed for major ions. Diffuse seeps through glacial sediment allow equilibrium adjustments prior to sample collection. Springs were at or above saturation with calcite. Gypsum equilibrium was variable, with the only saturated samples coming from an artesian well. Degassing of H_2S and lack of dissolved O_2 at the well suggest deep circulation of meteoric waters through a reducing environment. An iterative program was used to calculate chemical equilibria, interpret sources of dissolved components and create flow-path models. Models were used to determine mineral solubility for solutions including calcite, dolomite and gypsum. Results indicate decreasing calcite solubility and increasing solubility for dolomite and gypsum when they are in solution together. Decreased calcite solubility and potential calcite precipitation are due to the common ion effect as additional minerals are dissolved. Increased solubility of dolomite and gypsum (1.5 times and 3.7 times individual mineral solubilities respectively) increases secondary porosity within the aquifer. Based on chemical analysis and the results of modeling with the computer program. This study area provides a good field example for the diagenetic process of dedolomitization. Travertine deposition occurs where CO_2 degasses abruptly from calcite-supersaturated water.

Phosphate Mineralogy of Isla de Mona Caves

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Isla de Mona is a 55-km^2 island lying in the Mona Passage between Puerto Rico and the Dominican Republic. Large complex caves, with numerous entrances along the sea cliffs that bound Isla de Mona, extend along the island margin, often for 1,000 m or more, becoming smaller inland, ending within 250 m of the cliff face. Within the caves are thick phosphate deposits which were mined extensively in the late 18th Century. Phosphate minerals were sampled mainly from Cueva de Aleman and Cueva Lirio and characterized by x-ray diffraction, infrared spectroscopy, and scanning electron microscopy. The dominant minerals are brushite, $CaHPO_4\ 2H_2O$; hydroxyapatite $Ca_5(PO_4)_3(OH)$; and gypsum. Other minerals reported included monetite, $CaHPO_4$ (the mineral is named for Isla de Mona); whitlockite, $Ca_3(PO_4)_2$; and crandallite, a complex Ca-Al phosphate. At least three additional minerals occur in the phosphate deposits from these two caves. In a distinctly layered 30-cm section of phosphate minerals in Cueva de Aleman, brushite dominates at the top and decreases toward the bottom as hydroxyapatite increases to become the dominant mineral.

Evaluation of the Hydrologic and Geomorphic Characteristics of the Warrensburg Road Karst, Delaware County, Ohio.

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The Warrensburg Road Karst, Delaware County, Ohio, is characterized by numerous insurgent stream sinks, a subterranean drainage system, and a resurgent spring. This 1.75 km^2 karst drainage basin is representative of the karst developed in the Columbus Limestone in the mostly agricultural western portion of Delaware County. As the suburban fringe advances north from Columbus, Ohio, these hydrologic systems require investigation in order to assess potential environmental, engineering, and land use impacts associated with residential/commercial development. Furthermore, continued agricultural usage requires an understanding of the karst system to enable mitigation of future soil loss. The purpose of this study was to establish a baseline data set that includes the size and hydrologic and geomorphic characteristics of the drainage basin for the resurgent spring in order to facilitate future research. Fluorescein dye tracing was utilized to establish the hydrologic connections between the numerous sinking streams in the area and the resurgent spring. The boundaries of the drainage basin were delineated based upon the topographic catchment of the insurgent streams. Five major insurgences to the subterranean drainage system were identified and found to contribute 50-70% of the water discharged at the resurgent spring during storm events. The balance of the discharge is most likely derived from numerous small, sinkhole inputs and groundwater baseflow. Additionally, channel bed scour and deposition were evaluated within the sinking streams. Net scour rates of 12-76 mm were observed during April and May 1995, suggesting that large amounts of sediment are transported through the subterranean drainage system.

Gladeville Utility District Wellhead Protection Project: Use of Fluorescent Dyes to Determine the Groundwater Zone of Contribution to a Public Water Supply Source

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The Gladeville Utility District (GVUD) is a public water supply system servicing over 10,000 people in southern Wilson County, Tennessee. The GVUD is located in a maturely developed karst terrane and utilizes two wells as a raw water source. The purpose of this project was to define the surface and groundwater area of contribution for the GVUD as a tool for management of this important resource.

The hydraulic boundary of the GVUD was identified from topographic and geologic maps as well as field reconnaissance. Initially, the basin boundaries were monitored for the presence of background concentrations of dye. Quantitative and qualitative tracer tests were then performed using low concentrations of fluorescent dyes to confirm the basin boundaries and to estimate the time-of-travel for surface water and groundwater in the system. With the data collected from the tracer tests, the area of contribution for the basin was estimated to be 150 km. Further tracer testing is necessary to better define the northern and western boundaries of the basin. Results of the tracer tests showed the direct connection between surface streams, groundwater, and the raw water source for the GVUD. Results of quantitative testing to the GVUD indicated groundwater velocities as great as 443 m per hour. The area of contribution and groundwater velocities provide critical information for predicting the potential impacts on the GVUD from commercial and residential development and for planning response to a possible hazardous materials release.

A SAMPLING PLAN FOR CONDUIT-FLOW KARST SPRINGS: MINIMIZING SAMPLING COST AND MAXIMIZING STATISTICAL UTILITY

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Analytical data for nitrate and triazines from 566 samples collected over a 3 year period at Pleasant Grove Spring, Logan County, KY, were statistically analyzed to determine the minimum data set needed to calculate meaningful yearly averages for a conduit-flow karst spring. Results indicate that a biweekly sampling schedule augmented with bihourly samples from high-flow events will provide meaningful suspended-constituent and dissolved-constituent statistics. Unless collected over an extensive period of time, daily samples may not be representative and may also be autocorrelated. All high-flow events resulting in a significant deflection of a constituent from base-line concentrations should be sampled. Either the geometric mean or the flow-weighted average of the suspended constituents should be used. If automatic samplers are used, then they may be programmed to collect storm samples as frequently as every few minutes to provide detail on the arrival time of constituents of interest. However, only samples collected bihourly should be used to calculate averages. By adopting a biweekly sampling schedule augmented with high-flow samples, the need to continuously monitor discharge, or to search for and analyze existing data to custom design a statistically valid monitoring plan is lessened.

THE USE OF DISCHARGE BALANCING TO QUANTIFY THE ASSIMILATIVE CAPACITY OF A KARST AQUIFER: AN IMPORTANT TOOL IN PREDICTING CONTAMINANT CONCENTRATIONS AT A SPRING AND FOR DECISION MAKING FOR REMEDIATION OF ENVIRONMENTAL PROBLEMS IN KARST

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A tracer test investigation was performed by the U.S. Environmental Protection Agency (EPA) to delineate the groundwater drainage basins of an industrial area located on Ordovician carbonate rocks in the Central Basin of Tennessee. This area had been the focus of state and U.S. EPA investigations and response actions since the early 1980s. Based on the results of the tracer test, and by using the concepts of discharge balancing from Quinlan and Ray (1995), the percent contribution of groundwater discharging from a karst spring was determined for a site with a surface area that is a fraction of the total footprint of the groundwater basin. This was calculated by dividing the two dimensional area of the site by the two dimensional area of the groundwater basin. Soil response action levels for site related constituents were then calculated by dividing the product of each constituent's surface water criterion and its corresponding soil-water partitioning coefficient (Kd) by the estimated percentage of water contribution to the karst spring from the site. The calculations were also used to quantify the assimilative capacity of the carbonate aquifer for this industrial area. Soils with constituent concentrations that exceeded the soil response action levels were removed during the last and final response action. Monitoring of the spring before, during, and after a storm event by the U.S. EPA indicated that the water quality parameters were not exceeded. The State of Tennessee issued a "no action" Record of Decision for the Site.

THE STRUCTURAL FEATURES OF KARST CAVES AND GEOMORPHOLOGY IN PINGBA COUNTY, ANSHUN, GUIZHOU PROVINCE, CHINA

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Pingba County, Anshun, is located at the center of Guizhou Province, China. The geomorphology of the karst plateaus and canyons are classic and quite apparent. The plateau region lies in the upper course and the watershed area. The difference in elevation is less than 200 m. Geomorphologically, the area exhibits typical fenglin (isolated peaks), basins (polje,) and fenglin valleys. The river valley is wide and the terraces are well developed. The river gradient is normally less than 2%, and the water table gradient is 0 to 20 m beneath the surface. The surface slope gradient is 1-3%. The caves in the study area consist of relic caves within the plateau fenglin. The canyon zone is distributed in the middle and lower course of the drainage area. The elevation change is large and ranges from 200 to 500 m. The major geomorphic types are fengchong-canyon (isolated peaks and canyon,) and fengchong-depression (isolated peaks and depressions). The river valley is mainly canyon and gorge. The hydraulic gradient of the river in this area is more than 6%, and the subsurface water lies from 80-200 m below the surface, with its hydraulic gradient ranging from 7-20%. The caves in the study area have developed from canyon rejuvenation.

PRELIMINARY RESEARCH ON THE DEVELOPMENT OF A MATHEMATICAL MODEL OF KARST CANYONS: A CASE STUDY OF THE MIAOTIAO AND LIUCHONG RIVERS, CHINA

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Karst canyons belong to a special geomorphologic type which develop by combined river erosion, corrosion, and collapse processes. Their genesis and development are closely related to properties of the rock they are formed in, the hydraulic gradient of the river bed, and the discharge of the river cutting the canyon. Karst canyons and their specific features have very significant effects on local and regional projects concerning water conservation, soil erosion control, and hydroelectric power stations.

GEOLOGIC SETTING OF CUEVA DE VILLA LUZ - A RECONNAISSANCE STUDY OF AN ACTIVE SULFUR SPRING CAVE

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At least eight risings of thermal, sulfur-rich waters flow into an actively forming, currently air-filled cave in Tabasco, Mexico. Cueva de Villa Luz (aka Cueva de la Sardina) is located two kilometers south of the town of Tapijulapa in a small block of Lower Cretaceous limestone, which a federal geologic map shows as a northwest-trending anticline truncated and uplifted on the south by an east-northeast-trending normal fault. The resurgence entrance to the northeast-trending cave is along this fault. Also along this fault are at least six other smaller sulfur-rich springs. pH levels of the rising water both within the cave and on the surface were 6.9 - 7.0 (+/-0.5). The cave stream had values ranging from 7.2 upstream, near the risings, to 7.4 at the resurgence. Water drops from the ubiquitous "snotthems" displayed pH values of 0.5 to 3.0(+/-0.5). All water temperatures were 28°C in late December 1996 and early January 1997. Previous analyses of native sulfur and gypsum deposits in the cave determined light $d^{34}S$ values of -22.12 to 26.60 (Spirakis & Cunningham, 1991) and suggest a biological role in fixing the sulfur. However, the original source of the sulfur is unknown. The cave is 65 km from Villahermosa, which suggest a possible migration of hydrogen sulfide from petroleum reservoirs. However, the cave is also only 10 km from a Tertiary andesitic flow and 50 km from the recently erupted Volcan el Chichonal, which has sulfur-rich waters in its caldera.

HISTORY SESSION

Illinois Caverns, Pride of the Illinois Underground

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Previously known as Eckert Cave, Egyptian Caverns, Burksville Cave, Little Mammoth, and Mammoth Cave of Illinois, this cave remains the best known and most historic of all the caves in Illinois. The cave has probably been known since at least 1795. In 1901, the cave was proclaimed one of the "great wonders of the world" in an article that appeared in the St. Louis Post Dispatch. It was featured as part of the St. Louis World's Fair. Following the World's Fair, Charles White launched an unsuccessful attempt to commercialize the cave, and it was soon forgotten. Armin Krueger was one of the locals who actively explored the cave during the next thirty years. In the early 1940s, William Hayden attempted to commercialize the cave once more, installing electric lighting and a concrete stairway down into the cave. World War II intervened, and gasoline rationing soon speeded the end of this venture as well. Illinois Caverns once again became a "wild" cave, and was operated by Armin as caretaker until his death in August 1996. The cave now belongs to the Illinois Department of Conservation. It continues to be open to caving as of this writing. Few caves in this writer's experience are as well known and beloved as this beautiful cavern beneath the picturesque agricultural landscape of southern Illinois.

Identification of Kenneth Emory's Mysterious "Herbert C. Shipman Cave", Puna District, Hawaii County, Hawaii

Kevin Allred, Stephan Kempe, & William R. Halliday, Hawaii Speleological Survey of the NSS

In 1945, the great Bishop Museum staff archaeologist, Kenneth Emory, prepared a typescript report on what he called "Herbert C. Shipman Cave", located about 20 km from Hilo, HI. With increasing urbanization, repeated reference to this cave appears in archaeological sections of Environmental Impact Statements, but all are based solely on Emory's typescript. Until recently, no archaeologist or speleologist is known to have located Emory's cave. Recent studies by Hawaii Speleological Survey teams have shown that Emory was in two different caves in two different lava flows. Use of the name "Herbert C. Shipman Cave" or the abbreviated form "Shipman Cave" should be terminated, and the names of the individual caves should be used instead.

Early Midwestern Show Caves in Minnesota

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Until recently, it was assumed that no Minnesota show caves predated the 20th Century. Research indicates, however, that Minnesota had two of the earliest show caves in the Midwest, Fountain Cave and Chutes Cave. Both were located in an urban area, thus explaining how they were able to exist so much earlier than the state's rural show caves, which had to wait upon development of the automobile, and also why their existence was short: loss of scenic values due to encroaching urbanization. Fountain Cave (1852-1857), often claimed to be the birthplace of St Paul, MN, is featured in old travel guides. Near the cave there was a shanty, where, for a consideration, the visitor could obtain a guide and a tallow candle. The highlight of the tour was a room called Cascade Parlor, which contained a waterfall, but there were no speleothems in this sandstone cave. The cave is no longer accessible, having been buried during highway construction in 1960. Chutes Cave (1875-1883), in Minneapolis, was discovered in 1864 during the excavation of a power tunnel. Advertised in newspapers, ten cents purchased a ride in a boat with a flaming torch at the bow, floating more than 150 m through the abandoned tunnel and into the natural cave. It remains the most profusely decorated cave in this part of the state, containing a flowstone-coated breakdown pile called the "Tower of St. Anthony."

An Intriguing 1925 Sketch Map of Flint Ridge

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In 1925 the Chicago Tribune published a sketch map of "the great cave system underlying the entire region in the vicinity of Mammoth Cave, in Kentucky" in its coverage of the tragedy of Sand Cave. Some parts of it are ludicrous but other parts may have been based on actual exploration. Identity of the artist is unknown, but some deductions can be drawn from its contents. Location of an "Entrance #2" to Sand Cave suggests a focus for ridgewalking.

The Mysterious Miss Ruth Hoppin

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Ruth Hoppin is credited with the discovery of the Ozark cavefish (*Amblyopsis rosae*), the bristly cave crayfish (*Cambarus setosus* Faxon) and an isopod, the only one of three to be given her name–*Asellus hoppinae*. The woman, herself, has been quite a mystery, however, with much of what we know of her being derived from an 1889 article in the Bulletin of Comparative Zoology, *Cave Animals from Southwestern Missouri,* by Samuel Garman of Harvard. This spring, in connection with the purchase of Sarcoxie Cave, (aka Days Cave) in Jasper County, Missouri, Jan Hinsey of the Ozark Regional Land Trust unearthed a treasure trove of biographical information on Miss Hoppin, Preceptress of botany at Michigan State Normal School, Ypsilanti, Michigan. Although how she arrived in Jasper County is still a mystery, much light has been shed on the life of this botanist and cave biologist by these accounts.

INTERNATIONAL SESSION

The 1997 Gunung Buda Expedition to Sarawak, Malaysia

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The 1997 Gunung Buda Expedition was another successful attempt to document the caves and karst features of beautiful Gunung Buda (White Mountain) in Sarawak, Malaysia. A total of 25 km of new survey and 1.4 km of re-survey was completed in 17 caves. During the five-week expedition, eight new caves were surveyed (Hornbill, Loris, Babylon, Mojo, Langur, Thunder, Twilight, and Fruit Bat) in Buda and one in nearby Gunung Benarat (Deliverance). Additional survey work was completed in seven caves (Green Cathedral, Snail Shell, Quill, Lower Turtle, Upper Turtle, Sea Breeze, and Biocyclone) that were partially explored in 1995. Perhaps the expedition's most significant event was on February 12 when a team of four connected Green Cathedral and Upper Turtle caves, creating a cave system 24 km in length and over 300 m deep. Deliverance, Thunder and Hornbill caves feature much larger passages and rooms compared to the caves that had been previously explored in the area. This includes a 200 m diameter room in Deliverance, a 140 m diameter room in Thunder and a passage 30 m by 40 m with an 80 m skylight in Hornbill. Photographic documentation was undertaken in ten caves (Deliverance, Snail Shell, Mojo, Cathedral, Thunder, Biocyclone, Hornbill, Loris, Quill,and Fruit Bat). Members of the team, coordinated by Vivan Loftin, conducted a biological inventory in RolyPoly Cave, and Andrea Futrell collected sediment samples for paleomagnetic dating in several caves. This spectacular limestone mountain was first visited by British cavers in 1984, and a full scale American/Malaysian Expedition documented 30 km of cave passages here in 1995.

Speleological Potential of Kamchatka Oblast, Siberia, Russia

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Long the most forbidden, inaccessible part of Russia, Kamchatka suddenly has become its closest caving area to the USA Two areas of volcanic caves are known. The more important is just south of Tolbachik Volcano, in one of the world's most spectacular volcanic areas. While the longest cave here has only about 0.5 km of passages, there are potentials for much more. The area is nearly inaccessible, and special arrangements must be made for (Red) Army surplus 6-wheel vehicles, at considerable cost.

Exploration and Mapping of Cueva de Villa Luz (Cueva de la Sardina), Tabasco, Mexico

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Cueva de Villa Luz near the town of Tapijulapa has been used in indigenous religious ceremony since ancient times. Scientists visited the cave, also known as Cueva del Azufre, in April 1944 and returned in the 1940s and 1950s to study the partially cave-adapted mollies (*Poecilia sphenops*). Cavers, however, only discovered the cave in 1986. An NSS Caves of Tabasco, Mexico, Project expedition last winter completed the mapping of the 1613 m long cave and continued geologic and biologic observations. While the cave's air and water temperature (28°C) are comfortable, measured atmospheric H_2S ranging from 6-32 PPM limited exploration. Water pH measurements from 0.5 to 7.9 also raised interests. The abundance of the 25-55 mm long fish resembles a hatchery throughout the cave, which is also called Cueva de la Sardina. The fish are so crowded that it is easy to catch several in one's hand with a single attempt. They were also observed climbing up a series of rimstone dams looking like salmon climbing their ladders. Each spring, descendants of the Maya speak with their gods in the cave. The Chol ceremony includes scooping up cave fish with baskets and eating them. The cave houses a variety of invertebrates and a large colony of at least three species of bats. Abundant midges may provide a food source to the fish. Samples from the cave's rich microbial community are currently being investigated. Most noteworthy are the "snotthems", which look like small soda straws and curtains made of white mucous.

China Cave Project; Further Explorations of the Guadou System, Guizhou, China

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In the winter of 1994, Bob Cohen and Mike Newsome extended the map of Chuifeng Dong towards its suspected connection with the Doubin Dong upstream river. After setting up an in-cave camp, they descended three drops to the sound of river water, only to be stopped by lack of more rope. In 1995-95, Mike, Bob, Don Coons, Molly Lucier and Ian Baren returned and, with four cavers from Guizhou Normal University, made a connection between the two caves the first day out. After setting a base camp in Doubindong river passage, the team spent 18 days underground, mapping upstream towards a hoped for connection with two insurgence caves to the south, Xiaoludong and Youcaidong. Both had been explored to sumps in previous expeditions, but there was hope of a bypass. More than four kilometers of passage were mapped, including dry upper levels with many going leads. Rather than a bypass to the two caves to the south, three upstream sumps were discovered. An extensive surface survey was made to tie the entrances of five of the local caves with benchmarks, and water chemistry survey by Professor Xiong Kangning and Don Coons revealed the highly acidic river water which accounts for the impressive size of the caves. True to project tradition, a massive upper level borehole lead was sighted on the last day and headed south.

PALEONTOLOGY SESSION

Pliocene Cave and Fissure Deposits in the Northern Black Hills of South Dakota with Comments on the Carnivores

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About eight kilometers northwest of Lead, SD, in a limestone quarry at the Richmond Hill Gold Mine, cave and fissure deposits of Pliocene age are preserved at elevations between 1690-1710 m. Six separate localities within the north and east faces of the quarry high wall have exposures of deposits in caves and fissures in the lower portion of the Pahasapa Formation (Mississippian). The principal sites are the Unwily Coyote Site and East-West Fissure. These deposits are important because they record the existence of caves in the northern Black Hills at least by the Pliocene. Secondly, removal of Tertiary sediments of the White River Group that blanketed the Black Hills uplift must have occurred in this area by Pliocene time. Among the mammals recovered are the taxa *Canis lepophagus*, *Ferinestrex?*, *Mustela*, and cf. *Trigonictis idahoensis*. *Ferinestrix?* is a large mustelid carnivore that is larger than living *Gulo* and North American species of *Plesiogulo*. Three first upper molar teeth representing at least two individuals are present and are distinct from *Plesiogulo*. Front limb elements from the Unwily Coyote Site of *Ferinestrix?* are most similar to *Plesiogulo* among known late Tertiary mustelids. The assignment, *Ferinestrix?*, is tentative because it is based on material not previously recorded for *Ferinestrix* from the Hagerman local fauna.

Mammuthus primigenius from Endless Caverns: the First Cave Record of Mammoth from Virginia

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A mammoth tooth found in Endless Caverns, Rockingham County, is a first cave record for Virginia. This is only the fifth locality for *Mammuthus* within the Commonwealth. Differentiation as *Mammuthus primigenius* Blumenbach was made on the basis of size, number of enamel plates, and thickness of the enamel of this lower third permanent molar. The partially exposed tooth was discovered in a sediment bank, during July 1996. Study of the site during removal of this nearly pristine tooth indicated it was deposited by a debris flow through a former entrance. Endless Caverns is developed in the middle Ordovician limestones of a minor anticline on the northwestern flank of Massanutten Mountain, a complex sandstone ridge on the northwest limb of the Massanutten syclinorium. The caverns' seven kilometers of passage underlie the transition of the lower forested mountain flank and the adjacent grassland valley. Grassland apparently existed above a portion of the cave at the time this woolly mammoth perished. The rarity of mammoth remains from caves of the

Appalachian Highlands is mirrored by the scarcity of other large grassland grazers of the Pleistocene, such as horse and bison, in cave sites. Although few Virginia cave sites have yielded large extinct taxa, the scarcity of grassland grazers in caves elsewhere in the central and northern Appalachian Highlands implies grassland ecosystems were not extensive.

Late Glacial Mollusks from Little Beaver Cave, Central Ozarks, Missouri

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Paleontological excavations at Little Beaver Cave, Phelps County, Missouri, yielded a diverse fauna for the terminal Pleistocene of the Central Ozarks, including extinct, extralimital, and locally extant species. Three AMS radiocarbon determinations, from bone-specific amino acids, provide chronological control for the faunal samples, dating between 10 Ka and 11.5 Ka. The mammalian fauna has been analyzed by Schubert and documents an association of boreal and temperate taxa. The report about the mammals is the first documentation of several boreal species for the terminal Pleistocene Ozarks. This disjunct assemblage may reflect a retention of an equable climate up to the Pleistocene/Holocene boundary. Mollusks were recovered throughout the stratigraphic column containing fish, reptiles, birds, and mammals. Molluscan taxa include: 11 terrestrial gastropods, 4 aquatic gastropods, and 3 clams. All species can be located in the Ozarks today, except for the possible recovery of *Pupoides modicus* (today restricted to Florida). This find is an extralimital anomaly in the faunal assemblage. Previous studies of late Pleistocene mollusks are lacking from the Ozarks, except for a few of the larger taxa. The success in recovering mollusks at Little Beaver Cave was due to wet sieving through fine mesh (0.7 mm) screens. Even the modern malacofauna is inadequately understood for the Ozarks. The terrestrial gastropods indicate a woodlands habitat with abundant leaf litter and some areas of more open grassy lands, such as in a meadow. The aquatic mollusks indicate open bodies of water, such as rivers, lakes and streams; some had to be sluggish and others with more current action.

Paleoecological Implications of a Terminal Pleistocene Mammalian Fauna, Little Beaver Cave, Central Ozarks, Missouri

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Previous investigations of late Pleistocene mammalian faunas from the Ozarks are numerous but either lack systematic excavations, temporal control, and/or sufficient micromammal (e.g. voles and shrews) components essential for interpreting the environments of the Pleistocene/Holocene transition. At Little Beaver Cave, three high resolution radiocarbon dates on bone specific amino acids, systematic sampling, fine mesh wet sieving (0.7 mm), and diverse micromammal components provide an ecological basis for interpreting this temporal interval (approximately 11.5 Ka - 10.0 Ka). Extinct species represented are *Megalonyx jeffersonii* (Jefferson's ground sloth), *Mylohyus nasutus* (long-nosed peccary), *Platygonus compressus* (flat-headed peccary), and *Dasypus bellus* (beautiful armadillo). Of these, only *P. compressus* and *D. bellus* were recovered from controlled samples. Seven extralimital small mammals (1 shrew, 2 squirrels, and 4 voles) were recovered from systematic excavations. *Blarina* cf. *B. brevicauda*, *Spermophilus* cf. *S. tridecemlineatus*, and *Microtus pennsylvanicus* are locally extralimital and suggest open and moist habitats with some forest cover. *Tamiasciurus* cf. *T. hudsonicus*, *Clethrionomys* cf. *C. gapperi*, *Phenacomys* cf. *P. intermedius*, and *M. xanthognathus* are boreal extralimital taxa and require cool summers and boreal environments. The association of extralimital taxa with current resident species from Little Beaver Cave may reflect a mosaic of coniferous, deciduous, and open habitats during the waning years of the Wisconsinan for the Ozark Highland. A cool and moist equable (less seasonal) climate provides a possible hypothesis for this nonanalogous faunal assemblage. Further, having boreal affinities up to the Pleistocene/Holocene boundary supports a rapid transition into the climatic severity characteristic of the Holocene.

Fossil Mammals and Mexican Caves

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During the last decades, the knowledge of the Pleistocene in Mexico increased with the discovery of a large number of localities. A few caves with fossil vertebrate deposits have been known since the last century. In 1867, Weber recorded the finding of mammoth remains in Cueva del Padre, Nuevo Leon. Since then, more than 15 fossiliferous caves have been found, including Cueva de San Josecito, Nuevo Leon; Cueva Encantada de Chimalacatlan, Morelos; Actun Spukil, Actun Lara, and Gruta de Loltun, Yucatan; Monte Flor, and Cueva de San Agustín, Oaxaca; Cueva de las Iglesias, Durango; Cueva del Abra, Tamaulipas; caves of Bustamante and La Mina, Nuevo Leon; Gruta de Cócona, Tabasco; Cueva de Jimenez, Chihuahua; Cueva la Presita, San Luís Potosí; and, most recently, Mina San Antonio, San Luís Potosí. All but Monte Flor, with findings previously identified as archaeological remains, have been recorded as having animal remains from Late Pleistocene or earliest-Holocene age. Among the 16 caves, only San Josecito, Jimenez, Spukil, Loltun, and La Presita served as natural traps. San Josecito is the best known due to its abundance and diversity of vertebrate taxa. It and Loltun Cave are the only ones systematically excavated, accounting for a detailed stratigraphic record. Among the vertebrate taxa, the mammals are the best known, adding to 256 species, with the small mammals the most abundant, but the large ones the most studied. Excepting Iglesias and Jimenez, all caves are in eastern Mexico, and the analyses and comparisons of the mammal faunas should allow establishment of a zoological framework for the region during the Late Pleistocene.

Characteristics and Importance of Cave Sites in Quaternary Paleontology: Analysis of the FAUNMAP Database

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Paleontologists studying Quaternary taxa and paleoenvironments have long viewed caves as an important source of data. Analysis of the FAUNMAP database of North American Quaternary mammal occurrences confirms their importance. This analysis also elucidates some of the characteristics of faunas derived from cave localities. The FAUNMAP research database contains faunal lists for and information on over 2600 Quaternary mammal sites in the conterminous U.S. Sites identified as caves comprise approximately 11% of these sites. However, these cave sites represent 14% of all analysis units and over 20% of all individual mammal taxon occurrences. Cave sites average approximately 12 taxa per site compared to only seven taxa per site for other types of sites. The importance of caves for paleoenvironmental interpretation using mammalian fossils is even more pronounced. Twenty-six percent of the occurrences of environmentally

sensitive small mammals (Rodentia, Insectivora, Chiroptera, and Lagomorpha) in the research database are from cave sites. Perhaps more importantly, 74% of the mammalian occurrences from caves are from these taxa as compared to 53% of the occurrences from sites other than caves. The FAUNMAP database is an important tool for understanding the characteristics and importance of various kinds of fossil deposits.

RESCUE SESSION

Black Cave, Gila Co., Arizona Body Recovery

Raymond C. Keeler, 22354 N. 68th Drive, Glendale, AZ 85310

Three cavers visited Black Cave on Saturday, December14, 1996. The party included Bill Graff, Cochise County Cavers (CCC) and Southern Arizona Rescue Assn. (SARA) member, Dale Green (CCC), and Elizabeth Robb (CCC and Cochise County search team). The cave is horizontal, mazy and tight in many places with several passages not visited for long periods of time. They found a body a short distance down an extremely tight, down sloping side passage about 50 minutes from the entrance. Traverse distance is less than 120 m, 26 m below the surface. They extracted the keys for identification, left the other evidence in place and reported the situation to the Gila County Sheriff Office. Over the next three weeks, four attempts were made to extricate the body. The last attempt was successful, with the help of 18 cavers underground, electricity, and heavy drilling equipment on a nine hour effort. The long term impact to the cave will probably prove devastating.

SURVEY AND CARTOGRAPHY SESSION

Fiber Optic and LED Illuminators for the Suunto Compass

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An illuminator for the Suunto compass dial has been developed from a fiber optic cable, a specially designed aluminum block to position the fiber optic cable output tip, two AA cells, a common flash light lamp, a toggle switch, a wood block and some electrical tape. The fiber optic cable is long enough to prevent magnetic deviation of the compass needle by the electrical components. The aluminum block requires one 6-32 threaded hole in the Suunto body and is designed not to block the centerline of the Suunto case so that the one-eyed sighting method can be used normally. The compass with the aluminum block will fit in the Suunto case. A self-contained illuminator for the Suunto clinometer has been developed from a green light emitting diode (LED), a plastic right angle bracket, a 3 volt lithium button cell, a micro switch and some 5 minute epoxy. The micro switch is oriented downward so that the thumb holding the bottom of the clinometer in the usual manner can operate it. The unit can be taped or glued onto the clinometer case and it does not block the centerline of the case. The compass with both the LED illuminator and aluminum block described above for a backup will fit in the Suunto case.

U. S. EXPLORATION

Recent Exploration of Lava Tube Systems in Kona and on Mauna Loa, Hawaii

Douglas M. Medville & Hazel E. Medville, Hawaii Speleological Survey

The island of Hawaii contains over 1,000 recorded lava tubes, including the world's longest: Kazumura Cave (surveyed length of 47 km and depth of 888 m) on the east side of the Kilauea shield volcano. Other extensive systems of lava tubes are found elsewhere on the island of Hawaii: on the western slope of Hualalai, an older shield volcano on the island's west side, and on the north side of the largest volcano on the island: Mauna Loa. In recent years, over 30 km of lava tube has been surveyed in these two areas. The tubes have linear extents of up to 3 km, diameters of up to 15 m, and contain a substantial variety of secondary mineralization including sulfate crusts and soda straws and ribbons up to one meter in length. Some of the tube systems found in historic flows: e.g., the 1801 flow on Hualalai and 1855 flow on Mauna Loa, are compound and consist of several sub-parallel but separately developed tubes that are fairly complex, containing branching and braided passages resulting in passage density comparable to that seen in limestone maze caves. The tubes on Hualalai are near sea level and have a mean temperature of 26°C while those on Mauna Loa are at elevations of up to 3400 m and have mean temperatures as low as 4°C.

The Black House Mountain Cave System, Fentress County, Tennessee

Todd Rowland and Bryan & Lou Simpson, 750 Avon Fields Lane, Cincinnati, OH 45229

Venturing up Little Jack Creek for the first time, we thought, "Wouldn't it be neat if all the water in Little Jack and its tributaries, Bud and Jim, came out of caves just like what happens up the other branch of Rotten Fork?" Turns out it does. When our motley group of cavers from Ohio, Tennessee, and Kentucky gained access to this unexplored area west of Black House Mountain, we first discovered Red Bud, over 1.6 km, then Temple Falls, with kilometers explored beyond the 460 m Wet Wang entrance crawl, followed by the big overflow tubes of Alastor, and most recently the comfortable mazes of Cornstarch, with three miles mapped. Each of these caves has already been connected to at least one additional entrance. Although Alastor and Cornstarch are on opposite sides of Jim Creek, Cornstarch crosses under the creek, swallowing the river, and connects to an entrance high on the Alastor side. Dye tracing indicates a connection from insurgence entrances high up Bud Creek to Temple Falls and even to Red Bud ~1.5 km away. Down the ridge from the current end of Alastor lie springs and sinkholes for the next mile and a half. With more connections and big discoveries likely in the near future, we hope to integrate the separate caves into a major system.

Coldwater Cave–Thirty Years of Exploration and Discovery

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On September 17th, 1967, Iowa Grotto cavers Dave Jagnow and Steve Barnett dove into a spring in northern Iowa, finding what would quickly be known as one of the longest and most intensely decorated caves in the upper Midwest. After extensive exploration and mapping trips, the State of Iowa drilled a shaft entrance in 1970 into the mainstream passage to assess the possibility of commercializing the cave. Excessive development costs prompted the State to abandon these plans, and the leased shaft entrance reverted to the private landowners. Since then, cavers from a variety of regional Grottos have assisted the Coldwater Cave project in extending the known limits of this challenging stream cave that was designated a National Natural Landmark in 1987. Distant waterfall climbs, high carbon dioxide levels, impassable dome drains and low airspace traverses in 8.5°C water have required caver stamina and innovative techniques to safely explore the more than 24 km of mapped passageways while preserving Coldwater Cave's fragile beauty. Current efforts including mapping/exploration, water quality studies and the restoration of sensitive areas.

Exploration and Survey of Spring Cave, Northern Arkansas

Steve Kaub, PO Box 212, Villa Ridge, MO 63089

This is a physically challenging cave located in a remote area near the Buffalo National River. Prior to 1994, only a small portion of the cave had been explored. The entrance is a small but attractive spring that is known by local cavers but rarely visited. The main obstacle that was preventing the cave from being entered by cavers was water. To enter the cave one must crawl through a water passage to a small entrance room; beyond the entrance room the cave gets difficult. There is another water crawl lined with attractive soda straws, leading back to a sump. Beyond the sump was virgin cave until 1994 when we began our exploration. This area of the cave is full of obstacles. Beyond the second sump, the cave opens up to large stream passage with dry upper passages connecting. By following the stream you reach another near sump, also a third sump which can be bypassed by climbing high through a crack in the ceiling. Beyond the third sump is not completely explored so it is still calling us to return. This is a wetsuit cave that is as tough on your clothing as it is on your body. We have surveyed over 1000 m of passage so far and expect to reach at least 1.6 km of survey before the passage gets too small. But there are still some high leads that could take us to more big cave.

Correction

The wording of William R. Halliday's abstract, "An informative Pigeon River, NC Nitre Department Envelope", that appeared in *59*(1): 57 was mistakenly altered in a manner that changed its meaning. The second paragraph should read:

No caves are known near Pigeon River, North Carolina, but roosts of passenger pigeons existed in the area. It seems unlikely that they were mined extensively for saltpetre, if at all. The most likely reason for someone from the Confederate Nitre Department to have visited Pigeon River was to look into its possibilities. If that Department did so at remote Pigeon River, it is logical that it looked at other pigeon roosts. This cover opens a promising new channel for saltpetre research.

Dr. Cliff Boyd is currently an Associate Professor of Anthropology at Radford University, Virginia. He received an M.A. (1982) and Ph.D. (1986) in anthropology from the University of Tennessee - Knoxville. His research interests include archaeological method and theory, prehistoric Native Americans from the southeastern United States, and skeletal biology.

Dr. Donna Boyd is currently an Associate Professor of Anthropology at Radford University. She received an M.A. (1984) and Ph.D. (1988) in anthropology from the University of Tennessee - Knoxville. Her research interests include human osteology, skeletal biology, forensic anthropology, and human origins.

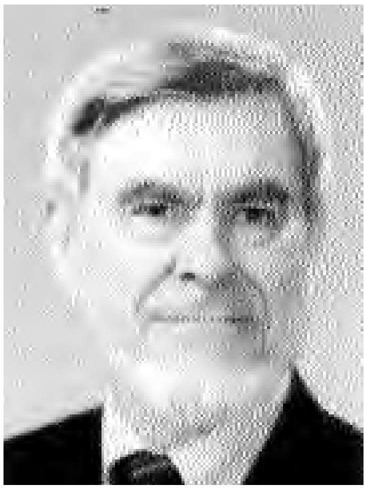
John E. Cooper is curator of crustaceans at the North Carolina State Museum of Natural Sciences. He has been a biospeleologist since 1957, and was editor of the *North American Biospeleology Newsletter*. A former NSS Executive Vice President and member of the Board of Governors, he received the Society's first Outstanding Service Award. His Ph.D. is from the University of Kentucky, where his research centered on the ecology of Shelta Cave.

Yuri V. Dublyansky. Graduated from Odessa University, Ukraine, in 1982. Senior scientist in the Institute of Mineralogy and Petrography, Russian Academy of Sciences, Novosibirsk. Studies caves of hydrothermal origin, cave minerals, cave aerosols, as well as issues related to geological disposal of nuclear wastes. Authored one monograph and more than 30 papers.

Charles H. Faulkner is a Professor of Anthropology at the University of Tennessee, Knoxville. He holds the M.A. and Ph.D. degrees in anthropology from Indiana University. Dr. Faulkner is the author of over 100 books, monographs, and articles on various anthropological subjects. He specializes in cave archaeology, Native American rock art, and historical archaeology.

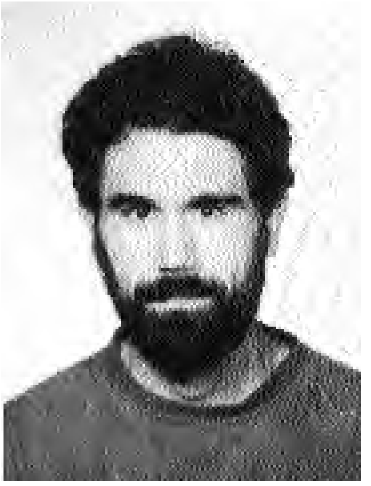
Dr. J. Philip Fawley is currently a professor of Biology at Westminster College, New Wilmington, PA, where he teaches courses in physiology. Fawley started serious cave exploration in the early 1970s and has studied caves throughout the United States. He has completed more than 120 trips into Harlansburg Cave.

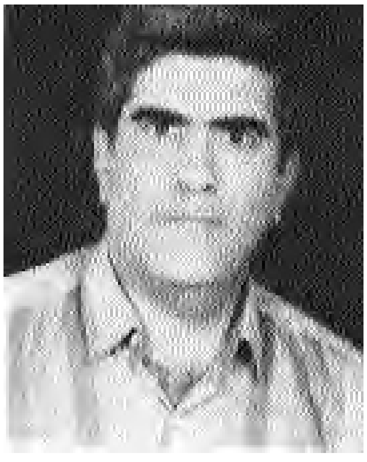
Serguei E. Pashenko. Graduated from Novosibirsk University, Russia in 1970. Head of the Laboratory of Atmospheric Ecology, Institute of Chemical Kinetics and Combustion, Russian Academy of Sciences, Novosibirsk. Has lead research projects on natural radioactive aerosols as well as those related to operation of nuclear facilities, nuclear accidents, etc. Authored 2 monographs and more than 50 papers.



Dr. Ken Long is Professor and Chair of Chemistry at Westminster College, New Wilmington, PA. He also teaches a geology course and has co-taught the geology and ecology of Hawaii. He has been caving since 1976 and has visited some caves in China.

Bogdan P. Onac is Senior Lecturer at the Department of Mineralogy, Cluj University, Romania. He received both his B.Sc. and Ph.D. from the same university in 1987 and 1996, respectively. Over the last 15 years, he has studied the mineralogy and crystallography of speleothems from caves in Romania and other European countries.





E. Raeisi is an associate professor of hydrogeology at the Shiraz University. He has contributed several papers in international journals in karst hydrology and hydrogeochemistry. He received for the best paper an award from the Iranian National Research Committee. He holds the Ph.D. from the Colorado State University in irrigation engineering.

Dr. Thomas R. Whyte is Associate Professor of Anthropology at Appalachian State University in Boone, North Carolina. He obtained his Ph.D. degree from the University of Tennessee, Knoxville, in 1988. He has conducted archaeological investigations throughout the southeastern United States and in the Bahamas. His analytical skills are in zooarchaeology, lithic analysis, and experimental archaeology. In 1994, he was presented with a National Award of Excellence by the U.S. Forest Service for his involvement with public volunteers in federally sponsored archaeological projects.

AGI PUBLISHES FOURTH EDITION OF GLOSSARY OF GEOLOGY

The fourth edition of Glossary of Geology, just published by the American Geological Institute (AGI), reflects the dramatic technolological changes affecting the earth-science profession. Editor Julia A. Jackson invited more than 100 geoscience experts to review and update terms and definitions for the latest edition of the Glossary, including an NSS team of speleologists headed by our AGI representative, Harvey DuChene. As a result, approximately 3,400 new entries have been added and another 9,000 definitions have been updated in the fourth edition, bringing the number of entries to 37,000.

The revision applies to nearly every discipline in the geosciences, including active fields such as carbonate sedimentology, environmental geology and geophysics, geographic information systems, global positioning systems, sequence stratigraphy, hydrogeology and hydraulics, marine and coastal geology, organic geochemistry, and paleoecology. The number of definitions for traditional fields such as seismology, stratigraphy, speleology and karst, structural geology and tectonics, paleontology, and igneous petrology has expanded as well.

The fourth edition of the Glossary of Geology can be ordered from AGI's Publications Center, P.O. Box 205, Annapolis Junction, MD, 20701. Telephone: 301-953-1744; fax: 301-206-9789. ISBN 0-922152-34-9, Hardbound, 800 pages. List price is $110.00 but NSS members may buy it for $88.00, plus postage and handling.

REVIEW OF FOURTH EDITION OF GLOSSARY OF GEOLOGY. JULIA A. JACKSON (ED.)

The American Geological Institute issues a new edition of the *Glossary of Geology* about every 10 years. This edition contains 37,000 terms in all fields of geology. Members of the National Speleological Society have traditionally reviewed the cave terms. William E. Davies began with the 1960 edition, and Harvey R. DuChene was the chief reviewer of this edition. Other acknowledged contributors to speleology and karst terms in this edition were Donald G. Davis, William R. Halliday, John E. Mylroie, Arthur N. Palmer, George Veni, and William B. White.

This edition of the *Glossary* contains 544 terms in the cave categories; a significant percentage has been revised, and 140 are new. Some additional cave terms beyond those in the cave categories appear in categories such as archaeology, surveying, soils, geochemistry, and environmental geology. For example, the book includes definitions of the biologic terms troglobite, troglophile, and trogloxene, which define the degree of adaptation of animals to caves. The book retains some obsolete words for their historical value, but it has dropped 31 rarely used cave terms that appeared in the 3rd edition (1987).

During the updating of the book, the editor could print out 31 subject categories and numerous subcategories separately from the book's computer file, so that the reviewers for each could compare the words easily and make certain that the cross references are correct.

Readers of this review will applaud and smile at the newly augmented definition of spelunker: A journalistic term for caver; what a noncaver calls a caver.

Dictionaries generally reflect a perception of current usage, but sometimes compilers cannot resist nudging usage a bit. Cave coraloid has replaced cave coral. I'll be the last to resist this if it takes hold, but the adjective "cave" of the former usage probably was sufficient to make clear that the term does not refer to reef animals. The word coraloid without the adjective is offered as a synonym of cave coraloid, and perhaps those with nimble tongues will find it a useful abbreviation.

I am less enamored of a couple of other changes: Cave bubbles have become calcite bubbles, and cave rafts have become calcite rafts. These revisions make little sense, inasmuch as those speleothems, although usually composed of calcite, are in some caves also composed of aragonite, iron minerals, and phosphate minerals. Similar structures occur in noncave environments, and in those places an ad hoc term such as calcite bubble may be appropriate for the specific case. But as designations for two important classes of speleothems, cave bubbles and cave rafts seem more appropriate general terms.

For a work of this size, remarkably few misspellings and errors in transferring the reviewers' intentions have crept in. An exception, however, applies to the term guano. In improving the discussion of cave guano, surficial guano was inadvertently dropped, even though the word itself comes from the fossil seabird guano of northern South America, an important fertilizer material there and on many oceanic islands.

The numbers of terms in each of the cave categories are Speleology, 301; Karst, 225; and Volcanic Caves, 18. This book is the most exhaustive and authoritative dictionary of terms in physical speleology and in geology in general. Although the price is high, it will amortize well for geologists, because the next edition will not appear until 2007. Those without a need for the entire volume will find a library's copy to be a valuable reference to cave terms.

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REVIEW: CAVE MINERALS OF THE WORLD, SECOND EDITION (1997). CAROL HILL AND PAOLO FORTI.

The new edition of *Cave Minerals of the World* looks about the same size as the 1986 version. Inside, however, are nearly twice as many pages, in smaller print that allows nearly 50% more material per page. This reflects the explosive increase in knowledge of cave features since then.

Soon after the 1986 edition was published, it was clear that new speleothem discoveries in Lechuguilla Cave alone would merit a significant revision. But that was just the start. Accomplished cave mineralogists in places as varied as Brazil, Australia, South Africa, and (with the end of the Cold War) eastern Europe and Asia - facilitated by increasing ease of communication via the Internet - have expanded the cosmopolitan perspective that began with the earlier edition. We can now, for example, compare Lechuguilla Cave with the Cupp-Coutunn system in Turkmenistan, which has both remarkable similarities and puzzling differences in its deposits.

Trevor Shaw's fascinating historical introduction has been republished largely unchanged from the 1986 one, but extended by the addition of a section covering non-carbonate minerals.

The text is somewhat differently organized in the new edition. In the earlier version, deposits were arranged first by mineral class - carbonates, halides, nitrates, etc. - with speleothems treated as subcategories under each chemical class. The 1997 book instead treats speleothems first, alphabetically by morphological "type," "subtype," and "variety," followed by a section on the mineral classes, for each of which the speleothem types known for that mineral are listed. This system is not a universal standard (some speleologists cited from the former Soviet Union prefer very different categorizations based on internal structure), but it is a practical, if somewhat arbitrary, approach that aids cavers without laboratory access to recognize and compare features in cave and book.

The "Special Topics" section has been expanded from 12 to 19 subjects-including, for example, archeology and microbiology as related to cave minerals-and some of the original topics, including color and luminescence of speleothems, have been re-written by experts in those fields to bring them up to date.

In a new section, "Top Ten Caves," speleologists from around the world describe the mineralogy of exceptional caves. This is not, as the layman might expect, the same thing as "The Ten Most Beautiful Caves in the World." Some, like Lechuguilla, are spectacular, but others, such as Australia's Skipton Lava Cave and Italy's Alum Cave, are remarkable less for beauty than for the rarity of their minerals, which may be manifested only as nondescript crusts or powders.

"The Blue Cave, France," one of these "Top Ten," seems a rather odd selection. It is an ancient copper mine in dolomitic limestone: "...the age of the speleothems...is known with certainty, as the Romans...mined the ore and so all of the speleothems...have grown since that time (during the last 2000 yrs)." While the blue-stained aragonite in this site is certainly interesting, its inclusion seems to contradict the book's introduction (p. 13), which restricts "caves" to natural subterranean cavities, and says that "minerals located in vugs, veins, mines or shelters do not qualify as 'cave' under our definition." Perhaps it would more fittingly have been considered in the section "Related Forms/Formations in Artificial Caves."

In an earlier review of *Cave Minerals of the World, 2nd Edition* on the Internet (Cavers Digest 5478, Sept. 18, 1997), Bill Mixon said that "the terms they're using are just common names, which means they are not at all analogous to things like binomial names in biology or mineral names, which are governed by international committees and rules of precedence. Common speleothem names mean what people use them to mean..." As a case in point, he criticizes the authors for using "'frostwork' for what most people call 'anthodites'." He does not mention that this is a change from the usage in the 1986 edition, adopted specifically because people were using "anthodite" in conflicting ways. Hill and Forti's re-definition is an effort to get consistent usage and to conform better to original definitions and precedents; that is, to make speleological terminology more like formal scientific nomenclature. I approve of that.

Another of Mixon's criticisms: "There can be little reason except showing off to list 99 references on goethite or 235 references about stalactites...I doubt if even a professional mineralogist would bother to seek out the vast majority of the references, because most of the total of nearly forty-five hundred are in literature so gray as to be practically black and obtainable, if at all, through inter-library loan from Mars." Here I disagree with Mixon completely. The authors point out that *Cave Minerals of the World, 2nd Edition* is a book for both cavers and mineralogists. Readers of either class can skip the references if they want to. But for those who do want to research a specific feature in depth, this chain of sources is a priceless treasure, all the more so because much of the literature is rare. Hill and Forti were able to cite so much of it because they encouraged input from the contemporary cavers who are making the observations. In another generation, it would be much harder for anyone to learn about all of these obscure publications. To posterity, the reference list may well be the most valuable part of *Cave Minerals of the World, 2nd Edition*.

What faults do I find with the book? Well, the photos are mostly smaller than those in the 1986 edition, and distressingly few have any scale shown. (On the other hand, there are many more, all in color this time, and the authors advertised to get the best ones they could for each feature.) Fig. 315 seems to be upside down, and may also be mis-captioned (it is supposed to show a pinnacle of dolomite, but appears to be iron-mineral dripstone). Fig. 31's caption is factually wrong: it is said to illustrate subaqueous coralloids in Lechuguilla Cave, but the actual features shown (which I have visited personally) are a re-flooding line below which corrosion residue was washed off, and below it, an air-stratification level with evaporative subaerial coralloids beneath.

There are occasional questionable interpretations or contradictions. For example, we read on p. 45 that "an anthodite is believed to form by solutions moving along its outer surface." On p. 47, however: "Anthodites are thought to grow by thin films moving by capillary action over the surface of needle stalks and/or through the central tubes..." This particular conflict arose because the first statement was held over from *Cave Minerals of the World, 1st Edition*, and applied to those "anthodites" which are now termed frostwork. The second applies to anthodites as treated in *Cave Minerals of the World, 2nd Edition*. Also, there are significantly more typos, misspellings and grammatical glitches than in *Cave Minerals of the World, 1st Edition*. These kinds of problems resulted at least partly from the pressure felt by the authors and publisher to have the book ready for the 1997 International Congress of Speleology. I would personally have preferred to see a little more care taken, even if that deadline had been missed.

Such quibbles aside, *Cave Minerals of the World, 2nd Edition* is an achievement in cave science whose equal I would be very surprised to see the NSS produce for many years. If the Society had never published another thing, this book alone, in my opinion, would entitle the NSS to respect as a scientific organization.

Donald G. Davis

UPCOMING MEETINGS

From Karst Landscapes to Karstic Geosystems: karst dynamics, structures, and indicators. Provence, France, 10-15 September 1999. France. For more information write: Colloque European-Karst 99, Universite de Provence, Institut de Geographie, 29 Avenue Robert Schuman, 13621, Aix en Provence, Cedex 1, France, telephone 0033-442-95-3870, fax 0033-442-95-0420, e-mail: martincl@aixup.univ-aix.fr.

Natural Caves Under Cities and Urban Areas. Budapest Hungary, 5-10 October 1998. For information contact: Magyar Karszt-es Barlangkutato Tarsulat, H-1027 Budapest Fou. 68. Telephone: 361-224-1427, Fax: 361-201-9423. E-mail: mkbt@mail.matav.hu.

CAVE-BIOLOGY E-MAIL DISCUSSION LIST

An e-mail discussion list for cave-biology has been established to promote respectable scientific dabate about all aspects of cave-biology. To subscribe to the list send a message to: majordomo@mcc.ac.uk with the following one line message: subscribe cave-biology. To send a message to the list use the following address: cave-biology@mcc.ac.uk. To unsubscribe from the list send a message to majordomo@mcc.ac.uk with an unsubscribe cave-biology message. Please do not send subscribe and unsubscribe requests to the list itself. Please let me know directly (g.proudlove@umist.ac.uk) if you have any comments or suggestion about this list.

Graham Proudlove

INDEX TO VOLUME 59 OF THE JOURNAL OF CAVE AND KARST STUDIES

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The index includes all articles and abstracts published in volume 59 issues 1, 2, and 3. The selected abstracts for the 1995 Society meeting in Blacksburg, Virginia, and for the 1997 meeting in Sullivan, Missouri, are contained in this volume. Also included are two additional abstracts from the Salida, Colorado, 1996 meeting.

The index consists of three sections. The first is a **Keyword** index, containing general and specific terms from the title and body of an article. This includes cave names, geographic names, etc. The second section is a **Biologic** names index. These terms are Latin names of organisms discussed in articles. The third section is an alphabetical **Author** index. Articles with multiple authors are indexed for each author, and each author's name was cited as given.

Citations include only the name of the author, followed by the page numbers. Within an index listing, such as "Bats", the earliest article is cited first.

Thanks to Keith D Wheeland for the use of his KWISOFT indexing program.

Keyword Index

Biologic Names Index

Author Index

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