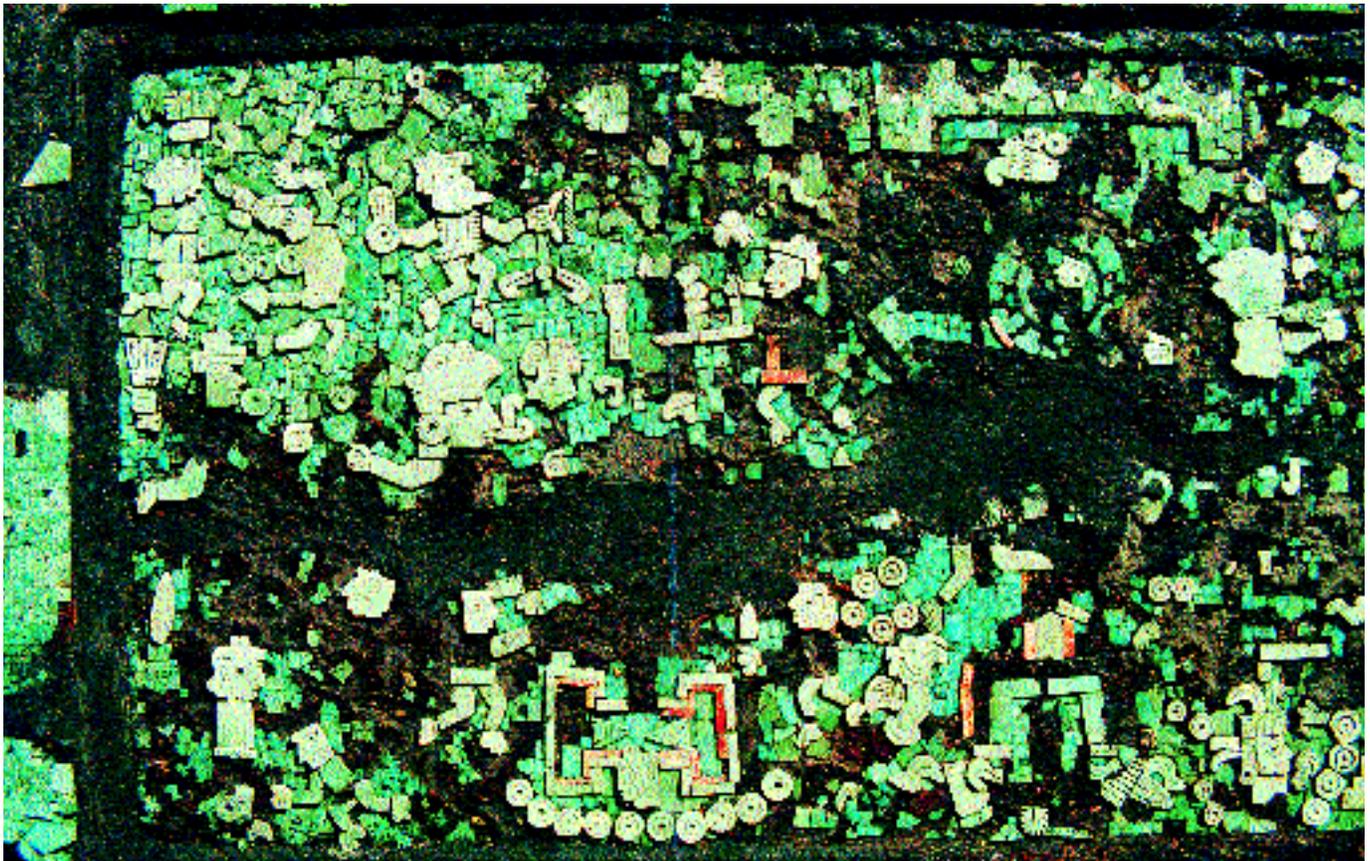


# JOURNAL OF CAVE AND KARST STUDIES

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Bulletin



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Excavations in Buried Cave Deposits: Implications for Interpretations

The Chronology of Early Agriculture and Intensive Mineral Mining in the Salts Cave and Mammoth Cave Region

An Ancient Rocky Mountain Caver

The Cave of Las Ruinas (Cerro Rabon, Oaxaca, Mexico): A Mazatecan Postclassic Funerary and Ritual Site

The Cueva Cheve Tablet

Regional Variation in Maya Cave Art

Selected Abstracts from the 1995 National Speleological Society National Convention in Blacksburg, Virginia

# Journal of Cave and Karst Studies

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# ELECTRONIC COMMUNICATION AND THE *JOURNAL OF CAVE AND KARST STUDIES*

IRA D. SASOWSKY

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Electronic communications and desktop publication are becoming a significant part of the way that the *Journal of Cave and Karst Studies* is doing business. For some time now, the review process has been expedited by the use of electronic mail. This allows fast communication between the editor, associate editors, authors and reviewers, which is important in reducing the time between submission of the manuscript and eventual publication. It also allows for fairly long, rapid communications, without the expense of phone calls.

When Dr. Louise Hose and Dr. Jim Pizarowicz were appointed to their current editorial positions with *Journal*, they began a conversion from our traditional publishing process to a more digital one. Previously, after a manuscript had been reviewed and revised, it was sent to the printer, who retyped the text from the hardcopy, and pasted up the photographs for the layout. The goal established by Hose and Pizarowicz has been to receive (via mail) a copy of the final manuscript on disk (because most authors now compose on computer anyway). This will save both time and money, because the manuscripts will no longer need to be retyped by the printer.

Recently, the process has been taken one step further. During early 1996, I received the first fully electronic submission to the *Journal*. This included both text, and figures, and came after an initial query by the author as to whether the *Journal* accepted such submissions. The author sent his manuscript over the Internet. Many questions were raised because we had never accepted such a submission before. In this case, the author, a resident of the former Soviet Union, preferred electronic submission because it was faster, cheaper, and more certain than physical mail.

As this manuscript has made its way through the review process, a number of difficulties, as well as benefits, have been recognized. Foremost among the benefits have been the speed and ease of communication between the author and the associate editor. This has easily reduced by 50% the time needed for review and revision. The main difficulties have been questions of electronic format. There are currently about 25 commonly used formats for text files, and about 35 for graphic files. Add to this the ten or so different compression routines which are used to prepare files for Internet transmission, as well as the different Internet mailing programs, and the complexity becomes obvious. Decompression of the files, and conversion between these formats is a tedious and frequently time consuming process.

Some scientific journals have taken electronic publishing a step further. The American Association of Petroleum Geologists now publishes their *Bulletin* on the Internet<sup>1</sup>, as well as in paper format. This is free for the taking and includes all text, data, and figures. The last three issues are always maintained on line. A paper subscription to the same journal (published 12 times a year) is \$140. One journal has gone yet another step. A consortium of five scientific societies has just begun publication of a journal called *Earth Interactions*<sup>2</sup>. It is published ONLY in electronic form, not in paper, and makes full use of interactive calculations and graphics. It is interesting to note that electronic publishing was initially viewed as a way to control costs of the production of a journal. The experience of those societies who have gone this route, however, has been that the costs are actually quite similar. What is saved in paper and mailing costs is lost to hardware, software, and communications expenses.

Of course all of this is limited by the access of authors, editors, and readers to computers and the Internet; not everyone is directly connected to the information superhighway. Consider the following: As a matter of course, I request e-mail addresses and phone numbers from anyone submitting a manuscript. A recent submission came to me with no e-mail address, phone, or fax numbers. In my letter acknowledging receipt of the manuscript, I requested this contact information from the author. The reply (by mail) was: "We live remotely away from roads and off the grid, so do not have a phone. However, if you leave a message at the local public radio station, they will broadcast a message, and then we can call you at a time you are at a phone."

The bottom line in producing a high quality *Journal* is not whether someone is on the Internet, or has a fast desktop computer. Rather, the bottom line is the quality of the scientific work that they submit. Given the diversity of the NSS, I expect that we will be receiving and reviewing high quality manuscripts in a variety of formats for some time to come.

<sup>1</sup> For those with Internet access, the AAPG site may be visited at <http://www.geobyte.com/current.html>. Adobe acrobat software (needed to read the journal) may also be downloaded freely from the site.

<sup>2</sup> Information on this journal may be viewed by <http://earth.agu.org/ei/>.

# CAVE ARCHAEOLOGY IN NORTH AMERICA AND MESOAMERICA

JANET FITZSIMMONS STEELE

Journal Guest Editor

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The papers included in this Special Issue were presented at the National Speleological Society Symposium on Cave Archaeology in North America and Mesoamerica, which was held during the 1994 National Speleological Society National Convention in Brackettville, Texas. My intention in chairing this session was to bring several of the principal cave archaeologists together. Much fine work has been done in cave archaeology, and the symposium papers address the state of the discipline today.

These papers concern archaeological investigations of prehistoric cave use in the dark zone, beyond the entrance. All the sites discussed demonstrate that ancient cavers extensively explored and utilized the inner passages of caves. Rockshelter sites, or sites where human remains or artifacts were dropped down pit entrances are not included. The symposium concentrated on the methods and the techniques used by archaeologists for documenting prehistoric use of the dark zones in caves.

Cave sites provide unique glimpses into the cultures of ancient people that are not available through surface site excavations alone. Because of the relative stability of the underground environment and lack of the weathering forces that are always active above ground, the artifacts in a cave are often completely undisturbed since the ancients left them there.

Comprehensive scientific information can be obtained only from intact sites. Much archaeological information is lost when a site is looted for relics and "collectibles." Never disturb an archaeological site should you encounter one underground. Step around the archaeology; do not pick up the artifacts or even touch them; report your discovery to appropriate authorities.

The papers in the symposium and in this Special Issue include papers from sites in the United States, Mexico, Belize, and Guatemala. I believe you will both enjoy them and learn from them.

# THE CHRONOLOGY OF EARLY AGRICULTURE AND INTENSIVE MINERAL MINING IN THE SALTS CAVE AND MAMMOTH CAVE REGION, MAMMOTH CAVE NATIONAL PARK, KENTUCKY

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*During the past 30 years, 57 radiocarbon determinations have been obtained from Salts and Mammoth Caves in Mammoth Cave National Park, Kentucky. These range from 4120 ±70 BP to 1920 ±160 BP, thus falling within the Late Archaic and Woodland periods of North American prehistory. We discuss the patterning of the dates, which cluster in two groups (Late Archaic, ca. 4200 BP to 3000 BP) and Early Woodland (ca. 2800 BP to 2200 BP). We also address the implications of those patterns for the history of aboriginal cave exploration and cave mineral mining in the Salts Cave and Mammoth Cave portions of the world's longest cave system, and for the development of early agriculture in Eastern North America.*

The Cave Research Foundation Archeological Project began work in 1963 in Salts Cave, expanding activities to Mammoth and other caves in Mammoth Cave National Park during subsequent years. From the inception of the project to the present time, we have concentrated primarily upon two research themes:

- 1) the specifics of when, how, and where prehistoric exploration took place in what is now known to be the world's longest cave system;
- 2) the information serendipitously provided by the ancient cavers about prehistoric agricultural origins and development in the Eastern Woodlands.

In this paper, we present the latest data and our interpretations of those data for both issues, emphasizing their chronological aspects.

## PREHISTORIC EXPLORATION AND MINING OF THE WORLD'S LONGEST CAVE: CHRONOLOGY

During the past decade, sufficient radiocarbon determinations have accumulated to enable us to define fairly clear patterning within the total date scatter (Kennedy, 1990, 1996; Kennedy & Watson, 1994). There are 57 determinations for the two caves from a variety of substances: soot, charred wood, uncharred wood and cane, weed stalks, bark, vegetable fiber fabrics, cane basketry, human gut tissue, and human paleofecal deposits. The oldest date is 4120 ±70 BP (2170 BC ±70 years), which is about the same as the only date currently available for prehistoric exploration of Lee Cave in nearby Joppa Ridge: 4100 ±65 BP (2150 BC ±65; Freeman et al., 1973).

The youngest date is 1920 ±160 BP (a.d. 130 ±160) years; this date is on internal tissue from the Salts Cave mummy (Watson ed., 1969, 1974). Two other mummy tissue dates are also young relative to the rest of the date sequence: intestinal tissue from the Mammoth Cave mummy (1965 ±65 BP, which

is 15 BC ±65) and a second determination on the Salts Cave mummy (1960 ±160 BP; 10 BC ±160). A fabric fragment closely associated with the Mammoth Cave mummy (a portion of his clothing, or of a bag he was carrying) yielded a determination of 2395 ±75 BP (445 BC ±75).

Nearly all the other Salts Cave/Mammoth Cave dates cluster in the mid-third millennium BC, i.e., ca. 500 BC ±200 to 300 years. There seem to be two fairly discrete episodes of cave use. We think the 1000 BC and earlier people (Late Archaic in archaeological terminology) were exploring, reconnoitering, or just caving for sport. The later people, ca. 500 BC, were intensively mining the cave's resources, systematically removing a variety of sulphate minerals in upper-level and some lower-level passages.

What specific substances were they seeking, and what did they do with the minerals they collected from the cave?

We think it highly likely that the prehistoric miners wanted gypsum in powdered form (which is what results if you pound gypsum crust off the cave walls) as a pigment base (just add water or grease and you have white paint), and in crystalline form (satinspar and selenite) probably for ritual use. We assume they also knew about the medicinal properties of mirabilite and epsomite (both of which are cathartic, and both of which occur naturally in various parts of the two caves, mirabilite being especially abundant), and made good use of them; and we assume further that they traded some of these substances outside the immediate region. We think we know a good deal about how the procuring of the various minerals was done (Munson et al., 1989).

## EARLY AGRICULTURE IN THE EASTERN WOODLANDS: CHRONOLOGY

As regards the early agriculture issue, we can be fairly certain that all the dietary and nutritional information in the

human paleofeces dates to about 800 to 200 BC. Although this data corpus provides the most detailed and best preserved such evidence available anywhere in the world for a prehistoric human group, it post-dates the earliest stages of plant domestication, which—at present—are best documented in upland locales of eastern Kentucky and central Tennessee.

Briefly summarized, the currently available archeobotanical record indicates the presence of *Cucurbita pepo* gourd (presumably wild) by 10,500 BC in Florida (Newsom, 1993); bottle gourd (*Lagenaria siceraria*, possibly domestic) by 5000 BC, also in Florida (Doran & Newsom, 1990, Newsom et al., 1993); *pepo* gourd (wild or domestic?) between 5000 and 4000 BC in Illinois (Conard et al., 1984); *pepo* gourd (probably domestic) in western Missouri (Kay et al., 1980), eastern Kentucky, and western Kentucky (Cowan et al., 1981, Crawford, 1982) ca. 2500 BC; domestic sunflower (*Helianthus annuus*) at 2300 BC in Tennessee (Crites, 1993); domestic sumpweed (*Iva annua* at 1800 BC in Illinois (Conard et al., 1984); domestic chenopod (*Chenopodium berlandieri*) in southern Ohio and eastern Kentucky at 1500 BC (Smith & Cowan, 1987); and domestic sunflower, sumpweed, chenopod, and maygrass about 1000 BC in eastern Kentucky, in the Arkansas Ozarks, and in several places in Tennessee (Chapman & Shea, 1981; Crites, 1978; Fritz, 1990, 1997; Gremillion, 1993, 1994; Watson, 1989). Then between 1000 BC and 500 BC, the full Early Woodland agricultural system exemplified in the Salts Cave/Mammoth Cave paleofeces appeared in eastern and western Kentucky.

Since the publication of the Salts Cave report (Watson ed., 1969), there has been a tendency to downplay or set aside—because of the unusual nature of the data base—Yarnell's calculations indicating that two-thirds of the plant foods in the Salts Cave feces were from cultivated and semi-cultivated or encouraged plants (Yarnell, 1969, 1974). We think, however, that the diet represented in the Salts Cave and Mammoth Cave paleofeces is a faithful indication of what the Early Woodland cave dwellers were eating above ground as well as below. Certainly this data corpus (paleofeces) is somewhat unusual for the Eastern Woodlands, and the archaeological site (deep cave interior) containing it is also out of the ordinary, but the accident of preservation that these caves represent is not necessarily the record of anomalous behavior in an anomalous site. Rather, we think the data derive from the fortuitous preservation of normal dietary intake, at least seasonally, for people in the region around Salts Cave and Mammoth Cave between 800 BC and 200 BC.

Some support for our contention is available from evidence elsewhere in Kentucky, in Tennessee, and in Arkansas (Fritz, 1986, 1997; Crites, 1993; Gremillion, 1994, 1997). These data considered as a whole imply quite strongly that various forms of pre-maize, upland agriculture were being practiced rather intensively in some places in the Midwest and Midsouth by and probably before 3000 BP.

#### NEW RESEARCH TRAJECTORIES: THE PALEOFECAL PROJECT

In September, 1992, in collaboration with Mammoth Cave National Park officials, we collected 12 paleofecal samples, six from Mammoth Cave and six from Salts Cave; an additional specimen was collected in 1993 from Mammoth Cave. This new project is actually the realization of a long deferred research strategy to date 20 paleofecal deposits, proposed over 30 years ago by Joe Caldwell (then Curator of Archaeology at the Illinois State Museum) and P.J. Watson. In the current version of this research, which was originally dubbed "Twenty Dated Dinners" by Caldwell, we seek to establish an AMS date and an analysis of the contents of a baker's dozen fecal samples. Our aim is a more complete understanding of the transition to agriculture in the Eastern Woodlands. Although more than 100 fecal specimens have been analyzed for dietary content (Marquardt, 1974; Stewart, 1974; Yarnell, 1969, 1974), only five had been directly dated by the radiocarbon technique (Kennedy, 1990; Watson ed., 1969: 69) before this latest set of fecal samples was collected.

In addition to clarifying the chronological relations between the fecal material and the entire span of Early Woodland cave use, we wished to address a number of other research problems recently noted by Kennedy (1990, 1996). One of these is to obtain dates from areas of the caves that had not previously been dated. Another is to attempt to locate feces that date to the Late Archaic period. Yet another is a range of issues related to accuracy and precision of these new dates, as well as those obtained previously. Finally, we thought it highly desirable to apply a state-of-the-science analysis to each specimen from macrobotanical, palynological, parasitological, and biochemical perspectives.

The radiocarbon determinations have been returned by the NSF-Arizona AMS Facility. As can be seen in Figures 1 and 2, these dates consistently cover the same general time period as do the nonfecal dates, and are unequivocally centered in the midst of the Early Woodland period. We were unsuccessful in locating any Archaic age samples, however. Portions of the samples are now being analyzed by several researchers: Kristen Grimillion, Ohio State University, for macrobotanical remains; Kristin Sobolik, University of Maine, for pollen remains; Charles T. Faulkner, University of Tennessee, for parasitological information; and Patricia Whitten, Emory University, for hormonal residues enabling sex determination (this type of work has been done for living non-human primates, but to our knowledge this is the first attempt to sex human paleofeces). Some reports of results have begun to appear: see Gremillion & Sobolik, 1996; Whitten, 1994.

#### NEW RESEARCH TRAJECTORIES: LEE CAVE AND LOWER SALTS CAVE

On March 19, 1994, a three-person Cave Research Foundation Archeological Project crew entered Lee Cave in Joppa Ridge, a southerly part of the Mammoth Cave system, in

# Radiocarbon Age Determinations

## from Mammoth Cave and Salts Cave, Kentucky

All representations are two-standard-deviation ranges

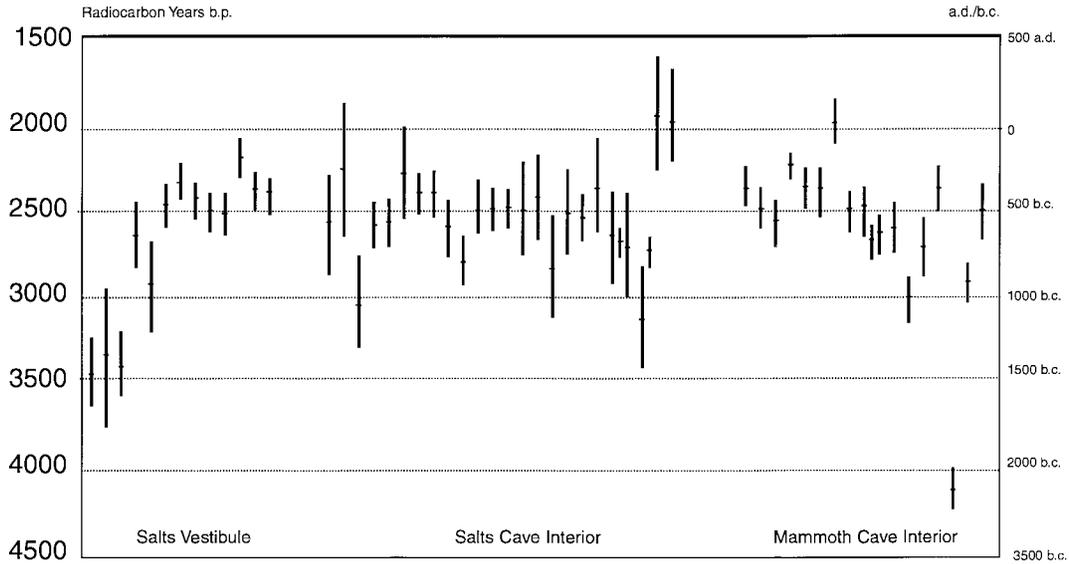


Figure 1.

# Paleofecal Dates

## From Mammoth and Salts Caves

in chronological order based on midpoint of range

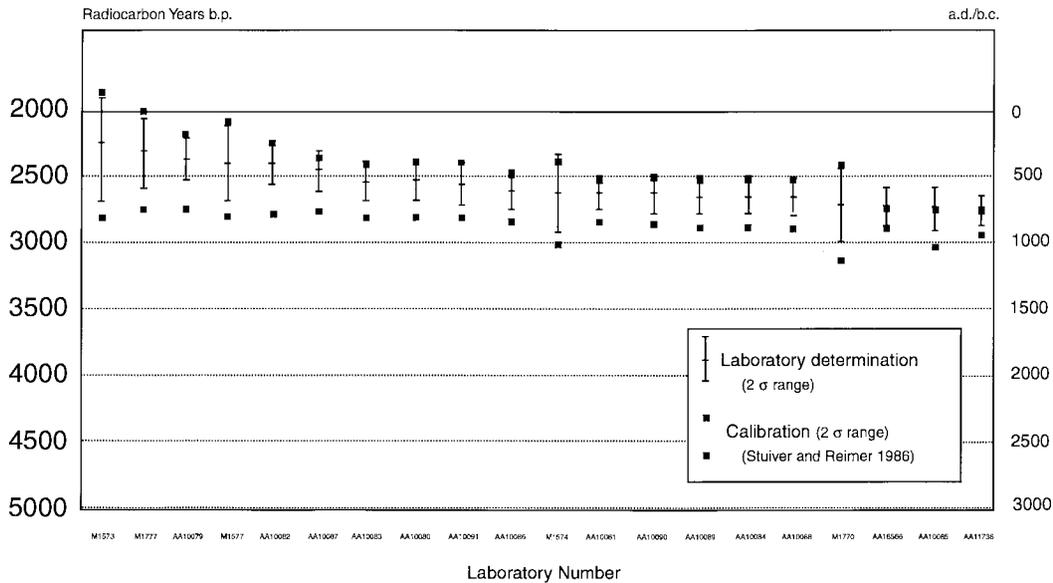


Figure 2.

search of paleofecal material potentially dating to the pre-1000 BC period. They succeeded in relocating a deposit noted during the late 1960s-early 1970s CRF documentation of Lee Cave (which was discovered by modern cavers in 1968, Freeman et al., 1973); and they also found four more deposits. At present, there are only two radiocarbon determinations for Lee Cave, one on cane from survey station K83 in Marshall Avenue (which is a 2 km long piece of trunk passage) and one on a log about 450 m west of K83 in Marshall Avenue, at survey station J25. The cane date is 2150 BC  $\pm$ 65, as noted at the beginning of this paper, and the log date is 4100 BC  $\pm$ 60. It has been assumed that the log arrived in the passage by natural means (a major flood, presumably), but that the cane determination dates the aboriginal exploration of Lee Cave. This date, one from Wyandotte Cave (Munson & Munson, 1990), and three others from Jaguar Cave in Tennessee (Robbins et al., 1981), make it clear that prehistoric cave exploration of the midcontinental karst region began before 2000 BC.

Had the Lee Cave paleofecal deposits turned out to be as old as the K83 cane torch material, then, in spite of our lack of success so far in securing Archaic specimens from Salts and Mammoth Caves, we would still have been able to obtain some detailed, Archaic-period data for comparison with the Salts Cave/Mammoth Cave dietary, nutritional, and agricultural information. Unfortunately, upon close examination, the Lee Cave specimens do not appear to be of human origin. Hence, we have returned our attention to Lower Salts Cave where two as-yet-undated paleofecal deposits remain in situ, and where many small intersecting passageways—some of which were entered prehistorically—are still unmapped and incompletely known. In January 1996 we obtained a radiocarbon determination on a climbing pole or scaling pole left by the aboriginal cavers at the north end of Indian Avenue, the main passage in this part of Lower Salts Cave: Beta-87915, 2760  $\pm$ 40 BP (810 BC  $\pm$ 40 years). Thus, it is possible that the two paleofecal samples on the floor of Indian Avenue may also date to the first part of the second (Early Woodland) period of cave use rather than the earlier (Late Archaic) horizon. But we cherish the hope that one or both may have been left on an earlier trip pre-dating the pole, and hence will provide at least a few clues to the information we have been seeking for a long time: what were the dietary and nutritional patterns in the Mammoth Cave area during the period prior to significant use of domestic food plants? By comparing Late Archaic dietary data (1500 to 2000 BC) with the agricultural complex so clearly documented in the Early Woodland Salts Cave/Mammoth Cave paleofeces, we can learn more about the foodways of the first prehistoric cave explorers in the region as well as those of the later cave miners, who were also superb cavers and some of the earliest farmers north of Mexico.

#### ACKNOWLEDGMENTS

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National Park Superintendents and other administrative officials, most recently Jeff Bradybaugh and Bob Ward of the Division of Science and Resources Management. All the work underground, since its inception, has been heavily supported by the Cave Research Foundation, both physically and financially. The Illinois State Museum Society awarded us a grant for the first summer's fieldwork (1963), published the first monograph (Watson ed., 1969), and is the repository for collections made in Salts Cave in 1963. Other support was provided by the National Geographic Society, the National Endowment for the Humanities, the National Science Foundation, and by Faculty Grants from Washington University. A substantial gift from Olga Munsterman paid for the paleofecal AMS dates. We are deeply grateful to these individuals, agencies, and institutions; and to the dozens of CRF Joint Venturers and Washington University graduate and undergraduate students who donated their time, expertise, and labor as members of field crews, above ground and below.

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# AN ANCIENT ROCKY MOUNTAIN CAVER

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*Approximately 8000 years ago, a man in his early 40s entered a small cave at an altitude above 3000 m in the Southern Rocky Mountains. He died there of a cause or causes unknown. His physical remains were found in 1988 by three NSS cavers, who contacted appropriate federal authorities, Native American representatives, and academic and privately based researchers. In this paper we describe and discuss preliminary results of the Hourglass Cave study.*

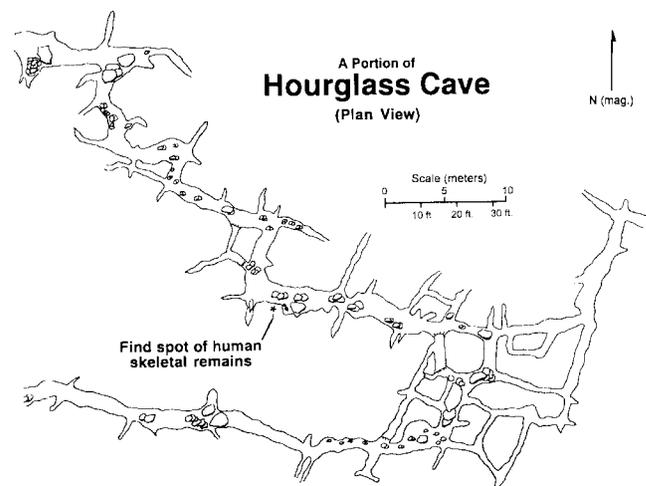
High in the southern Rocky Mountains, a man in his early 40s died ca. 8000 years ago in a small cave. His skeletal remains were discovered in 1988 by three cave explorers. Realizing the implications of their discovery, the explorers initiated contacts to form a research team to study the site. Our team has spent many hours discussing the possible motivations and circumstances bringing the man into the place where his life ended. The simple truth is that we do not know now—and we will perhaps never be certain of knowing—what brought him to the vicinity or why he entered the cave or how he came to die there. We have, however, been able to draw some strong inferences about details concerning the microenvironment where he died, and about the taphonomic processes that contributed to the condition of his remains as found in 1988. We also offer alternative interpretations about why he went into the cave, and about his last hours there.

## DISCOVERY OF THE SITE AND DEVELOPMENT OF THE RESEARCH TEAM

After finding the cave, which they named “Hourglass,” on July 31, 1988, the discoverers (C. Mosch, T. Shirrell, and R. Wolfert) initiated exploration, survey, and inventory. They noted the prolific occurrence of organic influx and animal bones on the passage floors and ledges. A week later, while exploring what by all appearances seemed to be a previously untraveled passage, they were startled to find human bones. Because no obvious traces of this or any other person’s previous travel through the cave were evident, they suspected that the bones could prove to be very old. They contacted Patty Jo Watson, knowing of her experience in cave archaeology and her familiarity with the nature and sensitivity of cave environments. She visited the cave in August 1989 with a colleague, Charles Hildebolt, a physical anthropologist and a caver. After examining the site (Fig. 1), they agreed with the initial assessment by the discoverers that the bones probably predated the modern era. Because the cave was on USDA Forest Service land, the group then contacted the regional office. The regional archeologist, Leslie Wildesen, directed the group to the for-

est archeologist, Bill Kight, and the research was formally initiated. An Accelerator Mass Spectrometer (AMS) radiocarbon date of  $8170 \pm 100$  BP (Beta 38554/ETH 6765; this is the conventional, uncalibrated 14 C age) from a single rib of the human skeleton established the antiquity of the remains. Two more AMS dates have been obtained by the NSF-Arizona AMS Facility at the University of Arizona, Tucson, on bone from the tibia (two determinations for the same sample, AA11808):  $7714 \pm 77$  BP and  $7944 \pm 84$  BP.

Due to the nature of the discovery and its setting, a special management/study team of diverse specialists was organized to integrate research findings concerning the whole of the cave’s resources. The team members also share strong interests in preserving, conserving, and managing the cave’s resources, and all were involved in preparing a site management plan. Detailed investigation of the cave’s archeological and anthropological aspects has greatly stimulated study of the paleontology, geology, and biota. Dialogue between people of differing viewpoints and expertise has resulted from this close working relationship, greatly enhancing the team’s collective



**Figure 1.**

knowledge concerning the cave and the remains of the special individual found within it.

#### THE MAN FROM THE CAVE: PRELIMINARY RESEARCH RESULTS

The physical remains thus far recovered and studied include:

- Skull cap (calvarium with portions of the frontal, parietal, temporal, sphenoid, and occipal bones)
- Right humerus
- Right and left femora
- Right first and seventh ribs
- Seventh cervical vertebra
- Right and left tibial shafts
- Fragments of the right and left pelves
- Eleven teeth

Morphological details of the pelves indicate clearly that the individual was a male. Other morphological and histological traits of the bones and teeth suggest an age between 35 and 45 years, probably closer to 40. He was 162.5 cm (approximately 5 feet 5 inches) tall, with no skeletal signs of poor health or poor nutrition.

Most of the bones show gnawing marks—some quite extensive—left by small animals (probably mostly packrats and porcupines), which frequented the cave in the long period between the man's death and the discovery of his skeletal remains. The bones were also dispersed by these animals, and many skeletal elements seem to be completely missing (e.g., the face, the left arm, the left part of the rib cage, the lower part of the right arm). The bones that remain, however, are mineralized and well preserved, as are the teeth. The cortical bone of the tibiae (the outer layers of both shinbones) are abnormally thick as if perhaps he had hiked and climbed in the mountains a great deal. He also had the beginnings of an arthritic condition in his neck, perhaps from habitually carrying heavy loads on his head and upper back and/or shoulders. In addition, a sclerotic (abnormally hard and dense) condition of the bone is evident in his right hip and leg (pelvis, femur, tibia), but not in the right humerus. The forensic radiologist's initial suggestion was that this condition may have been an unusual, if not unique, pathology that developed during life. After detailed discussion, however, we think that this may be a post-mortem phenomenon. If so, then it might have resulted because the body was lying on its right side in water and mud for some unknown, but presumably rather long period after death, before the bones were scattered.

Preliminary examination of the 11 teeth indicated that eight are from the lower jaw and three are from the upper. All 11 have been heavily and distinctively worn in a manner suggesting to the analyst that the individual was right-handed. People tend to put food or other objects into their mouths on the side of the dominant hand, using that hand. The Hourglass dentition shows heavier wear on the right teeth than on the few left

teeth. The wear is smooth, however, and the teeth are not chipped; this person apparently habitually ate grit-free food. The dental anthropologist does not know exactly what caused the wear that is so clearly evident on the ancient teeth, but suggests that the causal activity involved repeatedly pulling smooth but substantial material, such as hide or sinew, over the anterior dentition.

The team's DNA analyst reported that there is well-preserved DNA in the bone (a small sample from the left tibia), which seems to be original rather than a result of recent contamination, and which shows a 9 base-pair deletion condition. This is the oldest example yet known of this genetic characteristic in North America. Such a condition is lacking in northern Athabaskan populations (several American Indian groups in western Canada), but is present in some populations in regions south of the Canadian border. Details of the DNA work are now in press (Stone & Stoneking, 1996).

In late July, 1993, at a pre-arranged time and place, the physical remains of the Hourglass Cave individual were conveyed by the technical research team to Forest Service representatives who, in turn, gave them to the Native American Cultural Heritage representative, Kenny Frost, of the Southern Ute tribe. Although the bones and teeth are no longer in the public or scientific domain, extensive documentation, including casts, was undertaken.

Suggestions about who this man was, what he was doing at this mountain locale, why he entered the cave, and how he came to die there require initial reference to the geological and geomorphologic setting for the site.

#### THE SITE AND ITS SETTING

Hourglass Cave is on the western slope of the continental drainage divide within the Southern Rocky Mountain physiographic province. Situated close to the transition between the sub-alpine and the alpine zones, the site vicinity is snow covered between seven to eight months of the year. Both sub-alpine and alpine species have been noted in the site vicinity.

The range of ages for nearby geologic units is extreme, from Precambrian to Quaternary. The local Paleozoic strata (Leadville, Molas, Dyer, and Minturn Formations) are of significant interest because they could have been sources for knappable chert nodules and vein fillings. Black (1986: 172-174) notes that these units have supplied usable toolstone in the northern Sawatch Range. A prominently situated outcrop of silicified dolomite 2.5 km from the site contains siliceous vein fillings and a sizable (1 x 2.5 m) deposit of chert.

The local base level drainage is currently 650 m below the site, although intermittent springs and seeps do occur in the vicinity. Local topography consists of resistant beds that crop out as bluffs and cliffs between slopes of less resistant bedding. A thin soil (1-1.5 m) covers slopes over less resistant units. According to the team geomorphologist, solifluction features are evident in the vicinity, but the process has probably not dismantled slopes so effectively that significant karstic features

(such as collapse sinks or additional cave entrances) have been masked in the past 8000 years. This, and his observation that no significant talus has accumulated below the entrance outcrop, suggests that the general surface topography at the cave entrance is much the same as it was ca. 8000 BP. The team stratigrapher does note, however, that some blocks of rock may have collapsed more recently along the margin of the outcrop in which the cave entrance is located. About 2 m from the cave entrance, resistant beds roof a low overhang (less than 1 m in height), which shelters an area of approximately 6 m squared. Beneath this overhang are blocks of rock that have fallen from the roof overhead. They are not well weathered or indurated, and fresh exfoliation scars can be seen on the overhang. If these blocks have indeed fallen relatively recently, then the area sheltered may have been more extensive at the time when the ancient man visited the site than is now the case.

The cave is situated within beds of a lenticular, highly dolomitized limestone. Passage morphology and orientation in Hourglass Cave reflect strong structural control. Passages are primarily solutional along joints and bedding interstices with some vadose modification. The passages are narrow and change direction abruptly, with sharply angular turns that follow the strongly orthogonal joint pattern. The cave is maze-like, with numerous narrow side passages of limited length that terminate as upwardly pinching, mud-filled infeeders.

#### THE ANCIENT CAVER'S LAST HOURS

Because the processes (other than occasional rock fall) that have most rapidly changed the geometry of the cave passage have been rendered effectively inactive with the drop of the base level water table long ago, negotiating passages today is probably very similar to the ancient man's maneuvers as he moved through the cave.

Entering the cave almost immediately requires one to crawl, first on hands and knees, and then prone, body flattened completely into the animal-midden covered floor. It is 18 m before there is sufficient clearance to stand upright. Before being able to stand, one must squeeze through a constricted, sharp angled turn, out of the entry room into the complete darkness of a low, descending, clay-floored passage of barely body width. The cave temperature is noticeably cold (4-5°C), and the humidity is high.

The first hint that this route might have been followed by an early explorer is found approximately 33 m into the cave. At that point, charcoal fragments are visible on the damp clay floor. Seven meters farther along the passageway, charcoal marks on the walls occur above charcoal fragments on the floor. The wall marks may be smudges from light sources carried on one or more prehistoric trips.

In April 1995, we obtained radiocarbon determinations on two of these charcoal fragments: 1960 ±80 BP (Beta-81202) and 2330 ±50 BP (Beta-81202/CAMS-19328). Clearly, these charcoal fragments are younger than the trip made by the Hourglass Cave man, and must represent a later prehistoric

journey into the cave, or perhaps simply transport of two thousand year-old charcoal by animals and/or hydrologic factors (see discussion below). We think the wall smudges are indeed torch marks, but do not know yet whether they were left by the Hourglass Cave man or by some later prehistoric visitor. We are awaiting results of AMS dates on samples of the smudges, and also plan to obtain more determinations on charcoal fragments from deeper inside the cave.

At least 58 such smudge marks have been noted between the entrance and the locale where the Hourglass Cave man was found (some 300 m from the entrance). The marks are distributed along 280 m of passageway, and the 58 sites include 122 individual smudges. At 12 sites, marks occur in clusters ranging from two to eight smudges. At seven of the sites, marks on the wall are associated with charcoal fragments on the floor below. Approximately 20 occurrences of charcoal fragments on the floor have been noted between 33 m and 357 m from the entrance. The marks and charcoal fragments are not evenly distributed between the points where they are first and last observed. Most of the marks are found along the main passageway 40 m in from the cave entrance and in a narrow side fissure that branches from the main passage at 164 m from the entrance. Small fragments of charcoal are scattered intermittently on the cave floor along this entire route.

If the smudge marks and charcoal fragments are a result of natural processes (e.g., if charcoal were washed in after brush fires or forest fires), then the distribution of occurrences should be greater near avenues of influx (such as infeeders, or the entrance), and smudge marks should occur on wall surfaces below points of influx. The cascade of influx would be expected to accumulate on upward-facing surfaces (and not within sheltered recesses) over a wide range of heights above the floor. Overall, the occurrences do not fit the natural influx mode. At a distance of 41 m from the entrance, for example, an individual mark (15 mm x 9 mm) is situated well within a wall scallop cup, inaccessible to influx from above. The majority of infeeders observed along the main cave passage do not contain charcoal fragments. Median height from the floor of the 122 marks is 1.5 m (4 feet 11 inches), the highest is found at 2.9 m and the lowest at 0.46 m.

Both the lowest and the highest of the possible smudge marks were found in the fissure that branches from the main passageway 164 m into the cave. Entry into this fissure is accomplished by crawling on one's side for about two body lengths across a rocky, mud-covered floor. The ceiling rises abruptly to a maximum of 4 m, although the fissure remains not much wider than one's body. The low marks correspond to crawlway-sized passage, whereas the highest of the marks are situated in a part of the fissure that is accessible only by chimneying. This side fissure is a dead end passageway, so one must backtrack through it to regain the main passage.

The farthest extent from the entrance that charcoal fragments have been found is 357 m. If the charcoal traces correspond to the path the prehistoric man traveled, then he may have explored the cave at least 36 m beyond where his skeletal

remains were found. Except for a climb over a nearly 2 m high boulder, requiring two free hands to ascend or descend safely, this 36 m stretch is a moderately spacious walking corridor.

At the site where the bones were found, a large collapse-block is pendant in the passage above, wedged between the two walls, forming the most conspicuous low point of the otherwise high-clearance passage. Numerous large, breakdown rocks form collapse rubble on the floor at this point. A recent survey of the area directly above this point revealed a number of still precariously balanced rocks that could easily be tipped to fall to the floor.

Much of the passage between the entrance and the site where the bones lay cannot be traversed by simply walking upright. Hands and knees crawling, climbing under and over large fallen boulders (over 1 m high), and twisting one's body to fit through awkward, narrow squeezes in sinuous passages are all required to navigate the route. Determining the best route through the maze-like area near which the early explorer was found is quite difficult. Adding to those challenges are the additional hazards of unstable floor and ceiling rock, slippery wet and muddy surfaces, and low temperature. This ancient caver must have been agile and strong, as well as driven by an intense sense of purpose—or of curiosity—to have gone where he did, especially if he were alone.

#### COMPARATIVE ARCHEOLOGY

In a recent summary, Steele and Powell (1993) note that osteological remains of the first humans to enter the Americas are very few, totalling no more than some 21 fragmentary individuals. Although the Hourglass Cave remains are a little younger than most of the skeletal finds they list, he and the newly-dated 9400 year old man from Spirit Cave, Nevada (Kirner et al., 1996; see also Goldberg, 1996) can be added to Steele and Powell's series (1993: Table 1: 140). Besides the Hourglass Cave man, the only other discovery within Colorado is a burial from Gordon Creek in the north central part of the state (Breternitz et al., 1971). The burial—seemingly an isolated occurrence with no associated occupational deposit—was found in the bank of an arroyo tributary to Gordon Creek at an altitude of 6850 feet (2110 m). Two dates were derived from the left ilium: one on collagen (9700 ±250 radiocarbon years BP) and one on carbonate (3540 ±130 BP). The lab rejected the carbonate date on the grounds that interaction between the ground water and the bone carbonate had probably taken place post-depositionally, resulting in an erroneous determination (Breternitz et al., 1971: 172). The collagen date was accepted.

The bones are fragmentary, but portions of the entire skeleton are present, including skull with face. The individual is a female, 25 to 30 years of age. She had been laid to rest in a 1.0 m-deep by 0.75 m-wide pit, liberally sprinkled with red ochre and accompanied by nine lithic and six bone artifacts. The Gordon Creek woman was shorter (4 feet 10 or 11 inches; 145-148 cm) and more lightly built than the man of Hourglass Cave

("the length and overall size of the bones is small," Breternitz et al. 1971: 174), but her muscular processes were well developed.

James Benedict (1992) provides a summary of early prehistoric sites at altitudes above 3000 m in the Front Range of the Rockies. After reviewing Husted's earlier syntheses (1965, 1974), Benedict adds information from three sites excavated in the late 1960s and early 1970s: 5BL70, 5GA22 (the Caribou Lake site), and 5BAL120 (the Fourth of July site). Archeological materials from those sites date to periods ranging from 8460 ±140 radiocarbon years b.p. at the Caribou Lake site, to 7650 ±190 BP at 5 BL70, to 6045 ±120 BP and 5880 ±120 BP at the Fourth of July site. The average of the two determinations for the latter site—5960 ±85 BP—is accepted by Benedict as the best approximation of site age.

Benedict suggests that these Late Paleoindian to Early Archaic locales represent camp sites of hunting and gathering parties, or of groups simply in transit through the mountains. He believes two contemporary, but culturally distinct, populations were using the Front Range at the indicated time. One such group ranged widely from the High Plains to the Front Range, while the other had stronger ties to the mountains, was more insular, and seldom moved east of the Front Range. Both groups knew and used the timberline and alpine tundra portions of the Eastern Rockies, however.

Kevin Black (1991) has recently published a detailed consideration of high-altitude archaeology in the Colorado Rockies in which he comes to conclusions that differ somewhat from Benedict's. Black thinks that by 9000/8000 BP (and possibly as early as 10,000 BP), there were human groups who lived in the mountains all year around, participating in a Mountain Tradition that was distinct from Plains and Great Basin cultural developments. Black believes the postulated Mountain Tradition originally derived from the Great Basin, however; thus his interpretation differs from George Frison's account of Late Paleoindian foothill-mountain groups (e.g., Frison, 1992). The part of Black's formulation that is especially interesting in connection with the Hourglass site is his discussion of diverse mountain subsistence resources (including plants); seasonal transhumance in the foothills, montane, subalpine, and alpine zones; and overwintering in the warmer, drier mountain and foothill valleys.

The most recent contributor to relevant archeological research is Bonnie Pitblado of the University of Arizona, who is carrying out dissertation field work at the Caribou Lake site (5GA22) referred to above (Pitblado, 1996). Her work has just begun (a 2-week field season was completed in August 1995 with another season proposed for August 1996), and we await with considerable anticipation new 14C determinations and further information on the late Paleoindian/Early Archaic occupation of this high-altitude site (11,300 feet; ca. 3400 m) in the Rocky Mountains.

Finally, we note that Gunnerson (1987: 133) describes long, dry-laid rock walls—well above timberline—of the Early Archaic Mount Albion Complex as game drive sites; and that

Benedict (1992: 353) refers to game-drive installations at 5BL70 ("a U-shaped drift fence" incorporating a series of rock cairns). Frison et al. (1986), in describing a prehistoric net from the Absaroka Mountains in Wyoming, discuss the systematic hunting of deer and/or mountain sheep with the aid of nets, fences, pens, and corrals. The net was found in a small cave on Sheep Mountain (approximate altitude 2400 m), and dates to 8860 ±170 radiocarbon years BP.

Possible game drive installations have been noted 2.5 km from Hourglass Cave, but we do not know how old they are or whether they were associated with the man who died in the cave or with his community.

### CONCLUSIONS

Based on the radiocarbon determinations, we can assign the man from Hourglass Cave to the late Paleoindian/Early Archaic time period. The closest high altitude comparisons at present are probably with the Caribou Lake site (5GA22) near Arapaho Pass. Some 25 years ago, Benedict (1992: 348-351) found two Paleoindian workshops there, one of which was associated with a hearth radiocarbon dated to 8460 ±140 BP. Pitblado is now carrying out further field work at Caribou Lake to expand the information Benedict made available.

The man in Hourglass Cave may have found the cave while visiting known resources in the vicinity, or while prospecting for new ones on his own behalf or that of his kin group. Such resources could have included lithic outcrops, herbal foods and medicines, or big game such as elk, deer, and mountain sheep. If the man from the cave were a lone hunter-gatherer of high altitude resources who chanced upon the cave opening, then he may have decided to explore the interior, suffered a mishap while inside (e.g., became disoriented and lost, injured himself, lost his light) and died there involuntarily.

Kenny Frost (Cultural Heritage Representative for the Southern Ute Tribe and for our management team) suggests alternatively that the man in the cave went to an important ritual locale, well known to him, to die. Frost believes this man was not simply a hunter and gatherer, but also a wise man or elder of his group who knew about the cave and had used it and other local features for ceremonial purposes. He might have been inside the cave at least part way on more than one previous occasion. Ultimately, he deliberately chose the cave as his final resting place; when he entered it for the last time he fully intended to die there, and did so.

Although each member of the research team has her or his own convictions, the evidence currently available can partially support any one of these scenarios. Thus, as a group, we do not advance one interpretation over another to explain why this man, who was adapted to the rigors of the high country, chose also to explore the earth's inner realm.

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# EXCAVATIONS IN BURIED CAVE DEPOSITS: IMPLICATIONS FOR INTERPRETATION

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*As conduits for transporting ground water, caves are frequently wet and may be seasonally flooded. Cultural deposits in Maya caves are often buried under layers of mud that tend to be so plastic they are difficult to excavate and impossible to screen. There has been a tendency for archaeologists to ignore such areas. Yet ethnohistorical sources suggest that wet or watery places were sought in Prehispanic times for rituals directed to rain deities. Since caves are strongly associated with rain, it would not be surprising if these water-logged areas were precisely those selected for the performance of rituals. It is important to assess the extent to which archaeological bias against such areas has skewed data and interpretations.*

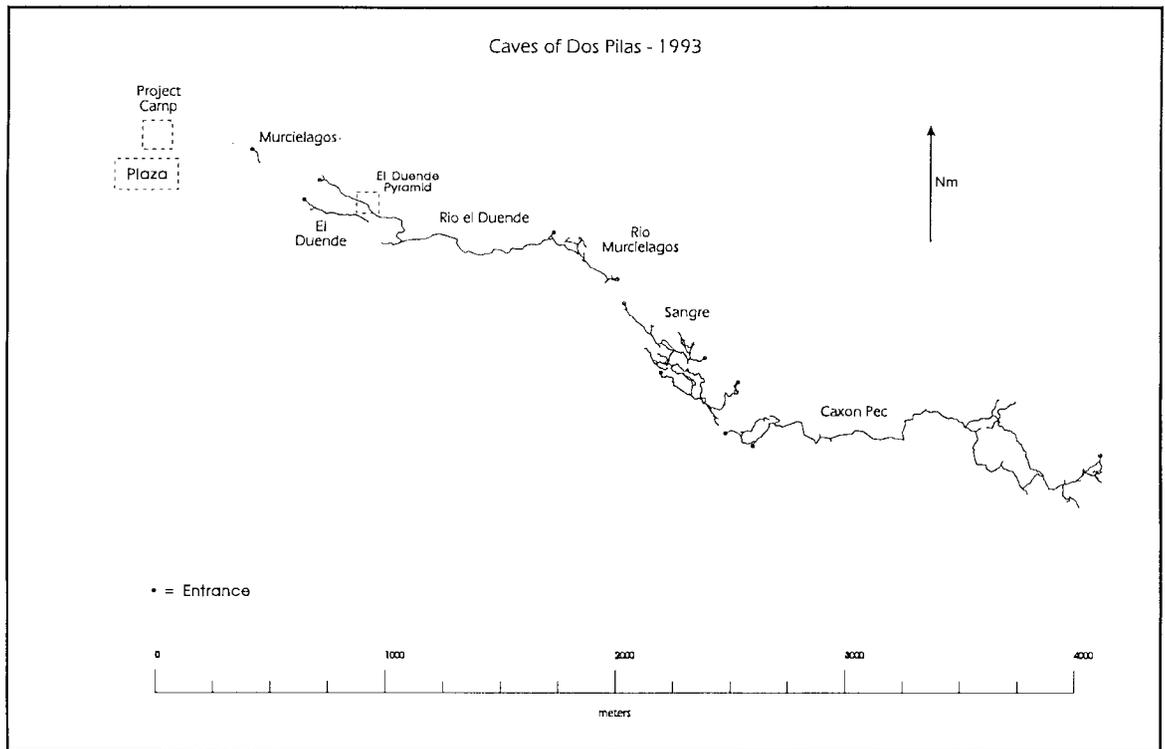
*The Petexbatun Regional Cave Survey, the largest and most intensive cave project mounted in the Maya area, has attempted to develop new field methods to address basic problems in cave archaeology. In 1993-94, several techniques for exploring water-logged contexts were tried, including the use of chemical deflocculants to dissolve cave mud. Field testing of the method in areas where the project had conducted completed surface collection recovered a large amount of ceramic indicating that sherd density was several orders of magnitude greater than previously reported. In addition, the percentage of Preclassic sherds in the test units indicate far more early utilization than suspected. More importantly, there is little overlap between the artifact assemblages recovered by the use of deflocculants with those recovered from surface collection, a fact that has important ramifications for the reconstruction of cave ritual. In general, the new techniques have revealed greater intensity of utilization in water-logged areas, and have produced an array of small artifacts that reflect a broader range of activities than suggested by surface survey alone.*

The Petexbatun Regional Cave Survey, a sub-project of the Vanderbilt University Petexbatun Regional Archaeological Project, is the largest and most intensive archaeological investigation of caves that has been undertaken in the Maya area (Fig. 1). During its four years based at the site of Dos Pilas, the project has attempted to develop new field techniques to address some of the problems of cave archaeology. As conduits for transporting water from the surface to the water table, most Maya caves are wet and may be seasonally flooded. This means that cultural deposits are often buried in water-logged conditions. Such conditions have been encountered in a number of caves in southeastern Peten (Brady, 1989; Brady & Fahsen, 1991) as well as in every major cave in the Petexbatun Region (Fig. 2). This is the major problem associated with the cave environment of this region. How does the archaeologist investigate these situations? In the past, such caves or areas of caves have simply been avoided. We feel this has biased data recovery and effected interpretation of cultural use of these areas.

Over the last two years, the Petexbatun Regional Cave Survey has systematically explored methods of investigating wet and water-logged environments. Two very different situations created by water were identified in this region. Where there is running water, artifacts are often buried under a layer



**Figure 1. Map of Guatemala Showing the Petexbatun Region.**

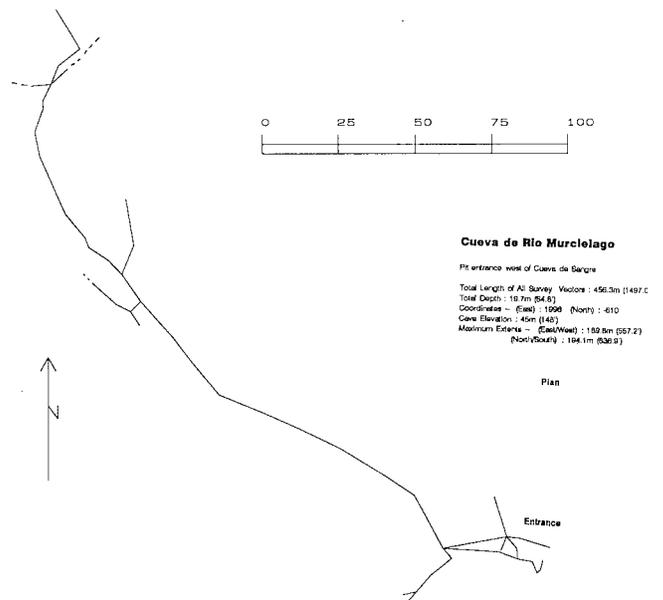


**Figure 2. Map of the caves investigated by the Petexbatun Regional Cave Survey.**

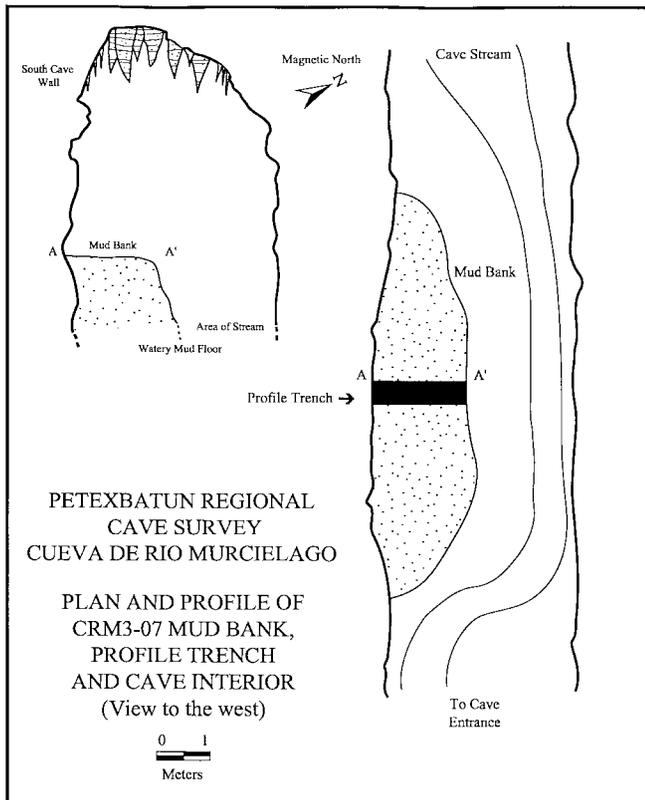
of sand and gravel. Our concern for this type of environment grew out of the investigation of the Cueva de Río Murciélago where the surface collection of a long section of river passage recovered a number of artifacts. After a heavy rain a project member reported seeing a large bifacially chipped blade on the surface which he marked with flagging tape. We were unable to return to the cave before another heavy rain by which time both the blade and the flagging tape had disappeared but a large jade hacha was found on the surface. With each rain, the water was apparently covering some objects and uncovering others. This raised questions about what percentage of artifacts were being recovered and how representative the surface assemblage was.

In 1993 an investigation of the riverine sands was conducted in the Cueva de Río Murciélago (Fig. 3). Two of four segments of the sandy tunnel were selected where a small stream ran along one side of the passage. In the first of these segments a trench 1 x 3 m was excavated to determine the nature of the deposit. It was found that artifacts were located in a 10 cm thick layer of sand which overlay a sterile base of mud. The trench yielded enough artifacts to suggest that a more controlled excavation was called for. The second segment of passage [CRM3-07] was selected because it contained not only sand and gravel but a large mud bank as well (Fig. 4). The sand from the entire passage, 12 m x 3.5 m, was excavated to the mud base and then washed through 4 mm mesh screen using river water. The mud bank was scrapped without finding a significant quantity of artifacts and was then trenched and profiled (Fig. 5).

The controlled excavation of the second tunnel segment using the same boundaries as the surface collection allows us to compare the two artifact assemblages and draw conclusions about the adequacy of our surface survey (Table 1). First, in considering ceramics, it should be noted that the surface survey found few ceramics in areas where there was flowing



**Figure 3. Computer line plot of the Cueva de Río Murciélago.**



**Figure 4. Plan and Profile of lot CRM3-07.**

water. Since the interpretation of the intensity of utilization of a particular area is, in some way, related to the quantity of artifacts recovered and since ceramics are the most common type of artifact, the lack of ceramics in these areas led one member of our team to argue that such areas were not heavily utilized. The systematic excavation of this section recovered over 1000 sherds where only two had been found on the surface. It must be recognized that these sherds tend to be small and the overwhelming number (932 of 1011) are too eroded to be identified. Nevertheless, the large quantity indicates higher levels of utilization than we would have been willing to suggest based on surface finds alone. It should also be noted that the ceramics recovered from excavation differed in an important respect from those on the surface. One Preclassic and 2 Early Classic sherds were identified where the surface produced only Late Classic material.

The surface collection from this area of the cave was notable for the recovery of a number of important non-ceramic artifacts including a slate mirror back with six pieces of hematite, a spindle whorl and two large bifacially chipped blades. The excavations recovered three additional pieces of hematite, four more spindle whorls, another blade and a jade hacha. In addition, the excavations recovered a number of artifacts not previously found including a worked bone spatula, a bone tube, a quantity of chert debitage and faunal remains. Even the smaller trench dug in the first passage segment

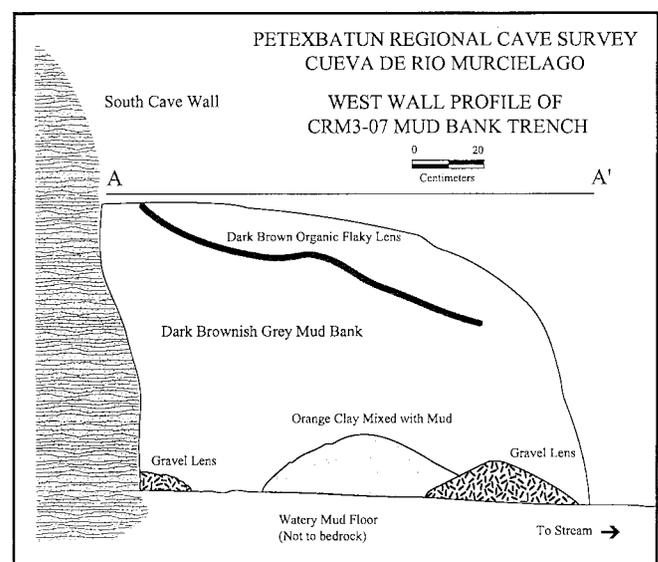
**Table 1. Ceramic Counts from Lot CRM3-07.**

| Context    | Lot #     | Sherd Count | Preclassic Slipped Ware |
|------------|-----------|-------------|-------------------------|
| Surface    | CRM3-07-1 | 2           | 0                       |
| Excavation | CRM3-07-2 | 1011        | 1                       |

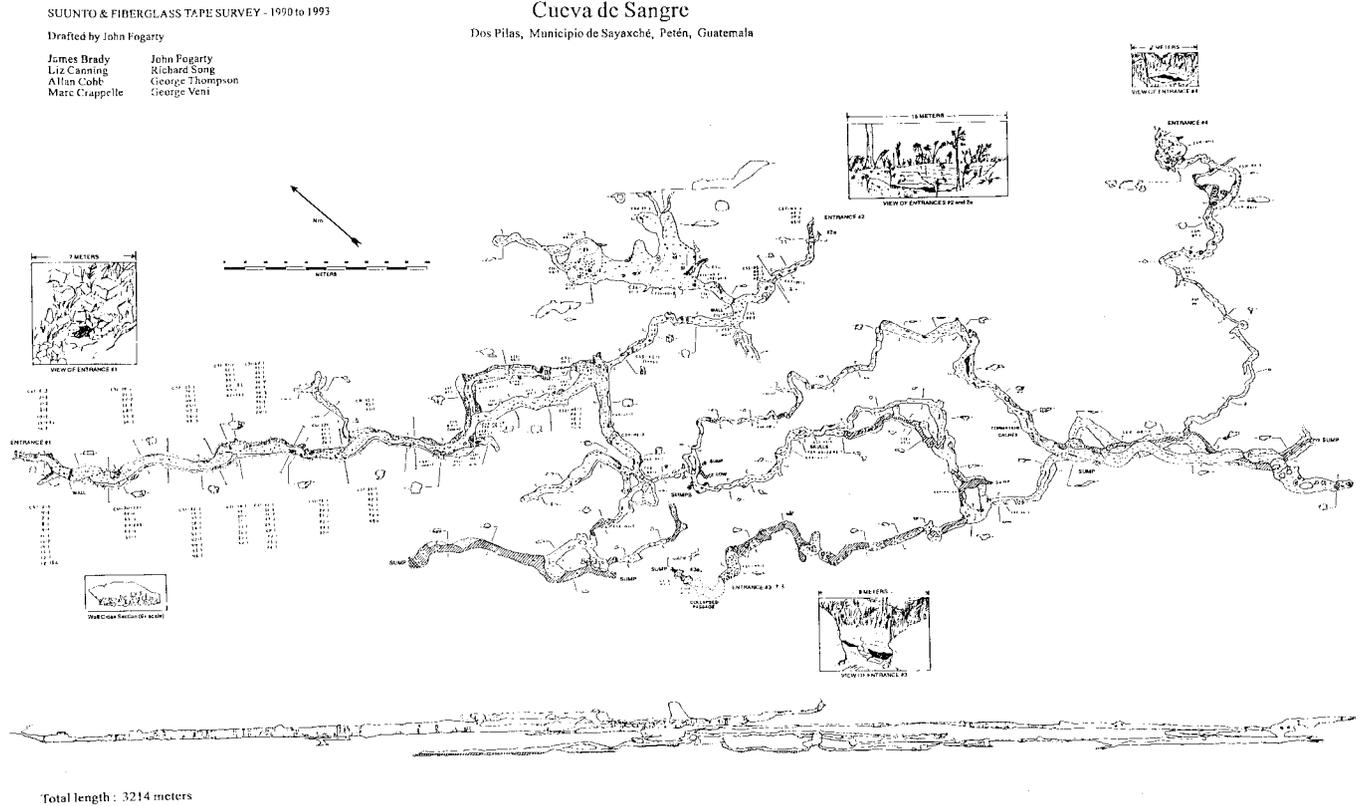
recorded impressive finds as compared to the surface survey. The surface collection recovered a jade bead, a jade hacha, and four bifacially chipped blades while the trench uncovered a second jade bead, a second jade hacha, 2 spindle whorls, 4 more bifacial blades and a worked bone spatula. Thus, the two excavations showed that high densities of artifacts were buried in areas where there were few surface indications of cultural activity. Even among the larger artifacts, the surface collection recovered no more than half the material and completely missed smaller items.

In situations which lack quickly flowing water layers of thick, impermeable mud form which are so plastic that they are difficult to excavate and impossible to screen. Several hundred pounds of the mud were brought to Guatemala City for laboratory testing. The initial experiments combined soaking the mud in water to soften it with various methods of wet screening. The mud's plastic consistency is a result of ion bonding between clay platelets making it impermeable to water (Van Horn & Murray, 1982) so these attempts were a resounding failure. It was concluded that it would be necessary to employ a chemical deflocculant to break the ion bond and dissolve the mud. Tests of an array of detergents and other reagents were carried out on the mud by chemical engineer Luis Greñas. Factors considered in the experiments were:

1. effectiveness of the agent,
2. time required for the reaction,
3. effects on the environment and artifacts,



**Figure 5. Profile of mud bank trenched in lot CRM3-07.**



**Figure 6. Map of the Cueva de Sangre.**

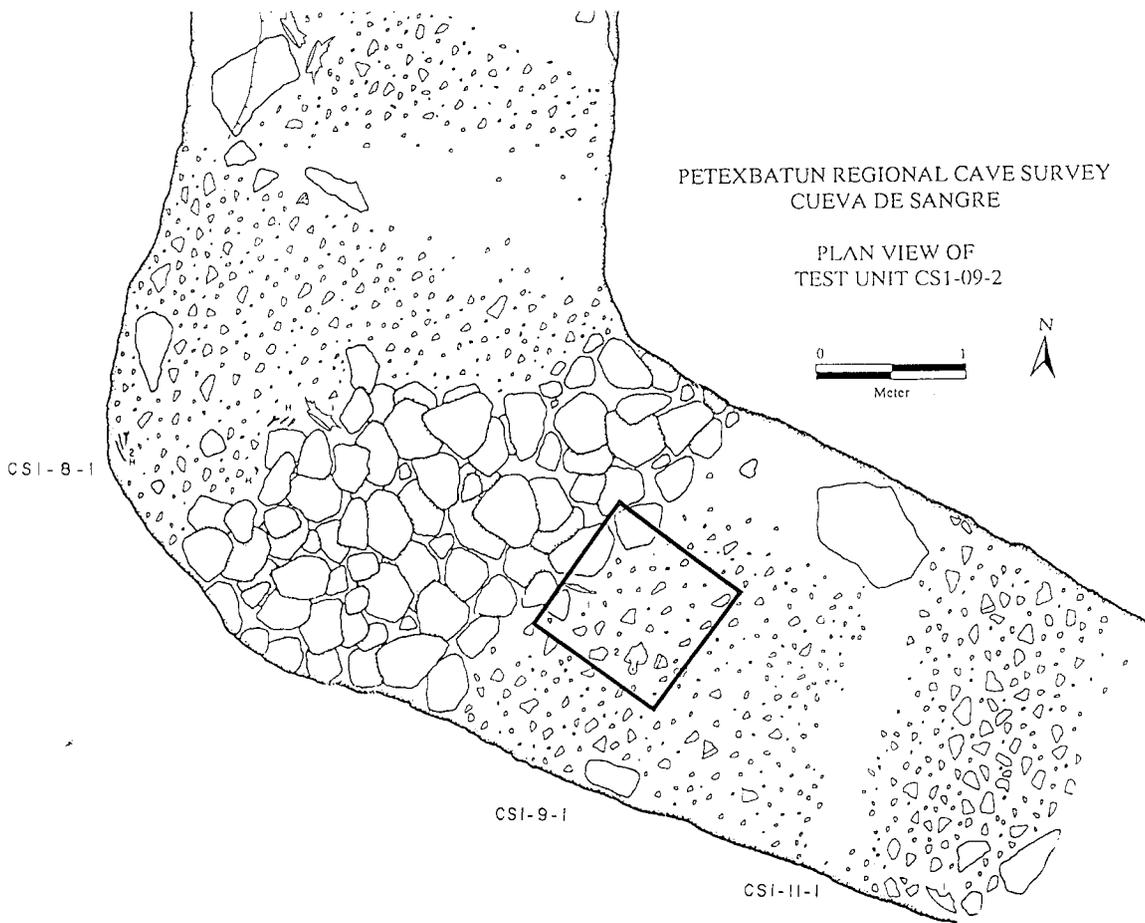
4. cost, and
5. ease of transport.

In weighing all factors, we concluded, as did Van Horn and Murray (1982), that industrial bicarbonate of soda would offer the best results. During the 1993 season field testing of the method was attempted. Problems were encountered because large amounts of water were needed when processing mud in quantity. After trying several arrangements, a workable system was developed. An entire level, 10-20 cm thick, of an excavation unit was removed, packaged in plastic bags and carried to the spring at the camp. The mud was then broken into smaller pieces, placed in plastic screens, and soaked in a tub containing a solution of bicarbonate of soda and water. After 20-30 minutes, the screen was removed from the solution, washed thoroughly in running water and returned to the tub. Three or four soakings were generally required to completely break down the mud. By rotating eight screens between five tubs, large amounts of mud could be processed, although the method is slow and time consuming in comparison to other forms of excavation.

While working out the details of the method, mud was excavated from a 1 x 1 m test pits in the cave closest to the camp, the Cueva de El Duende. Once the method was functioning, actual testing was carried out on the Cueva de Sangre where our most intensive investigation had occurred (Fig. 6). Over the first 400 m of the cave, huge quantities of artifacts

had been mapped and collected giving us good control over the density and distribution of surface artifacts in this area (Brady, 1990). There was a concern, however, over the inability to investigate the thin layer of mud which covered this entire section of passage.

Our test began with a 1x1 m test unit placed just behind a Maya dam (Fig. 7) where only a light scatter of sherds had been found in our surface collection [lot CS1-09-1]. The location was selected because it was close to the entrance but, at the same time, within the area where the carpet of artifacts had been encountered. The excavation quickly disclosed that the damming of the passage had resulted in larger quantities of silt being deposited here than elsewhere so arbitrary 10 cm levels were utilized [lots CS1-09-2 through CS1-09-6]. While remembering that the surface collection had covered a large area, it is instructive to compare the surface material with that recovered from excavation. Using raw ceramic counts, it is apparent that the deposition of silt had buried much of the cultural material obscuring most of the evidence of utilization (Table 2). It could be argued that this is not significant if the composition of the excavated assemblage does not differ radically from that recovered by surface collection. However, this is not the case. Three hundred twenty-one sherds, or over 40%, of the ceramics recovered in excavation consisted of Late Preclassic slipped ceramics, an important point considering that the surface collection for the entire cave produced only



**Figure 7. Location of test unit CS1-09-2 in relation to the Maya dam.**

105 Preclassic sherds, or less than 1%, in an assemblage of over 25,000. Thus, the results suggest that the mud buried a substantial early utilization of the cave which the surface collection failed to indicate.

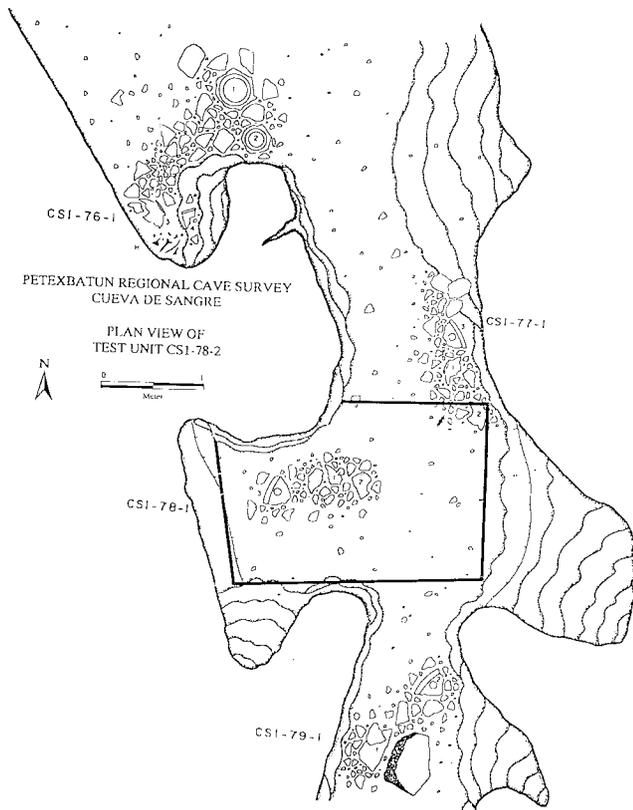
**Table 2. Ceramic Counts from Lot CS1-09.**

| Context               | Lot #    | Sherd Count | Preclassic Slipped Ware |
|-----------------------|----------|-------------|-------------------------|
| Surface               | CS1-09-1 | 30          | 0                       |
| Excavation            | CS1-09-2 | 142         | 43                      |
| Excavation            | CS1-09-3 | 77          | 32                      |
| Excavation            | CS1-09-4 | 382         | 159                     |
| Excavation            | CS1-09-5 | 121         | 77                      |
| Excavation            | CS1-09-6 | 15          | 10                      |
| TOTAL FROM EXCAVATION |          | 737         | 321                     |

Since the first test unit was placed near the entrance to the cave, a second unit [CS1-78-2] was excavated further down the passage close to the end of the area containing a high density of surface artifacts. This location was selected because it is within an enclosed chamber. This chamber is blocked on both ends by fallen formations which prevented artifactual material from entering or leaving due to water movement. The unit, 2.5

m long, spanned the width of the tunnel, about 4.0 m of which was covered with mud (Fig. 8). Since the maximum depth of the mud was about 10 cm, approximately 1 m<sup>3</sup> of mud was removed from the cave. Once again a comparison of the results of the excavation with that of the surface collection indicates that the soda process recovered far more sherds (Table 3). This is somewhat misleading because the ceramics from the surface were much larger and probably represent a similar sherd weight. Nevertheless, since so much was recovered from the surface, it was surprising to find the quantity that was hidden by the mud. The major difference between the two collections is in the quantity of Preclassic material recovered. A fair amount of Preclassic material was once again found by the soda process after the surface collection failed to recover a single sherd.

More interesting is a comparison of non-ceramic artifacts. Other than two large, bifacially chipped chert blades, the surface collection reported a near absence of non-ceramic material. Forty-two pieces of worked shell representing a variety of beads and decorative items were recovered by the soda process from an area where none had been previously reported. Thirty-seven pieces of worked bone, mostly needles, picks, spatulas and perforated animal teeth, came from an area which had produced only one piece of worked bone from the surface. Ten



**Figure 8. Location of test unit CS1-78-2.**

obsidian blades and two spindle whorls were also encountered in the mud. Human bone representing one or more individuals is another class of artifact reported for the first time from this lot. The soda process also accounted for 496 animal bones and unmodified fresh water shells. This is particularly impressive because only one bone had been recovered from this area previously, and the entire Cueva de Sangre surface faunal assemblage numbered only 440.

The use of chemical deflocculants and wet screening on cave mud has yielded important insights for our interpretation of cave material. In both excavation units, the method recovered large numbers of sherds from areas which had previously been collected. These results indicate that sherd density was several orders of magnitude greater than had been suspected. In sampling, most archaeologists would agree that 100% recovery of artifacts is not necessary as long as the sample is a faithful reflection of the whole. Our test excavations indicate that the surface collections do not closely reflect the entire sample. Furthermore, the excavations show the dynamic, almost imperfect relationship that can occur between surface and sub-surface regions and the problems of interpreting data (Sharer & Ashmore, 1987). Results indicate that preclassic sherds were seriously under-represented in surface collections and thus the early use of the caves was more intensive than suspected. These findings mirror those reported for our investigation of riverine sands.

**Table 3. Ceramic Counts from Lot CS1-78.**

| Context    | Lot #    | Sherd Count | Preclassic Slipped Ware |
|------------|----------|-------------|-------------------------|
| Surface    | CS1-78-1 | 261         | 0                       |
| Excavation | CS1-78-2 | 1323        | 28                      |

More importantly there is little overlap between the artifact assemblages recovered by the two methods. This point has important ramifications for the reconstruction of cave ritual. Obsidian blades and bone needles are generally believed to have been used in rites of auto-sacrifice. If the results of the soda process are correct in indicating that these artifacts are under-represented by a factor of 10 or more, then the importance of auto-sacrifice in cave ritual grows enormously. It has been proposed (Brady et al., 1992) that the presence of a weaving kit in caves, represented by the presence of spindle whorls, bone picks, and perhaps needles, is related to rites directed at Ixchel, the patroness of weaving. The soda process recovered several spindle whorls, once again suggesting that this ritual was more important than previously suspected. The human osteological analysis of the cave material indicates that six times as many individuals were recovered as reported from surface excavation project. It is likely that this figure may be on the low side. The ritual context suggests that the individuals may have been sacrificial victims so the importance of human sacrifice in Maya society may need to be re-evaluated. The soda process has certainly produced far more evidence for animal sacrifice than our previous work. In general, this new technique of investigation has revealed a greater intensity of utilization in buried areas. Additionally, it has produced an array of small artifacts that reflect a much broader range of activities than suggested by surface survey alone. Once again these results follow the general pattern established in the riverine sands.

While the discoveries made in these previously ignored deposits are important for our reconstruction of Maya ritual, the methods have larger implications. In a recent paper (Brady, 1994) the cave artifact assemblage at Dos Pilas was compared with the assemblage recovered from surface excavation at the same site. Despite the fact that the cave project is far smaller and has worked fewer seasons, the cave artifacts make up between 20% to more than 50% in many categories of the overall assemblage. Yet interestingly, the initial application of these methods in the Cueva de Río Murciélago and the Cueva de Sangre suggests that the quantities of bone, shell, obsidian and other artifacts in the cave are staggering and that these items are grossly under-represented in the cave artifact assemblage. This suggests that a significant portion of Maya economy was being expended on these rituals. Thus, our data is providing the first quantitative data on the size of Maya society's allocation for its ritual fund.

Maya cave archaeology is in its infancy. As a specialized subfield it is still struggling to develop its field methodology and to determine the scope of an adequate study. Until our

experiments last season there was little awareness of the possible shortcomings imposed by archaeology's inability to deal with buried, water-logged deposits. As we continue to apply this method we hope to collect data on area to area and cave to cave variation and to offer a more systematic assessment of the nature of these buried deposits. Finally, our preliminary results already suggest that the methods will change our interpretation of site history and function.

#### ACKNOWLEDGEMENTS

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# LAS RUINAS CAVE, CERRO RABON, OAXACA, MEXICO: A MAZATEC POSTCLASSIC FUNERARY AND RITUAL SITE

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*Some 48 different caves and rock shelters were surveyed in a karstic region of the state of Oaxaca, Mexico. A brief discussion of the morphological variation encountered and methods of underground archaeological survey is presented. The cave of Las Ruinas has been chosen for detailed examination in this paper. This cave best illustrates a typology for the considerable number and variety of funerary and other structures documented in the cave; and, different aspects of the relationship between human society and the subterranean environment. The pottery found in the archaeological survey has allowed relative chronological dating of all 48 studied sites. All belong to the Postclassic Period (900-1521 A.D.). The pottery also facilitated an evaluation of external contacts and influences on this region.*

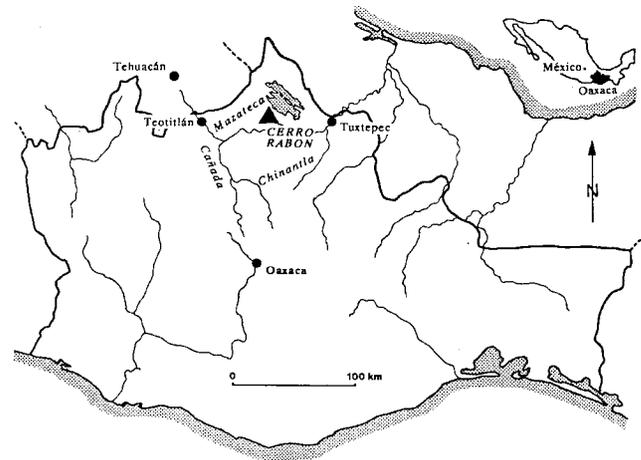
In 1971, the discovery of a cave beneath the Sun Pyramid at Teotihuacan, Mexico (Heyden, 1975), shed new light on the role of the subterranean world in Mesoamerican civilizations. Subsequent discoveries in Mayan areas have confirmed the role of caves as sacred sites, with an increasing number being found beneath later major temple structures, such as the group in the Petexbatun region of eastern Guatemala (Brady, 1991). This survey has been carried out in a karstic region of Mexico situated far from all major ancient ceremonial and economic centers, in the hope of investigating the importance of the subterranean world in Mesoamerican culture, and especially that of the Mazatecs. Recent discoveries made by this and other studies in the Cerro Rabon plateau have revealed evidence for previously unknown important ritual and funerary activities.

## GEOGRAPHICAL SETTING

The Cerro Rabon is situated 300 km south-east of Mexico D.F., in the Sierra Mazateca (Fig. 1), bordered by the states of Oaxaca, Puebla and Veracruz. It is part of an important range of mountains extending between the cities of Orizaba and Oaxaca. We worked successively in two areas (Fig. 2), one located at San Jose Tenango in a steep valley between 700 to 900 m, the other on a central plateau in San Martin Caballero at a higher altitude (1300-1700 m).

## MORPHOLOGY AND METHODS

Among the caves inspected, 48 archaeological sites have been found and documented. The caves are of various dimensions and morphology ranging from a simple rock shelter to a big vertical pit. The small caves, however, and some large horizontal systems were favored by the ancient Mazatecs. The Cerro Rabon plateau shows marked limestone relief and constitutes a fully karsified block through which rainwaters swiftly infiltrate large surfaces, without ever being able to form a



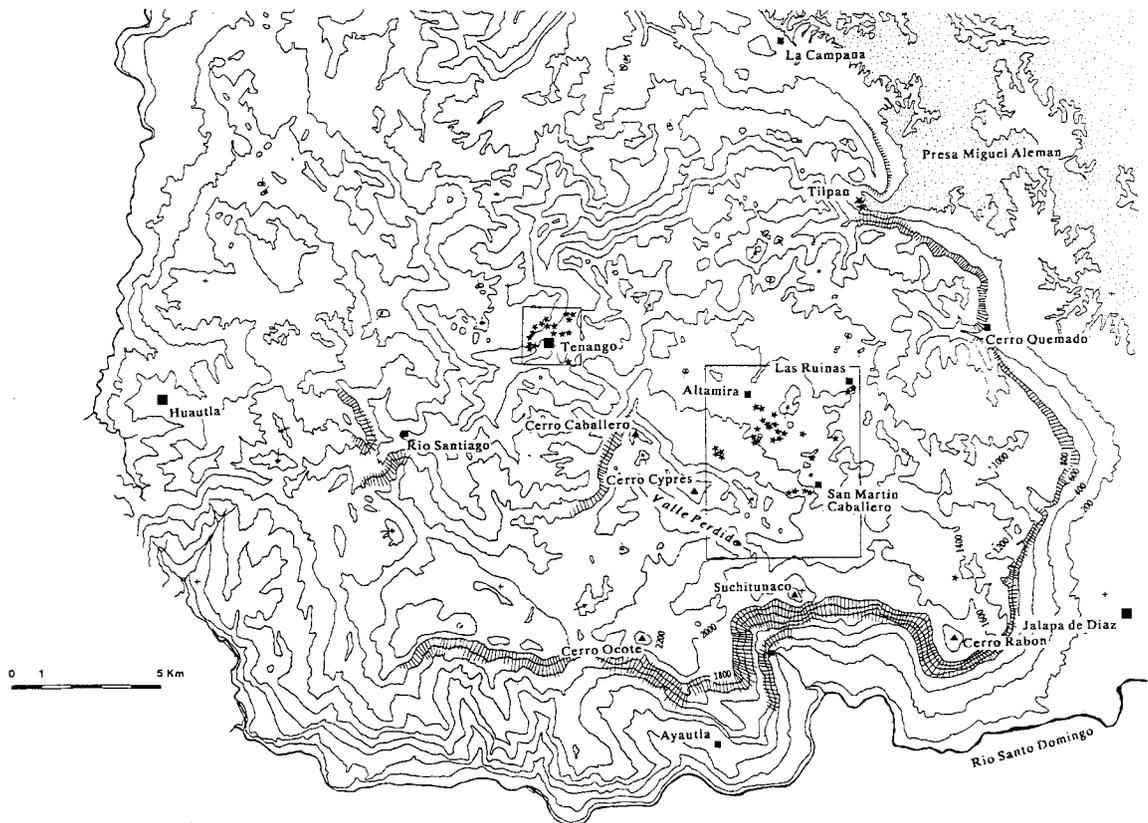
**Figure 1. Location of the Cerro Rabon in the state of Oaxaca and in Mexico.**

river. Huge dolines are the characteristic features of this landscape. The particularly complex terrain covered with a thick rain forest makes the locating of caves difficult. In the caves, on the other hand, most of the remains are clearly visible, such as the improvement of certain key passages (i.e., stairs). Therefore, a good knowledge of the underground environment is essential. The origin, functioning and morphology of the cave (shape of the galleries, possibilities of continuation, difficulties brought about by the obstacles, age of the sediments, the collapsing of the walls, etc.) all follow physical laws. One must know these laws in order to spot traces of human activity more easily, and to distinguish them from natural phenomena.

## UNDERGROUND CONSTRUCTION AND IMPROVEMENTS

The underground constructions and improvements found at the Cerro Rabon are related to different uses: funerary prac-

**Figure 1.**  
The two areas surveyed (boxes), at San José Tenango in a steep valley and on a central plateau in San Martín Caballero; (\*) archaeological caves documented.



tices (tombs), altars, a "lithophone", terraces and water collection, either for ritual purposes or domestic use. Walled-up passage entries have also been observed in many caves.

Las Ruinas Cave (Fig. 3) has been chosen here for a more detailed examination. This vast cavity is located on the plateau at an altitude of nearly 1100 m. It is a complex cave reaching to nearly 500 m in length and down to a maximum depth of 39 m. It opens at the side of a huge doline, very close to the village of Las Ruinas. The result of this situation has been the partial destruction and looting of some structures. The entrance constitutes a shaft with vertical walls. Without too much difficulty, however, it may be traversed to reach the sub-horizontal gallery, where the archaeological remains can be found. Three different areas can be distinguished from the morphological and archaeological points of view: the entrance, the Necropolis gallery, and the Lithophone gallery.

The main characteristic of the entrance is the natural lighting. A stepped ramp of 40 m in length with a slope of 20 m, allows passage from the bottom of the doline to the entries of the two galleries. Big blocks have been laid down to create more or less even steps. The drain-pipes coming down from the vault supply different water points, whose frequent use is attested by the many jar sherds on the ground.

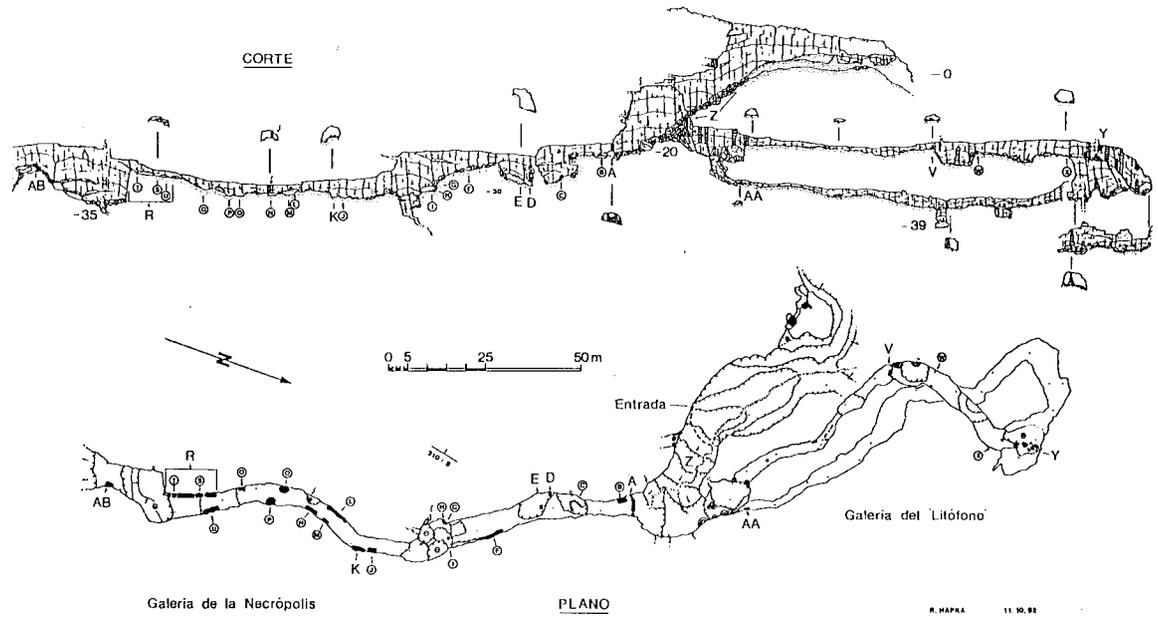
The Necropolis gallery leads southwards 125 m, and has an average width of 5 m. Four imposing stalagmites separate this gallery from the entrance room. The space in between the stalagmites are filled by a wall (A) made of large blocks and dry stones. The construction of the wall was intended to prevent

access to a burial chamber containing groups of funerary structures (B to U and AB). The thirty tombs of the Necropolis have allowed us to draw up an initial typology of funerary architecture. The tombs can be separated into four main groups, according to the number of natural walls integrated into the construction.

To the north, the ritual function of the Lithophone gallery seems to have been of the highest importance, given the presence of an altar (V) and of a lithophone (Y). The altar (Fig. 4) is made up of two stalagmites, each half a meter high, surrounded by a base of slabs. Two concentrations of charcoal indicate hearth areas. Thirty meters or so beyond the altar one finds the lithophone (Fig. 5). It is a group of stalagmites, stalactites, columns, and drapery of various colors and shapes, among which about ten have percussion wear on one or several sides. Other much smaller stalagmites are scattered broken on the ground. Using one of these to strike the speleothems of the lithophone produces particularly harmonious sounds, and their use as musical instruments is quite conceivable. It is interesting to point out that the acoustics in and between the lithophone room and the altar room are excellent. The resonance creates a phonic space among these different structures: it is thus perfectly imaginable that people near the altar would have received the full effect of beating on these "stone drums", a term derived from a Maya glyph translation (MacLeod & Puleston, 1978).

Except for some domestic activity which took place in the entry room, remains found in Las Ruinas Cave are of a funer-

**Figure 3.**  
Profile and plan  
of the cave of  
Las Ruinas;  
locating of the  
archaeological  
structures.



ary and ritual nature. Construction shows careful planning in the organization of space. Only after a thorough visit did the ancient Mazatecs decide where to place the different constructions. In the case of the necropolis, they decided upon a large-sized gallery, allowing the fairly simple transporting of the mortal remains; whereas, the place chosen for celebrating the cults in the Lithophone gallery is accessible only after a tiresome crawl.

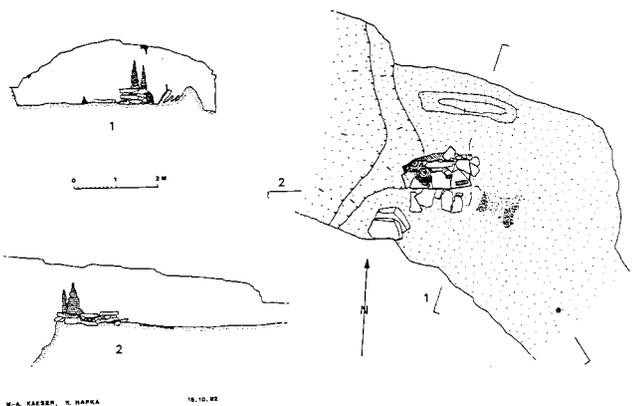
**MATERIAL AND DATING**

The pottery found in the archaeological survey has allowed relative chronological dating of all 48 sites studied, all belonging to the Postclassic Period (750-1521 A.D.). In Las Ruinas, four pottery groups have been identified. The same groups were found in the other survey sites:

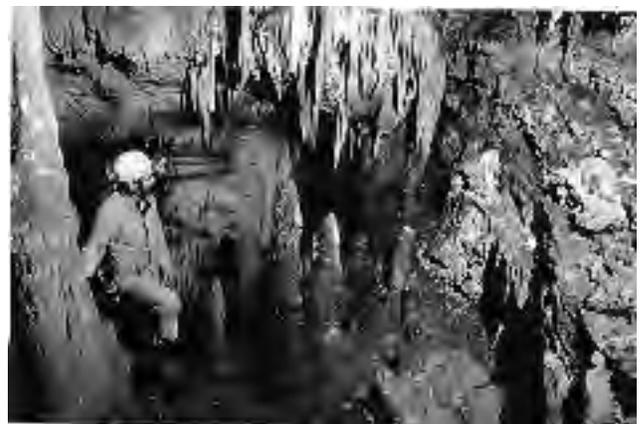
1. Coarse orange-brown ceramic (Fig. 6); it is mainly composed of big utilitarian containers, such as jars, pots and

- pitchers.
- 2. Ceramics of a fine grey clay, common to several regions of Oaxaca during the Postclassic Period and apparently produced in different places during that epoch. Forms include hemispherical and tripod bowls (Fig. 7).
- 3. Finely painted ceramic, representing a type specific to the Sierra Mazateca.
- 4. Richly decorated ceramic, including Incised Teotitlan ware, coming from the Tehuacan Valley (MacNeish et al., 1970: 204-205) and Chinantla polychrome.

The first three groups are of local production, whereas the fourth one is imported. These imported ceramics give evidence of constant contacts with the Chinantla and Tehuacan outlying areas during the Postclassic Period, as well as those



**Figure 4.** Plan and profile of the altar of Las Ruinas.



**Figure 5.** The lithophone, a group of stalagmites, stalagmites, columns and drapery, among which about ten concretions bear traces of percussion. Photo courtesy of Urs Widmer.



**Figure 6. Coarse orange-brown ceramic. Photo courtesy of Ernie Garza.**

between the Tenango Valley and the Cerro Rabon plateau. To determine a more precise regional chronology of the Postclassic Period is not possible until an excavation with a good stratigraphic sequence takes place.

#### CONCLUSION

The role of caves has been studied and discussed in Mesoamerica mainly within the context of the Maya culture. Looking at the Mazatec area in particular, we notice that, besides the domestic function confined to collecting water, the Mazatec culture of the Postclassic Period is characterized by the use of the underground world as much in the funerary as in the ritual contexts. In research at the present time, the Sierra Mazateca, an outlying area isolated from the capitals, has not revealed vast ritual architectural centers (like pyramids). One can suppose that the caves probably played the ritual role. These different elements support the existence of a Mesoamerican tradition exceeding well beyond the Maya sphere. It is linked to common beliefs about caves and to very



**Figure 7. Tripod bowl of a fine grey ceramic. Photo courtesy of Ernie Garza.**

strong symbolism present in the whole of Mesoamerica (Carot, 1989).

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# CUEVA CHEVE TABLET

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*A turquoise mosaic tablet was discovered within the archaeological site in Chamber 1 of the cave, Cueva Cheve, in the Cuicatec region of Oaxaca, Mexico, in March, 1989. Its four sections were found stacked, two fragments facing up and two facing down, in a space under breakdown rocks in the large entrance chamber. The tablet dates to the Late Postclassic Period (1250-1500 AD). The tablet has now been partially restored from the pieces retrieved. One quadrant pattern includes a battle scene with winners and losers. Other artifacts within the cave help explain the ceremonial context of the tablet, including obsidian blades, jade beads, a wooden mask, in situ vessels, and a platform containing buried human remains built on top of giant spalled ceiling blocks of rock. The cave was also likely used from the Classic Period (250-750 AD), and there is evidence that the cave continues to be used ceremonially today by the local Cuicatecs.*

*Although initially studied using methods that limit site disturbance, the tablet was removed and the three archaeological chambers in Cueva Cheve were subsequently excavated in the spring of 1990 and 1991. The excavation was necessary as there was an increase in visitors to the cave due to Cueva Cheve having become well known among speleologists at that time as being the deepest cave in the Western Hemisphere. Further, the tablet needed to be climate stabilized at the Oaxacan Museum to prevent further damage to its wood resulting from the cave's humidity.*

Archaeological investigations in 1988, 1989, 1990, and 1991 revealed Cueva Cheve to have likely functioned as a ritual site. The cave was used during the Classic Period (250-750 A.D.) and Late Postclassic (1250-1500 A.D.) based on cross dating of cave ceramics to the Monte Alban ceramic sequence (Caso et al., 1967). One of the two entrance chambers is still being used ritually by the Cuicatec people who live in the region.

A Late Postclassic mosaic was discovered within the cave, and has been designated the Cueva Cheve Tablet. It has been removed from the cave ritual context, and is now partially restored. Its four assembled sections measure 43 cm by 40 cm by 1.5 cm thick, making it perhaps the largest Pre-Columbian mosaic from Mesoamerica (Fig. 1 and front cover).

## SETTING

Cueva Cheve is located in a mountainous area twenty kilometers northeast from the town of Conception Papalo, northern Oaxaca, Mexico, in the Cuicatec region (Fig. 2). Although this is a tropical region, the elevation of the cave is about 3,000 m, so the area's vegetation is alpine. Winter ice storms may occur during the dry season months.

The cave entrance is in a large valley sinkhole. The south half of the sinkhole is metamorphic rock and the north half, where the cave is located, is limestone. A stream enters the sinkhole from the south as a 7 m waterfall and flows along the northeast cave wall into the cavern's depths. Cueva Cheve is one of the deepest caves in the Western Hemisphere, over

1,000 m in depth (Oliphant & Pistole 1994), but only a small portion of the cave contains cultural material.

## ARCHAEOLOGICAL BACKGROUND

A team of National Speleological Society cavers led by Carol Vesely and Bill Farr began exploring Cueva Cheve for its world class depth potential. In December, 1987, cultural material was noted by the speleologists. On January 24 and 25, 1988, the Cheve Archaeological Project (CAP) explored, recorded and mapped portions of the cave. CAP studied the cave using *preservation methods*, in which nothing was removed or even touched. All artifacts were surveyed, photographed, measured and recorded in place (for a discussion of methods see Steele, 1987). The initial report to the Instituto Nacional Antropología e Historia (INAH), listed the cave as *Estrella* to protect it from looting (Snavely et al., 1988). For the purpose of recording, the archaeological chambers of the cave were labeled Chambers 1 - 4. (Fig. 3).

The entrance to the cave (Chamber 1) is naturally lighted and accessible, measuring 50 m wide at the entrance drip line and 30 m at its maximum height. The large passage extended 200 m back into the cave to the northeast cave wall. There is evidence that some of the archaeological material in this room has been disturbed by looters prior to 1987.

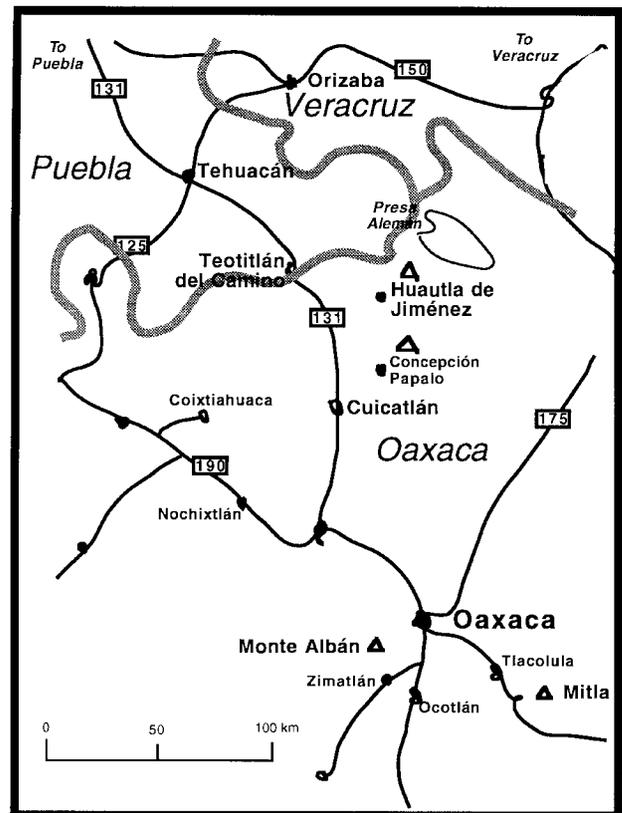
A rectangular stone platform (4 m x 10 m) was constructed towards the center of the chamber 40 m down a rocky slope from the entrance. Several roof spalls were incorporated in the platform by filling in gaps and leveling the gaps with smaller

**Figure 1.**  
The assembled Cueva Cheve Tablet.  
Photo courtesy of Ernesto González Licón.

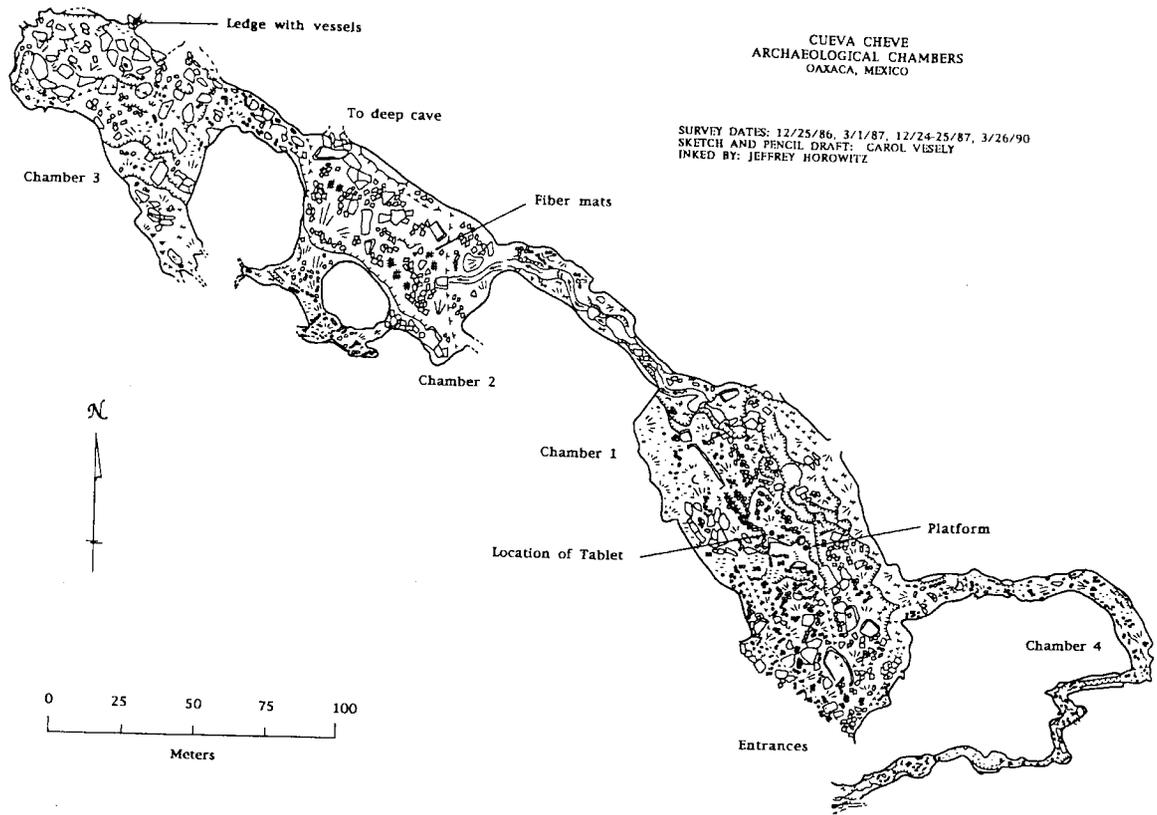


stones. Wooden beams had roofed the platform, although water damage has made the wooden structure almost unrecognizable. Only 30 cm remains of one upright beam located on the platforms' southeast corner. The beams were finished on the edges, a few pieces of turquoise remain in place suggesting a mosaic design. A wooden mask of the upper half of a face, or perhaps broken with the lower section missing, was found under a rock to the south of the platform. Human remains, obsidian blades and jade beads in a variety of shapes and sizes were found on and around the platform. When similar archaeological evidence is found within caves in Oaxaca, it is thought to represent the performance of rituals. Two other Oaxacan ceremonial caves with human remains, obsidian blades and jade beads are in the Mazatec region, Blade Cave (Steele, 1987) and Cueva de Tenango (Winter, 1984). The rituals in these caves possibly were directed toward rain-related deities. This belief is based partially on archaeological and ethnographic information from Oaxaca (Steele, 1997) and the Maya region (for a survey of Maya ritual cave use see Brady, 1989).

The stream entering Chamber 1 from the surface continues a course through Chamber 2. Along the bank, fiber mats and scattered ceramic sherds were found. The sherds may be compared to the Monte Alban sequence (Caso et al., 1967) and are representative of the Late Postclassic Period. On the walls above the stream bank, a bright red pigment is painted in a few round splotches. One red circle has been painted around the entry to a dead end crawl space in a wall in Chamber 2. The cave then bifurcates. One passage plunges with the stream to deeper portions of the cave. A second passage, however, leads from the stream bank to Chamber 3.



**Figure 2. Proximity Map.**



**Figure 3.**  
Cueva Cheve  
map showing  
the four archae-  
ological cham-  
bers

In Chamber 3, there is a squeeze marked by red pigment which leads to a ledge (1.5 m x 2 m) just large enough to accommodate two or three people. This small ledge is at the edge of a 30 m sheer drop to the descending stream passage. Splotches of red pigment were painted on the ledge wall. A curious protrusion on the north wall is outlined in red and has the size and features of a human face. This face seems to have been painted to look upon seven *in situ* vessels sitting below it on the ledge next to the south wall. One vessel is a cylindrical, tripod, white alabaster bowl. The vessel is splashed with the same red pigment as the chamber walls (Fig. 4). Another vessel is a black ceramic bowl with a lid in the form of a bird effigy knob. Each of the seven vessels is intact. Chamber 3's vessels help date this portion of the site to the Classic Period. The placement of the Chamber 3 vessels on the ledge far from the light of the entrance represents the deepest pre-Hispanic exploration in the cave. The Chamber 3 ledge could have been viewed as the entry to the dark underworld, perhaps similar to what the Maya called Xibalbá (MacLeod & Puleston, 1978).

Chamber 4 in Cueva Cheve is being used today for rituals by the local Cuicatec population. Current rituals include the use of chicken eggs, torches, centavo coins, pieces of newspaper, red yarn which overlays a list of people's names, and chicken bones which are very prominent throughout the passage. This chamber was photographed and documented, but left undisturbed by the archaeologists. Contemporary ritualistic use in Chamber 4 of Cueva Cheve may serve as an ethno-

graphic basis for a pre-Hispanic ceremonial interpretation of the archaeological evidence. Elsewhere in the Cuicatec region, three human sacrificial knives from the Late Postclassic Period were found stored in a cave and, also, ceremonially used by modern Cuicatec people in blood sacrifices of chickens and turkeys (Holland & Weitlaner, 1960).



**Figure 4.** The alabaster vessel has been smeared with red pigment. Photo courtesy of Brian Steele.

## CUEVA CHEVE TABLET

Ralph Snavely and Adrian Garcia returned with the speleologists in March, 1989. As the archaeologists were continuing the work of documenting artifacts within arbitrarily-delineated zones, Ralph Snavely discovered the tablet in Chamber 1. In a cavity beneath large breakdown blocks he saw two sets of two boards next to each other on a ledge. He could not see them well, however, because of the lack of head room. By holding a mirror above the boards, he saw turquoise mosaic pieces. The tablet was not touched or moved, but Snavely could, nevertheless, see evidence of deterioration. An arrangement was made to salvage and restore the tablet at the Oaxaca Regional Museum of Instituto Nacional Antropología e Historia.

In 1990, the tablet was removed to prevent further humidity damage. Assisting CAP in this project were Dr. Marcus Winter, Oaxacan archaeologist for INAH, Ernesto González Licón, then Director of the Regional Office of INAH, and his wife, Lourdes Marquez Morfín, a physical anthropologist.

The Cueva Cheve tablet is constructed of finely micro-carved turquoise inlaid on two wooden boards, each broken in two pieces. The four matching boards are approximately the same size (43 cm by 20 cm by 1.5 cm thick). Each piece of inlay is a carved form, averaging one half centimeter. All thirty figures are composed of more than one carved inlay piece. Each arm, leg, face, headdress and weapon is a separate and accurate carving. Using different tones of turquoise, the clear blue figures are arranged in codex-type scenes on a darker background similar to the style employed by the Mixtecs (Licón & Morfín 1994). Various other stones are used in lesser quantity, including what appear to be coral and jade from a visual inspection.

The upper left quadrant of the tablet is a battle scene between warriors with eagle, jaguar or alligator crests on their helmet-like headdresses, and people without them (Fig. 5).



**Figure 5. The upper left quadrant of the tablet showing the battle scene, photographed as it was removed from the ledge. Photo courtesy of Bill Steele.**

Men face each other in fighting stances with upraised arms holding weapons such as shields, knives, clubs and ropes (Fig. 6). One warrior wearing a jaguar headdress holds a captive man by his hair (Fig. 7). A rope around the neck holds another prisoner wearing a feathered headdress (Fig. 8).

On the right side of this quadrant, there is a single dominant figure sitting on a throne or litter, with rays over his head. He is clearly watching the battle and commenting (Fig. 9). One other speaking figure is a prominent warrior with an eagle crest on his helmet (Fig. 10).

The lower left quadrant displays a partially deteriorated circular design with hanging adornments. Beneath this is a ball court with ten disks below it (Fig. 11). Perhaps the disks are numeral dots associated with the head of a snake affixed to it, and could be read as 10 Snake: a day date (Henry Munn, personal communication, 1995).

The two right quadrants of the tablet were badly water damaged. All were wrapped in plastic and packaged in cotton, inside cardboard boxes. No chemicals were required to remove the artifacts. An orange Late Postclassic ceramic vessel containing jade beads was found next to the tablet and was also removed to the museum (Fig. 12).

## EXCAVATION DISCUSSION

Although the tablet was taken to the Oaxaca Regional Museum, all other artifacts, in particular the Chamber 3 *in situ* vessels, remained in the cave. The decision was made to leave the vessels in place until a contextual grotto-like setting could be arranged for them at the museum. The next spring of 1991, however, the decision was reversed. Cueva Cheve was receiving increased foot traffic due to increased notoriety as the deepest cave in the Western Hemisphere. The Chamber 3 vessels were removed and an excavation was conducted with the help of the speleologists and a team from INAH.

More than 80 secondary burials were excavated from the platform in Chamber 1. The human remains had been carried to the cave and buried in a group ceremony. Disarticulated skeletons were placed in recesses between the rocks formed by breakdown boulders in the platform. Rocks were then placed to cover the bones, keeping the platform somewhat level. They were not entombed in a recognizable pattern (for a discussion in Spanish see Licón & Morfín, 1994).

## CONCLUSIONS

In March, 1990, the Cueva Cheve tablet was salvaged from Chamber 1 due to its imminent destruction by the cave's damp environment. The tablet is believed to date to the Late Postclassic (1250-1500 A.D.) because vessels from that chamber belong to that part of the ceramic sequence. The codex style occurred among many linguistic and cultural groups, so it may not necessarily be valid to attribute the tablets' creation to the Mixtecs. The cave's location might imply that they had belonged to the Cuicatecs. Possibly, pilgrims brought and left



Figure 6. The warrior with an alligator helmet holds a rope and shield

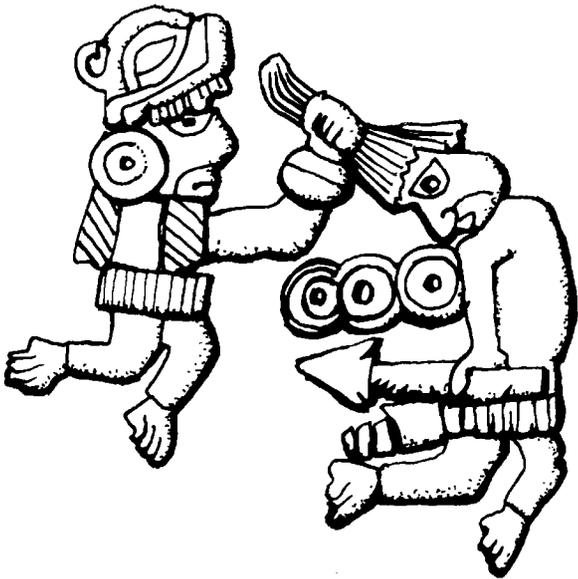


Figure 7. The warrior with a jaguar helmet holds a captive man by his long hair.

the tablet there because no urban centers have been found nearby.

The tablet appears to record an important battle scene observed by a lord or deity. This individual may be in a conversation with a warrior on the victorious side involved in the battle scene. Similarly equipped warriors are overcoming less well elaborately outfitted warriors, taking them captive, tying ropes and subjugating them to their knees. The victorious warriors wear headdresses in the form of eagles, jaguars and alligators;



Figure 8. A prisoner wearing a full feathered headdress is guarded by a warrior who holds him with a rope. The face of the prisoner has not been recovered.

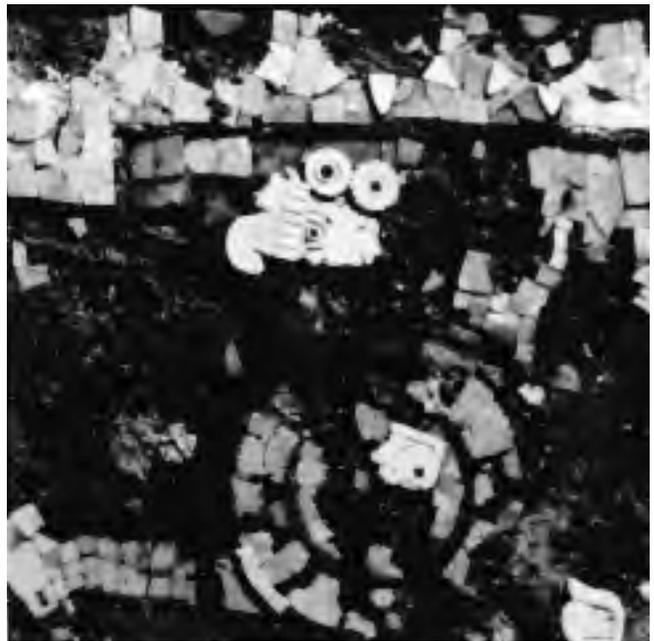


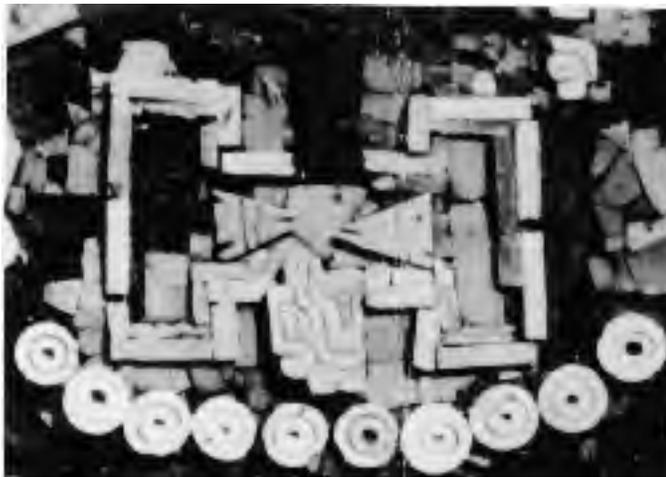
Figure 9. A lord or deity sits above the battle with rays over his head and spears.

perhaps representing warrior classes. The opposing army's uniform is more primitive. One prisoner wears a feathered headdress, a few others wear a couple of feathers in their hair and some wear no feathers at all. Perhaps the battle is documenting the military conquest giving the priests use of the cave for organized state rituals.

Cueva Cheve appears to have had a ceremonial function. The grand platform scattered with obsidian blades and jade beads in Chamber 1 further suggests that the cave passage was not limited to cemetery use. Judging from the size of the platform alone, some ceremonies may have been public events. We do not know what rituals were performed, but there is similarity to evidence for rain deity rituals such as the ancient Mazatecs and Maya are thought to have conducted. The tablet



**Figure 10.** A prominent warrior with an eagle crest on his helmet speaks.



**Figure 11.** A ball court with a head of a snake affixed to it. There are ten disks below it.

may have had some other use originally but was left secondarily as an offering. It was deliberately hidden.

Earlier, during Classic times, people had ventured deep into the dark, inner section of the cave and left vessels where they may have believed they were in touch with their concept of the underworld. Today, Cueva Cheve is used ceremonially by the local Cuicatecs; although we have never seen the rituals enacted, only the remains of the activity.

The documentation of the archaeological evidence in Cueva Cheve, including the recovery and restoration of the tablet is one of the important contributions of CAP. Constant care by the NSS leaders of the deep exploration team, including directing foot traffic away from the archaeological zones, enabled Cueva Cheve to be studied as a preservation site for

several years. Proper reporting of this archaeological encounter has made possible the cooperative relationship between project members and the government authorities.

#### ACKNOWLEDGMENTS

The authors appreciate the guidance of Marcus Winter and Patty Jo Watson throughout this project. Thoughtful opinions from James E. Brady, Barbara MacLeod and Henry Munn were helpful. We thank Adrian Garcia for his expert help in the field. We are grateful to the speleologists, especially Don Coons, Carol Vesely, Bill Farr, Peter Sprouse and Susie Lasko who discovered that Cueva Cheve contained archaeological evidence. Our admiration goes to those cavers who continue to explore the passages of Cueva Cheve, notably Matt Oliphant and Nancy Pistole. A contribution from Mr. O. Scott Petty was instrumental to successful field expeditions, and we are thankful for his support. We appreciate Judy Weill for providing the regional inset map, Jeffrey Horowitz is thanked for providing the Cueva Cheve map. We are grateful to John Labadie for the illustrations. Appreciation is extended to Louise Hose and Brian Steele who helped with photography and the removal of the vessels from Chamber 3. We thank Bill Steele for his help in removing the tablet and for the photograph of the upper left quadrant of the tablet. Ernesto González Licón in furnishing the photograph of the assembled tablet, the Mexican team which helped us in the field and in the restoration of the tablet, and the continuing cooperation of Instituto Nacional de Antropología e Historia are appreciated.



**Figure 12.** A Late Postclassic orange ceramic vessel containing jade beads was left next to the tablet. Photo courtesy of Bill Steele.

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# REGIONAL VARIATION IN MAYA CAVE ART

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*The Maya area is well endowed with cave art, one of the rarest art forms known in the world. Over 25 caves with paintings and handprints have been documented in a recent survey by the author, and an undetermined additional number contain carvings. In this paper, I outline regional differences in the corpus. For example, cave painting in the Puuc area of western Yucatan has a relatively coherent style and subject matter, distinct from contemporary cave painting in the Southern Maya Lowlands. Cave painting in southern Belize is stylistically heterogeneous. I consider the issue of stylistic variation in Maya cave art from a functional and chronological perspective.*

In this paper, I will focus on regional variation in Maya cave art from the Puuc Hills of western Yucatan and a zone encompassing southern Belize and southeast Peten in Guatemala. The cave art under discussion is broadly divided into two groups: pigment-based and sculpted. Beginning with these typological distinctions, I will explore differences in the style and subject matter of cave art from the two regions. Differences may be the result of a number of factors, including functional, climatic, and chronological variation and the relative strength of ties to the elite segment of Maya society at local surface sites.

Any seasoned Maya archaeologist knows that, along with temples, palaces, and tombs, caves are rich repositories of ancient Maya material culture. And in terms of preserving wooden objects dating from the more remote archaeological epochs (e.g., Velázquez, 1980), caves are far and away superior. Caves also have significant ethnographic import. That the Maya continue to use them in some of the same ways as their forebears is a testimony to the persistence of Precolumbian culture into the present day, even in the face of unrelenting modernization. This persistence not only colors our view of contemporary Maya, but also sheds light on ancient cave practices (Thompson, 1959, 1975) in ways that are beyond the reach of ordinary archaeology.

Caves have played a role in Maya religious life at least since 1000 B.C. as indicated by ceramic artifacts found in caves as geographically distant as Loltun Cave in Yucatan (González-Licón, 1986) and Petroglyph Cave in Belize (Reents-Budet and MacLeod, 1986; Stone, 1992). The Late Classic (ca. 600-850 A.D.) saw an unparalleled expansion of the cave ritual complex in the Maya area, no doubt a consequence of explosive population growth which ultimately contributed to the downfall of Classic Maya civilization. Although Pendergast (1970: 51) suggests that the Late Classic was “a restricted period of ancient Maya ceremonial use of caves in general,” I would characterize it as one of intensive and far-flung utilization of caves across the Maya Lowlands.

The archaeological wealth of Maya caves extends to some rather interesting wall art. By wall art, parietal art, or rock art, terms which are, for all practical purposes, interchangeable, I mean art created on any natural rock surface not intended to be

moved (Meighan, 1981). Cave art is a distinct sub-class of parietal art and by definition must exclude all art of the “portable” variety, even modified speleothems if they have been moved from their *in situ* geological setting by the people who made the art in the first place.

Like all rock art, Maya cave art can be divided into two technologically distinct groups. One consists of pigment-based art: paintings, drawings, and imprints. For the Maya, paintings were often rendered with brushes, although the actual implements have not survived. Drawings seem to have been made with charcoal or hard pieces of clay used as crayons. The most typical colors found are black and red. Visual inspection suggests that black was usually derived from charcoal, although other black pigments, like manganese may have been used. The red (usually an orange-red) comes from iron-rich clays found in the caves themselves, as well as ground hematite (a bright, deep red), known, for instance, from Dzibichen, in the state of Yucatan (Stone, 1995). Yellow and blue are rare, the former occurring at Joloniel Cave in the state of Chiapas (Riese, 1981; Stone, 1995) and Cueva de Galón in Guatemala (Mayer, 1995), and the latter, at Tixkuytun in the state of Yucatan (Stone, 1995: 69-71, Pl. 5). Maya caves also contain positive and stencilled handprints and, more rarely, footprints, both positive and negative (Strecker, 1982).

Sculpted cave art constitutes the other major group. Rock carvings, or petroglyphs, are made by incising, abrading, and pecking, the most common techniques employed in the production of Maya cave sculpture. Another class of cave sculpture includes three-dimensional images modelled in unfired clay, a rare and very fragile art form. Indeed, these sculptures are frequently destroyed not long after discovery.

The pigment-based and sculpted cave art exhibit pervasive differences that go well beyond the use of different media and techniques. In fact, they vary so dramatically that they seem to have different motivations as well as different artistic sources. Pigment-based art is more likely to follow the pictorial conventions of Maya high art. Paintings typically portray symbols and naturalistic forms, particularly animals and humans, seen in the scribal art tradition, such as in pottery painting and monumental relief sculpture. While a small percentage of the sculpted cave art also was inspired by elite Maya art, the bulk

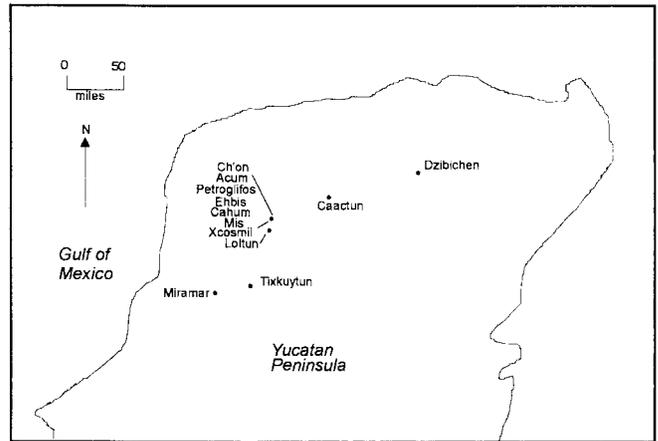
of it is technically crude and seems to lie outside of the high art tradition. For instance, cave petroglyphs often consist of meandering geometric patterns and simple frontal faces, nothing at all like the grand sculptures of the great Classic Maya cities. The crudeness and inscrutable designs of Maya cave sculpture do not make it any less important, however, as evidence of past human behavior. Indeed, the diversity of sources and styles of Maya cave art is a signal of the cave's functional complexity in Maya society.

It would be difficult to pin down the total number of Maya caves known to contain wall art of one kind or another. In a recent monograph, I documented 25 caves with pigment-based art (Stone, 1995). Since this synthesis was published, one new painted cave has come to light (Mayer, 1995) and a new set of paintings has been found in Actun Kaua, in the state of Yucatan, previously only known to contain handprints (Allan Cobb, personal communication, 1995). A rigorous count of caves with sculpted art has not been conducted, but it is easy to imagine the total number of Maya caves containing some form of wall art reaching, if not surpassing, 50. This number is not extremely impressive—remember that there are over 250 Paleolithic cave art sites in Europe—but it is also not a trivial one when we consider that the world has not seen many “cave art cultures” in its entire history; and when the criterion of decorating deep caves is added, the global list shortens considerably (Stone & Bahn, 1993). Here again the Maya qualify with such spectacular deep painted caves as Loltun (Zavala Ruiz et al., 1978) and Naj Tunich (Stone, 1995). To my knowledge the only non-Maya cave in Mesoamerica with deep art is Juxtlahuaca in the state of Guerrero, Mexico, which has Olmec-style paintings located about a kilometer from the entrance (Gay, 1967). In terms of our current understanding, cave art appears to be more abundant in the Maya area than any other part of Mesoamerica.

The corpus of Maya cave art is large enough to permit observations with respect to regional variation, although with caution owing to the limited sample available in most regions. The geographical distribution of decorated caves as it now stands is rather lopsided with the majority being found in the Northern Maya Lowlands, more narrowly defined by the state of Yucatan.

YUCATAN, MEXICO

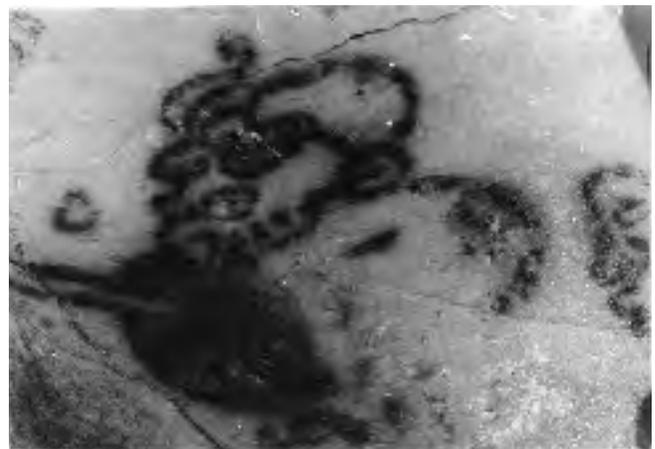
A recognizable style of Maya cave art is one that I call the “Sierrita de Ticul” style. Geographically, it includes caves found along the eastern range of the Puuc Hills of western Yucatan, known as the Sierrita de Ticul. The style is exemplified by four caves: Loltun (González-Licón, 1986; Zavala-Ruiz et al., 1978; Stone, 1995), Acum (Strecker, 1980, 1984a; Stone, 1995), and Ch'on (Stone, 1989; 1995), all located in relatively close proximity, and Tixkuytun (Stone, 1995) which lies about 20 kms to the south (Fig. 1). Sierrita de Ticul painted cave art is characterized by the use of thin paint, usually black or red, the latter probably taken from the cave's own lateritic clay



**Figure 1.** Map showing selected cave art sites in the Sierrita de Ticul (Puuc Hills) of the western Yucatan Peninsula.

deposits. The paint is generally applied with a firm hand in a broad line that defines simple, flat shapes (Fig. 2). The line is not the modulated, whiplike line used in Maya pottery decoration but tends to be wide, of even width, and rigid. Some paintings are filled with solid areas of pigment. The blunt ends of the line suggest that these paintings were not executed with a brush.

Sierrita de Ticul cave art also has a characteristic inventory of motifs. One recurrent image is a large human head, ranging in size from a half to over a meter in height. Loltun has at least seven such heads (Fig. 3). Two appearing in Edward Thompson's (1897) nineteenth-century study of Loltun are the first published examples of Maya cave painting. The nearby cave of Acum, a major cave art site surveyed by Matthias



**Figure 2.** This painting in black of a death demon from Acum illustrates typical traits of Sierrita de Ticul painting. Notice the broad line, emphasis on flat shapes, and lack of fine detail. Areas are filled in with paint. The painting is fairly large, though exact measurements are not available. Photo courtesy of Matthias Strecker.



**Figure 3. Painted head from Loltun, Yucatan, measuring over a meter in height. The black patch over the eye and spots on the cheek may identify this head as that of a death god.**

Strecker (1980, 1984a), has five heads, which are on the whole smaller. The heads are barren of detail, although they sometimes have an earflare or the suggestion of a headdress (Stone, 1995: Fig. 4-49). In one case at Acum the eye is closed, suggesting a moribund being. The heads are often clustered in one area. At Loltun, for instance, four of the seven heads are located in one chamber.

An interesting variant of the human head can be seen at Acum: large painted skulls, five of which have been documented (Fig. 4). Several include part of a skeletal body (Stone, 1995: Fig. 4-44). Some of these skulls and skeletal beings measure over a meter in height. As obvious death figures, they recall one of the large heads from Loltun with a blackened eye and spots on the cheek (Fig. 3). This possibly depicts a youthful death god known by students of the Maya as God A'. It may be that the heads, both fleshed and skeletal, have some connection with death and by extension, ancestors. Such an idea could account for the Acum head with closed eye which may be a deceased ancestor.

Another typical Sierrita de Ticul motif is the isolated symbol or glyph-like element, again painted at a fairly large scale in a broad, simple line. These symbols include some well known in Maya art and writing; for instance, the *k'an* cross (meaning "yellow" or "ripe"), the *ik'* symbol (meaning "breath, wind, or spirit") and the *pop* symbol (meaning "mat" and by extension "throne") (Fig. 5). One section of a corridor at Acum has *k'an* crosses and *ik'* symbols, measuring about a half a meter on a side, painted at eye level in a row (Fig. 6). In the Chamber of Acum the ceiling is painted with a *pop* symbol, smoke scrolls, and other large symbols, some in a stencil technique (Stone, 1995: Fig. 4-53). Acum has a number of other isolated symbols, some with bar and dot notation, but otherwise unidentifiable.

The large *k'an* cross is featured at Tixkuytun in some interesting variations. The cave has one plain *k'an* cross, reminiscent of the Acum examples, but also one with four concentric crosses. The most novel has bar and dot notation along the edges, the meaning of which presently eludes interpretation (Fig. 7). Like Acum, Tixkuytun has two *pop* symbols but is lacking the *ik'* symbol (for Acum examples see Stone, 1995: Figs. 4-43, 4-53). Tixkuytun cave art also includes sim-



**Figure 4. One of the painted skulls in black from Acum, Yucatan, measuring 1.10 m high. Photo courtesy of Matthias Strecker.**

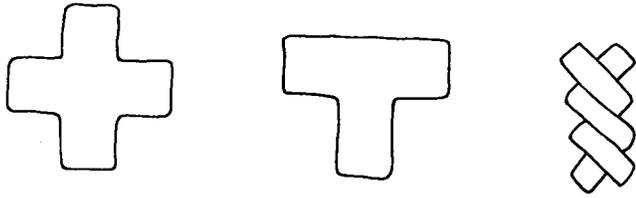


Figure 5. Standard form of *k'an* cross (left), *ik'* (middle), and *pop* (right) symbols.

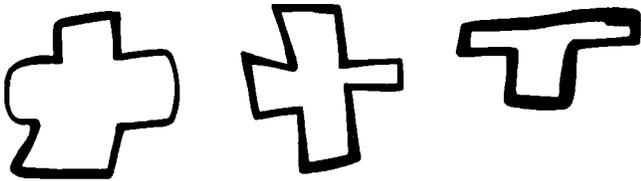


Figure 6. Two *k'an* crosses and an *ik'* symbol in black from Acum, Yucatan, measuring about half a meter on their long side. After Stone, 1995: Fig. 4-43.

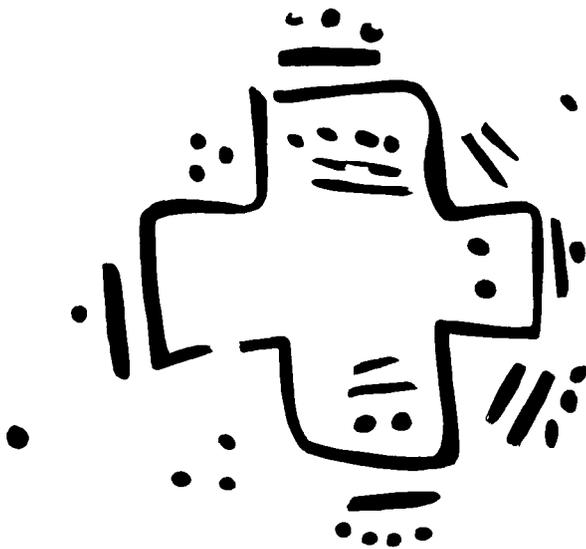


Figure 7. A *k'an* cross painted in red with bar and dot numeral notation from Tixkuytun, Yucatan. The painting is on the ceiling and has no obvious up-down orientation.



Figure 8. Black painting of a turtle, long-necked bird, and a possible deer from Acum, Yucatan. After Stone, 1995: Fig. 4-50.

ple circles, sometimes concentric circles; occasionally the centers are filled making them look like breasts or eyes. These circles often appear over the low entrances to side chambers. Both Acum and Tixkuytun have paintings of animals: a deer at Tixkuytun (Stone, 1995: Pl. 5), and a turtle, long-necked bird, and a deer head at Acum (Fig. 8). Again, the painting style is simple and bold.

While handprints have a wide distribution in Maya cave art, the imprints (both hand and foot) in Sierrita de Ticul caves are distinct and very abundant. They therefore seem to have special importance in this region. Acum, for instance, has more handprints than any other site in the Maya area, perhaps in Mesoamerica, with 135 handprints (Strecker, 1982). Loltun is not far behind with 85 handprints. Quantity is not their only striking feature, as the stencil handprints are of exceptional complexity. At Loltun, for instance, two hands and a thin rod attached to the tip of the index fingers were stenciled as a unit (Stone, 1995: Fig. 4-34). The most amazing negative handprints are those forming animal heads at Acum (Fig. 9). Also seen at Acum are two-handed negative handprints with the fingers retracted, creating interesting, odd patterns. At Tixkuytun some negative handprints in red are encircled by a carefully drawn black line, a motif also observed in a nearby cave at Akil (Lisa Rock, personal communication, 1990). Interestingly, a graffito in Group 5E-11 at Tikal shows three positive handprints encircled by a line, but in this case thick and crudely drawn (Orrego and Larios, 1983: Lam. 5b).

Thus far I have omitted Ch'on from the discussion (Stone, 1989a, 1995). Ch'on has a much smaller corpus of paintings than the others, and only two exhibit style traits of the Sierrita de Ticul group. One is an isolated glyph with a bar and dot numeral prefix. The placement of the glyph on the ceiling recalls paintings from Acum. The other elaborate painting is a scene consisting of three figures; the central one, bound and



Figure 9. Black stencil handprint forming an animal head. The little finger creates the "ear", from Acum, Yucatan. Photo courtesy of Matthias Strecker.

nude, appears to be a prisoner (Stone, 1995: Fig. 4-38). Multi-figure narrative scenes, such as this, are rare in all of Maya cave art; yet the manner of painting in simple, flat silhouettes and the large scale of the Ch'on figures is fully consistent with the Sierrita de Ticul style group. It is worth mentioning that this style of painting, although generally conforming to Late Classic pictorial conventions (e.g., the way profiles are rendered and the use of certain symbols), and although surely contemporary with some mural art in the vicinity, such as the paintings of Chacmultun (Barrera-Rubio, 1980: Figs. 5-6), has a character that is different from art of regional surface sites. For example, at none of the nearby Puuc sites (Pollock, 1980) do we find large heads, concentric crosses, or animal figures of the type found in the caves. This suggests that Sierrita de Ticul painting enjoyed some degree of independence from the surrounding urban centers. This is likely due to the unique function of the cave art in associated ritual activities; yet we do not know precisely what these functions were.

Strecker (1984b, 1985) located several caves with petroglyphs in the Sierrita de Ticul: Mis, Petroglifos, Ehbis, Xcosmil, and Cahum (Fig. 1). In addition, Loltun has long been known to contain petroglyphs (Thompson, 1897: Figs. 8-9). One famous petroglyph sits astride Loltun's Nahkab entrance. This portrait of a ruler accompanied by hieroglyphs relates technologically (as bas-relief) and iconographically to contemporary monumental stone carving from the Protoclassic period, around 100-200 A.D. (Proskouriakoff, 1950: 104, Fig. 38b). A question is raised in my mind as to whether the Loltun bas-relief should be classified as cave art in the truest sense. First, it is found outside the cave proper, on an exterior wall. Second, the relief's similarities to monumental stone carving relate it more to open-air rock art than to cave sculpture *per se*, and, so, I would liken it to the former.

Other petroglyphs deep inside Loltun compare to petroglyphs found in nearby caves. They are generally formed from deeply pecked lines. One common type seen at Xcosmil, Cahum, Petroglifos, Ehbis, and Mis shows schematic, frontal faces, some of which have a skull-like appearance. At Ehbis heads of this type were carved on a stalactite (Strecker, 1985: Fig. 1). Another type of petroglyph, found at Xcosmil, Cahum, Petroglifos, and Loltun, consists of a meandering line, which forms curlicues, boxes, circles with connecting lines, and ladder-like designs (Fig. 10). Little of this can be interpreted, although some from Petroglifos have been identified by Strecker (1987) as skeletal figures. Further north in the Sierrita de Ticul, near Calcehtok, Actun Ceh also has crude linear petroglyphs of schematic faces and the outlines of a deer (Rätsch, 1979: Abb. 5).

The cave petroglyphs in the Sierrita de Ticul have little in common stylistically or iconographically with the paintings. Is this simply due to a lack of contemporaneity? The paintings obviously have more in common with Maya art prior to the conquest, and those of Acum, Ch'on, and Tixkuytun appear to be Late Classic. The situation is more complicated at Loltun. One group of paintings is Protoclassic, contemporary with the

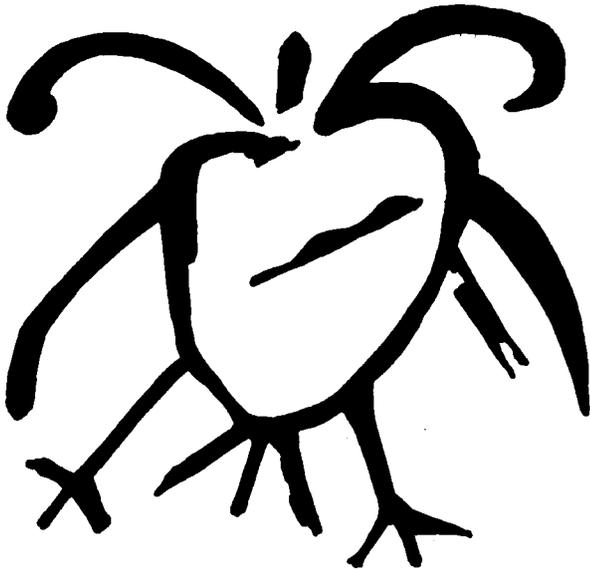


**Figure 10. Petroglyph showing volutes, rectangles, and circles from Loltun, Yucatan.**

entrance relief (Stone, 1989b: Figs. 22-3 & 22-4); the large faces appear to be Late Classic. Some paintings may also date from the Colonial period. Unfortunately, the petroglyphs are impossible to date as they bear no relationship with securely dated styles. Furthermore, these caves would have been accessible to local populations since the Preclassic. In other words, the petroglyphs could date from almost any period.

Differences between the paintings and the petroglyphs could also be accounted for by the different social contexts of their production. The paintings appear to be the work of more highly trained individuals. On the other hand, the petroglyphs may represent a vernacular art practiced only by "common folk." I will return to this notion of a vernacular art below, since it is critical in sorting out the radically different styles represented in Maya cave art.

Once we move away from the Sierrita de Ticul, Yucatecan cave art becomes more sparse and what there is lacks areal consistency. There are two important sites in central Yucatan, Dzibichen (Stone, 1995) and Caactun (Stone, 1995) (Fig. 1). Caactun overlaps with the Sierrita de Ticul style in its abundance of handprints and, especially, the stencilled prints that make unusual patterns. Caactun is also unique in having Early Classic incised wall art. Dzibichen has Colonial cave drawings in charcoal; these include Hapsburg eagles and a type of circular face found in Colonial manuscripts. Colonial cave art, including Hapsburg eagles (Fig. 11), is also known from one cave in the state of Campeche, Miramar (Stone, 1995), also called Actun Huachap (Reddell, 1977). In general the Dzibichen art recalls simple forms of drawings from the

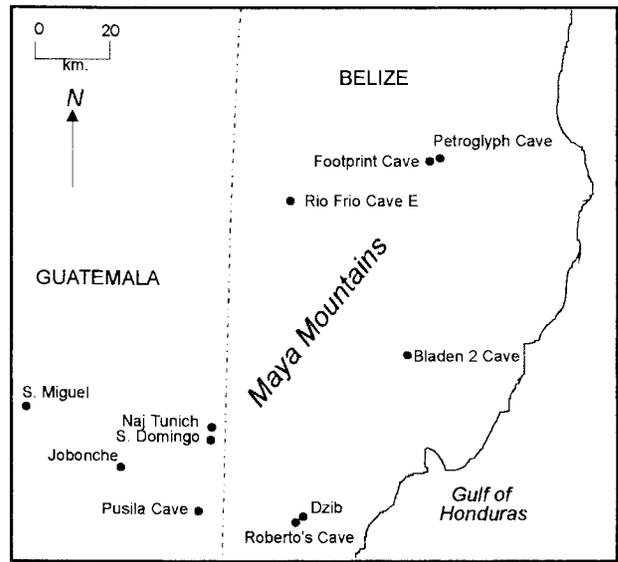


**Figure 11.** Two-headed eagle painted in red from Miramar, Chiapas. After Stone, 1995: Fig. 4-86.

codices. It also shows vernacular iconography in depicting the female pubic region, or “vulva” as it is usually called in rock art literature, as triangles with slits at the base. The vulva motif is also found in the rock art of Chalcatzingo, in the state of Morelos (Apostolides, 1987).

PETEN AND BELIZE

The Maya Mountains of southern Belize and southeastern Guatemala (Fig. 12) are surrounded by a major karst zone with some of the biggest caves in Central America. The most massive are on the northern flanks in the Caves Branch River Valley, such as Petroglyph Cave (Reents-Budet & MacLeod, 1986) and on the Vaca Plateau in the watershed of the Chiquibul River (Miller, 1989). Although many of these caves are richly endowed archaeologically, they are notable for lacking cave art (McNatt, 1996). A few exceptions can be found in the Caves Branch Valley. For instance, Petroglyph Cave contains, as its name implies, petroglyphs: volutes and glyph-like forms incised into rimstone dams in the entrance (Reents-Budet & MacLeod, 1986). Waterfall Cave houses a petroglyph of concentric circles (Barbara MacLeod, personal communication, 1994). In addition, until the late 1970s when it was destroyed, a grotesque face sculpted in a clay deposit was located in Footprint Cave (Graham et al., 1980: Fig. 3). Since the clay sculpture lay in its original deposit, it can be considered nonportable cave art, as are the famous Paleolithic clay bisons from Le Tuc d’Audoubert, France (Bahn & Vertut, 1988: Fig. 61). Only one other clay sculpture of this type has been reported in a Maya cave, and rumor has it that it was also destroyed: a lifesize deity sculpted in clay in a cave in the Peten (Stuart & Stuart, 1977). One might also designate as cave art a human-looking stalagmite from Río Frio Cave E in



**Figure 12.** Map of the Maya Mountains region with cave art sites mentioned in the text.

the Mountain Pine Ridge of central Belize, which has cuplike depressions carved into the “stomach” (Pendergast, 1970: Pl. 3). However, the stalagmite is not in its original position, disqualifying it as nonportable art. Caves found in the vast karst zone north of the Maya Mountains exhibit a noticeable lack of pigment-based art. In fact, the first examples have only recently been discovered in Actun Uayazba Cab, near Roaring Creek in the Belize River Valley (Jaime Awe, personal communication, 1996). Among them are the first examples of handprints reported from a cave in Belize. This dearth of painted art may have to do with intermittent flooding which reaches catastrophic proportions in many of these caves and which would obliterate fragile wall paintings.

Cave art is more common around the southern reaches of the Maya Mountains in Belize and Guatemala (Fig. 12). On the Belizean side are two caves with painted art: Actun Dzib and Roberto’s Cave (Walters, 1988). While Roberto’s Cave has a mere handful of fragmentary paintings, Actun Dzib is far more significant in housing a large collection of paintings in a vernacular style. Most are linear, schematic images of toad-like, lizard-like, and insect-like creatures, spirals, human stick-figures, comb-like, and inverted T-shaped forms (Fig. 13). Some resemble certain pottery and textile motifs from the Classic period but otherwise they have no relationship with known styles of Maya art. Interestingly, one figure painted away from the two panels of stick-figures is in the Classic style. This figure resembles one from a cave painting site, known as Bladen 2, recently discovered by Peter Dunham (personal communication, 1993) in southern Belize. Actun Dzib thus houses two entirely distinct styles of art, one that seems vaguely Classic and another that is idiosyncratic but may again reflect a vernacular style of drawing coexisting alongside Classic Maya art.

**Figure 13.**  
**A typical painting from Actun Dzib, Belize.**  
**Note the schematic lizards, human figures, and spirals.**



On the Guatemalan side of the southern Maya Mountains are several caves in a fairly restricted area with paintings or drawings (a technical distinction sometimes hard to make). The preeminent cave in this region is Naj Tunich (Stone, 1995). Related to it is Santo Domingo, about four hours away on foot (Brady & Fahsen, 1991). Santo Domingo has preserved a single painted hieroglyphic text (Stone, 1995: Fig. 4-111), while Naj Tunich has dozens of hieroglyphic texts and figures, as well as some handprints and about a half dozen incised petroglyphs (Fig. 14). Refined, calligraphic painting of this sort is what the Maya might have been expected to produce in many more caves with Late Classic occupation. Yet, there are few painted caves of this caliber. Apart from Naj Tunich and Santo Domingo, the cave Yalaltsemen in the state of Chiapas also has a painting using the modulated whiplike line characteristic of fine Late Classic painting (Stone, 1995: Pl. 7).

The elite context of the art of Naj Tunich and the richness of the archaeology (Brady, 1989) are testimony to the importance of this cave as a holy place. The texts show that the cave was a pilgrimage shrine attracting elites from surrounding sites. Even a ruler from the major Classic Maya city of Caracol, 60 kms to the north (Chase & Chase, 1987), is mentioned in the texts, as Stephen Houston has observed (letter to Nikolai Grube, 1991). One wonders why the elite of Caracol were not utilizing caves closer to home in the same way.

The third painted cave in the area is near Pusila, Guatemala (not to be confused with Pusilha in Belize), about 10 kms south of Naj Tunich and Santo Domingo (Siffre, 1979). The cave has drawings of a seated figure, a profile face, and other curious concentric circles, and meandering lines that appear to

be rendered in charcoal. Handprints and footprints are also found there. The figures are Late Classic, making them roughly contemporary with Naj Tunich and Santo Domingo, but the quality of drawing is much inferior. Another cave painting site in the general region of these three, but lying further to the northwest, is San Miguel (Siller, 1989; Stone, 1995: Figs. 4-112-113). The paintings, however, do not appear to be coeval with either Naj Tunich, Santo Domingo, or Pusila art.

Siffre's (1979) cave explorations in southeast Peten uncovered several caves with petroglyphs taking the form of crude faces with deeply drilled eye holes carved into flowstone protrusions or stalagmites. One is the previously mentioned Pusila cave (Siffre, 1979: Fig. 38). Others include Jovelte, Poxté, and a cave Siffre calls Canchacan (Siffre, 1979). Brady (n.d.) carried out a systematic study of the latter cave which he has renamed Jobonche. He notes the presence of four carved faces with large staring eyes with deeply drilled centers, prominent brows, and thick, squared lips (Fig. 15).

These roughly carved faces might be thought of as a type of vernacular cave art. Brady (n.d.) argues that carved stalactites, such as these, might have functioned as "idols" and discusses literature demonstrating that stalactites functioned in this manner, either in caves or removed from caves and used in surface contexts. Crude faces carved in calcite deposits represent a type of vernacular cave art seemingly restricted to caves. They may relate, as Brady suggests, to certain types of associated ritual activities and may have functioned in a manner similar to the crude human sculptures, sometimes found in caves, such as at Quen Santo in highland Guatemala (Seler, 1901).

There is one other petroglyph site southeast of the Peten-southern Belize zone. Around Lake Izabal, near the Atlantic



**Figure 14.** Drawing 69 from Naj Tunich, Peten in black, measuring 19 cm. high, painted in a refined Late Classic style reminiscent of vase painting. This style of painting is known from few caves in the Maya area. Photo courtesy of Chip and Jennifer Clark.



**Figure 15.** Detail of a head sculpted in a flowstone concretion at Jobonche, Peten. Crude heads of this sort represent a class of sculpture especially prevalent in the southeast Peten. Drawn after a photo by Siffre, 1979.

coast of Guatemala, the Cave Agua Caliente contains crude incised petroglyphs. One can be identified as a monkey, but the others are vague and cannot be dated stylistically (Voorhies, 1969: Fig. 7).

#### CONCLUSIONS

Two regions emerge in the Maya area where cave art is relatively common: the Sierrita de Ticul in the Puuc Hills of Yucatan and the southeast Peten-southern Belize zone. Elsewhere cave art occurs sporadically. The painted art in these two regions clearly differs, even though it is largely contemporary. The fine Classic painting found in southeast Peten, most importantly at Naj Tunich, may have been influenced by local traditions of painted ceramics. Conversely, the lack of intricate, narrative pottery painting in the Puuc area might have some bearing on the stiff painting style of Sierrita de Ticul cave art. This could also explain differences in scale, those in the Puuc area generally being much larger than Classic paintings in the Peten. The small scale of the Naj Tunich paintings again seems tied to a ceramic painting tradition. Perhaps the Naj

Tunich artists were ceramic painters who conceived their compositions in a diminutive scale, while the Sierrita de Ticul painters adjusted their images to the vast wall space.

Right now, the overall picture is one of idiosyncrasy in cave decoration. In some cases we have only one cave representing a style, as at Actun Dzib, Belize. The Sierrita de Ticul is an exception with a cluster of caves with comparable imagery. The close proximity of these caves and their easy accessibility may have contributed to the proliferation of a single style of cave art in this area. Sculpted cave art is far more likely to be in a crude vernacular style than the painted art, which, on the whole, shares more with the elite art of surface sites. Some of the sculpted art may have been the focus of propitiatory rituals. The human-looking stalagmite from Río Frio Cave E, for instance, has a carved depression near the head found to contain burnt wood, charcoal, and carbonized sherds (Pendergast, 1970: 8). These kinds of sculpted "idols" are probably widespread in Maya caves and have largely gone unreported.

In conclusion, wall art is one of the most interesting expressions of ancient Maya material culture found in caves, although it is still relatively unknown to scholars. Our ability to understand why regional styles of cave art developed can only improve in the future as the corpus grows; new cave art is being discovered annually. One factor to consider is preservation, which might explain the lack of pigment-based art in Chiquibul and Caves Branch caves. A hypothesis worth testing is whether regional variation is tied to functional variation, not just in the rites performed in caves but also in the status of those who used them. For example, if elites patronized caves in one area, then the art might assume a certain character, more like the ceremonial art of surface sites. If only the peasantry were using a particular set of caves, then the art might take on a vernacular character. Classic period vernacular cave art demonstrates that Maya art was not monolithic, but that there were concurrent artistic traditions whose expressions depended on social and spatial context. Regional variation may also be linked with chronological variation. For instance, Colonial cave art has been found only in the Northern Lowlands to date. It is also possible that Maya cave art will turn out to be relatively idiosyncratic from site to site owing to the private nature of cave use. Our grasp of regional variation in Maya cave art is truly in its infancy; only continued research will give it a more solid form.

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# SPELEOTHEMS OF AEROSOL ORIGIN: DISCUSSION

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The aerosol model of speleothem origin suggested by Klimchouk and others (1995) contradicts physical principles, because aerosol generation driven by radiation from the decay of radon gas required for this model would accumulate lead and other heavy metals in unrealistic and never-observed quantities. The aerosol hypothesis was offered as an alternate to mechanisms based on vapor condensation and thin-film evaporation. The reasons were intuitive—if something looks like hoarfrost, it must have a similar origin. But the condensation, thin-film, and aerosol environments have very different properties. In the cases of condensation and thin-film evaporation, the curvature of the depositional surface controls the process (Jabin, 1979; Stepanov, 1971). Following the Curie principle, this results in an inverse-conical symmetry for the mineral deposit in the case of condensation, and a conical symmetry in the case of evaporation. The Curie principle says that as long as a mineral aggregate is considered a product of some crystallization environment, then its depositional symmetry is a reflection of the environment's mass-transport symmetry (Stepanov, 1971).

In the aerosol-precipitation case, the surface geometry doesn't affect the process, only its orientation relative to the vertical or to the wind direction. This results in cylindrical symmetry for the deposit. Figure 1 shows vector diagrams of speleothem growth for these cases. In these diagrams, we can note an interesting feature. In analogy with the ice case of condensation-crystallization, real ice hoarfrost shows symmetry and growth speeds corresponding not with the condensation-controlled environment, but with an evaporation-controlled environment. The supply is condensation controlled, but the crystallization is really evaporation controlled. Both condensation and crystallization of water release much heat, and when the growth is fast, the thermal conductivity of both the ice and the surrounding air is insufficient to remove this heat. On the other hand, evaporation can remove a significant part of the heat. So, if the humidity allows condensation on depositional surfaces with a low relief, and at the same time allows evaporation from surfaces with a high relief, we receive the pattern seen in the figure. The mass transport from condensation areas to evaporation areas goes through a "quasi-liquid" phase on the ice surface (Parungo, 1983). This example clearly shows the difference between the supply mechanism and the crystallization mechanism that is even more significant for the aerosol case.

Several mechanisms are known to generate aerosols in caves. The most common mechanisms involve splashing from water drops and streams (Mavludov & Morozov, 1984; Gadoros & Cser, 1986), vapor condensation (Zamorsky, 1955), and the falling of small particles from the ceiling (Pashchenko & Sabelfeld, 1992).

Klimchouk and others (1994, 1995) suggested a new mechanism for aerosol generation in caves. This mechanism involves ions and particles knocked out from the gypsum rock by alpha particles and reactive atoms, produced by the fission of radon atoms. They consider that this aerosol generates gypsum crystalline crusts, hoarfrost, "snow," rims, and hollow stalagmites.

Indeed, some alpha particles coming from radon gas have enough energy (up to 7 Mev) to knock out ions and gypsum molecules. This cannot be said about "reactive atoms", however. Simple consideration of Newtonian mechanics shows that a "reactive atom" has kinetic energy about 2500 times less than that of the alpha particle. So, we will consider herein only the possible effects of alpha particles. The probability of the alpha particle knocking something out is very low, but we'll ignore this and let the probability equal 1. We will, however, use the geometric considerations that only about 1/3 of the particles move in a proper direction to hit the walls, and only those originating 1 to 3 cm from the walls (the effective distance of alpha particles in air) can reach them. For the gypsum caves at Podolia, that is about 5% of their volume, so only about 1 particle in 60 has a chance to knock something from a wall. In the best case, one Ca<sup>2+</sup> ion, taken into the aerosol, balances with 60 ions of lead and other heavy metals, formed originally in aerosol from the Rn decay. For the weight of gypsum crystals in Optimisticheskaya Cave considered to have an aerosol origin, we calculate 12,000 to 35,000 tons of lead. But, of course, no such quantities of lead are known for the Ukrainian caves.

Any lead produced must be precipitated at the points of aerosol precipitation, at just the places where Klimchouk and colleagues search for the aerosol-crystallized gypsum. In those places, much more Pb than Ca must appear, so much more that it would be seen without special study. The Pb/Ca ratio in the places of aerosol precipitation would remain constant at about 60 to 1 for the Ukrainian caves with narrow passages, and much greater for others.

Klimchouk and Nasedkin (1994) note that some cave silt and clay contains Pb levels up to 6 times that of the average for the Earth's crust (Gorbunova & Kropachev, 1970). But these are reasonable values, corresponding to the fact that in karst areas most of the short-lived radon gas decays in the caves. But the values are several orders of magnitude less than those that must appear as a result of the aerosol model.

The radiation levels, reported by Klimchouk and Nasedkin (1992), as a basis for this theory, are themselves questionable. Maltsev, et al. (1995) compare such data for the Kugitangtou caves, with data from other sources, and from their own measurements. These data, well correlated between the sources, are 3 to 8 times lower, and show nothing unusual. Values ranged from 5-8 mkr/h in deep areas to 20-70 mkr/h in main

galleries, where the radioactivity comes from clay, brought from the surface. The only possible reason for this, other than possible methodological error, is that there was a short radon gas concentration increase before the earthquake that happened in 1990 on the fault, intersected by caves.

Klimchouk and others (1995) printed a compilation of the aerosol quantity in caves. But cave air is an unstable system. Any external heat creates a zone of condensation around it. An explorer generates lots of aerosols. All cavers can see fog around themselves. A proper aerosol-measuring instrument must be isolated and must be equalized to the cave temperature for at least several hours—in other cases the aerosol measured will be mostly artificial. The only data on aerosol quantity that can be accepted are the data with a proved absence of artificial effects. Photographs of laser-light beams (Klimchouk et al., 1995) show nothing except fog generated by cavers.

Anthropogenic dust pollution is common in caves. Bartenev and Veselova (1987) carried out measurements of dust sedimentation from aerosols in the Cupp-Coutunn Cave System. They proved that the sedimentation speed rises more than 10 times within 20 meters around the main tourist passages, reaching 0.2 mm/year (Oleg Bartenev, pers. comm.).

Klimchouk and others (1995) state that gypsum hoarfrost (attached crystals) from Ukrainian caves were initially believed to be subaquatic, then were considered as thin-film generated, now as aerosol generated. In reality, Moroshkin (1979) proved their thin-film genesis, described all their symmetry features, all the mass-transport physics, and grew such formations in laboratory experiments. His model is in full accord with physics. All the features that Klimchouk and others (1995) outline as evidence of an aerosol origin (location at passage intersections and so forth) show nothing but enforced evaporation at these localities.

Klimchouk and others (1995) postulate that gypsum “snow” or “frost” (loose crystals) from Ukrainian caves precipitate in aerosol droplets. The alternate model is well known (Maltsev, 1990). This “snow” consists of relicts of gypsum frostwork growing on the ceiling from thin films during dry seasons, and falling down during wet seasons (controlled by cave-wind inversion). Epsomite varieties of the same “snow” were known and described long ago, with the same genetic model (Locke, 1842; Hill & Forti, 1986). All the phases of this frostwork generation, dissolution, falling, and subsequent snow dissolution and recrystallization are easily seen, if observed during the course of a year.

With gypsum rims, the situation is slightly more complicated. The alternate model (Hill, 1987) supposes a thin film of the solution moves by the wind at holes in gypsum blocks.

Klimchouk and others (1995) wonder how the wind can lift the film several meters upward. In reality, no aerosols are needed, and no wind is needed. The surface tension of water to air is about 73 erg/m<sup>2</sup>, and the wetting angle of limestone is 5-10 degrees. From this, the capillary pressure in a 0.01-0.1 mm water film is more than 10 atmospheres, thus providing almost unlimited elevation of such a film toward the evaporation area without any external force. A good example may be found in any desert—the salt rises to the surface through the pores (the same capillary forces, but demonstrably without wind or aerosol) from the water table dozens of meters below the surface, and crystallizes on the surface. If a seasonal humidity cycle provides the water supply, rims appear around any niche (condensation is most likely inside and evaporation outside), and the niche itself grows due to dissolution inside. In the Kugitangtou Caves (Cupp-Coutunn, Geophyicheskaya) the rims grow on highly porous massifs of fallen gypsum crusts, and around niches in limestone where redox processes generate gypsum from the limestone (Korshunov et al., 1994).

Hollow gypsum stalagmites are mostly described from the Cupp-Coutunn Cave System, and their genesis is also known and described (Maltsev, 1990, 1993). They grow only where the cave is near a canyon, and a seasonal humidity cycle exists. Gypsum is a very soluble mineral, and a dripping solution cannot stay continuously saturated. During the periods of under-saturation, a drill hole appears, and then condensation inside together with evaporation outside increases the hole size, recrystallizing the stalagmite walls into crystallites. This process can be seen clearly from corroded inner surfaces, recrystallized wall structure (bushes with conical symmetry), and rims around accidental holes in the walls. Klimchouk and others (1993) consider the Tres Amigos group from Lechuguilla Cave, New Mexico, as the same type of hollow gypsum stalagmites, but they aren't speleothems at all—they are dissolution remnants (Hill, 1987).

One can now see that all the speleothems referred to by Klimchouk and others (1995) have their explanations in “usual” mechanisms. According to Occam's razor, a very strong reason is needed for suggesting some new model against proved and workable ones, and the physics of such a new model must be proved.

Some aerosol effects really do exist. They certainly may form cave sediments and may effect the shape of speleothems generated by other mechanisms (like the aragonite trees at Snesznaya Cave). Their study is needed—but genuine studies, not attempts at new speculative explanations for the most beautiful and best studied speleothems.

# SPELEOTHEMS OF AEROSOL ORIGIN: REPLY

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We strongly disagree with the comments by Maltsev on our original article, and hope that our response clearly explains our disagreement.

We do not feel sufficiently qualified to discuss whether the Curie principle is so universal a tool for identifying a speleothem's origin. In real cases there may be many factors complicating this rule. It seems that Maltsev is wrong in saying that surface geometry does not affect the process of aerosol deposition. Based on the works of Hungarian researchers (Cser & Maucha, 1968; Cser & Gadoros, 1988; Gadoros, 1989) we emphasized that the behavior of charged aerosols must be determined to a certain extent by forces of electric interaction. Surface geometry may affect aerosol deposition through distribution of the electrostatic potential, which has been shown both experimentally and theoretically. In addition, the mechanisms of precipitation from aerosols are not very clear. We suggested that crystallization occurs when a supersaturated hydroaerosol droplet contacts the rock (crystal) surface, but we also hypothesized that microcrystals form in the aerosol droplet when it joins with other particles which can play the role of the crystallization nuclei. After "dry" aerosols precipitate, the speleothem so formed may be further recrystallized.

For a long time the main problem with the interpretation of aerosol effects was that previously suggested mechanisms of cave aerosol generation had limited applicability for the formation of speleothems. The central point of our article was in offering a new hypothesis of aerosol generation: high-energy alpha particles and recoil atoms may dislodge clusters out of a mineral crystal lattice and knock out mineral fragments, generating small-sized aerosol particles. Combining with hydroaerosols, or becoming condensation nuclei themselves, such particles dissolve in water provided that the hydroaerosols contain sufficient dissolved material which may be deposited under appropriate physiochemical conditions. Because elevated levels of radon and its daughters are a fundamental characteristic of the cave environment, the above mechanism can, most likely, be widely applied to explain aerosol effects in caves.

To disprove this hypothesis, Maltsev calculated unrealistic quantities of lead which would accumulate at the base of the radon decay chain as a result of aerosol generation driven by alpha-decay. These calculations (and accompanying speculations) are based on numerous faulty assumptions and miscon-

ceptions.

First, clusters may be dislodged out of a crystal lattice not only due to alpha-decay occurring outside of a rock, but also due to alpha-decay occurring within the rock (of course, the effective distance of alpha particles in a solid material is lower than in the air).

Second, not only can alpha-decay of radon produce the effect under discussion, but three radon daughters are alpha emitters as well.

Third, recoil atoms do have the same kinetic energy as alpha particles, although their initial speed is only 2% of the speed of alpha particles and the effective distance is much lower (approximately 0.1 cm) due to difference in mass and size (Serdjukova & Kapitanov, 1975). Recoil atoms can, however, contribute to the effect along with alpha-particles.

Fourth, the assumption about the "effective volume" is very far from reality. In fact, radon release from a mineral grain occurs not only into the cave space but also into porous and micro/macro fissure space. The combined volume is, most likely, much greater than the volume of the cave itself. The same applies to aerosol generation; however only those pores and fissures which are directly connected with the cave volume can supply aerosols. But even this "connected" space can be comparable to, or exceed, the volume of the cave. Moreover, the effective surface is not merely a formalized geometric figure of the cave but, in reality, has well developed relief and includes the surface of all loose rock fragments (for example, breakdown boulders). It is difficult to make realistic assumptions using the above parameters, but it is clear that Maltsev's 5% is an underestimated figure. The true figure is more likely between one to two orders of magnitude greater.

Fifth, we hypothesized that not only single ions can be knocked out from the solid phase but clusters of crystal lattices consisting of many atoms. It has been shown by Baranov et al. (1981; cited after Dubashinsky et al., 1988) that alpha-decay can cause detachment of small particles, containing approximately 10-1000 atoms, from a solid matrix. This further changes Maltsev's ratio between aerosol material and lead generation to one to three orders of magnitude greater.

Finally, it is not clear what the quantity of "aerosol" gypsum that Maltsev assumed in his calculations was. We would roughly evaluate this quantity for Optimisticheskaya Cave at around 2000 lbs. (one ton), which appears to be much less than

the figure used by Maltsev.

In general, we do not see much sense in pursuing such rough calculations when so many factors and parameters are involved where quantification is highly uncertain. However, it is quite clear that Maltsev's quantities of lead are truly unrealistic, not because our model is patently wrong, but due primarily to the wrong assumptions and methodology that form the basis of Maltsev's calculations.

Although it is not directly related to the aerosol topic, it is interesting (and possible) to make some rough calculation on the quantity of lead which could be produced under certain radon levels. Assuming a radon level of 20,000 Bq per cubic meter for Optimisticheskaya Cave that is in equilibrium for 400,000 years (the suspected duration of the vadose stage), we calculated that  $1.3 \times 10^{-4}$  gm. of lead would be produced from 1 cubic meter of cave volume. This gives 6.5 kg of lead for the 500,000 cubic meters of the cave.

Another obvious misconception in Maltsev's comments is his statement that any lead produced must be precipitated at the points of aerosol precipitation. Aerosols, radon, radon daughters, and lead itself—all have different migration properties and mechanisms of accumulation, so there is no expected spatial relation between areas of aerosol precipitation and lead accumulation.

We stress that the hypothesis of aerosol generation driven by alpha-decay is based not only on our speculations. After publishing the Russian version of our article (1993) we found some other publications in the physical sciences supporting the hypothesized mechanism. In addition to the above mentioned work of Baranov and others, Dubashinsky et al. (1988) have estimated that for particles  $< 0.1$  mkm, the adhesion energy of any bond is as high as several 0.1 Mev, and that the same order of energy is required to split particles of 0.1 mkm or to separate such particles from the massive sample. The experimental work of the same authors has demonstrated that above a radioactive soil surface the concentration of large aerosol particles ( $< 1.1$  mkm) is 2.5-10 times greater than that observed in a control (nonradioactive) situation; the difference in concentration increases considerably with time. These references had been used in our English publication, but were ignored by Maltsev.

Maltsev also questions our data on radon levels reported in detail in Klimchouk and Nasedkin (1992). From Maltsev's text it could be understood that in Maltsev et al. (1995) data on radon measurements in Kugitang caves are compared from other sources and from Maltsev's own measurements. In reality, there was no other radon measurements made in these caves except ours. However, it follows from the units that appeared in the text that he actually meant gamma radiation. Our reported gamma-radiometry data range from 17-149 mkr/h while Maltsev indicates 5-70 mkr/h; it is not a striking difference if one considers that the measurements were made in different places. However, it is absolutely incorrect to compare measurements of gamma radiation with radon measurements made in different points and at different times, primarily due to the

high spatial variability of both parameters and the temporal variability of radon concentrations. As to the methodology of our radon studies, we are quite sure that it was correct: it was used during the two year program that encompassed many caves in various regions, including 15-months monitoring in Marble Cave, Crimea, repeatedly controlled and published in detail along with the results (Klimchouk & Nasedkin, 1992).

As far as speleothems are concerned, Maltsev repeated conventional views on their origin giving no additional solid arguments in favor. In our article we certainly suggested alternative explanations based on the newly hypothesized mechanism of aerosol generation. Occam's razor is fully justified in cases where existing models are strongly supported by solid theoretical and experimental data, but that cannot be said about many fields of cave mineralogy. We assert that at the present stage of the study of speleothems concerned, conventional models are "proved and workable" no more than our suggested explanations. The appearance of new data on the physical characteristics of the cave environment, and of new hypotheses on the processes evolved, are strong enough reasons for suggesting new explanations for the origin of some speleothems.

Maltsev, referencing his article in the *NSS Bulletin* (Maltsev, 1990), states that the model for gypsum "snow" is well known. In this article he suggested that the growth of gypsum frostwork in Dzhurinskaya Cave, Western Ukraine, and the fall of crystals and their accumulation on the floor in form of "gypsum snow", are evaporation-condensation phenomena related to a seasonal reverse of airflow and subsequent change of relative humidity between 70-100%. The model has many controversial points, commented on in Klimchouk and Nasedkin (1984), but here it is enough to note that Maltsev's basic assumptions about microclimate of the cave, on which his speculations are based, are completely wrong. Our detailed 18-month monitoring of microclimate in this cave (Klimchouk et al., 1990) showed that the zone of notable seasonal variations of temperature and humidity encompasses only a limited part of the cave close to the entrance. But 5-10 m deep into the cave the relative humidity is nearly constant throughout the seasons (close to 100%). One of us has worked in the cave hundreds of hours in all seasons and has noticed nothing like Maltsev's "findings" that were made during his single visit to the cave. In other giant maze caves of the Western Ukraine, gypsum frostwork and snow is widespread, but not in conjunction, in the deep internal parts of the caves where there is no measurable seasonal variations of temperature and humidity.

Another reference made by Maltsev in his Comment is to the same article, and concerns hollow stalagmites from the Cupp-Coutunn Cave: "their genesis is also known and described". In fact, the only mention of these speleothems in his article is as follows: "Stalagmites present are hollow and may be up to 3 m in diameter. Their walls are 1-30 cm in thickness and consist of recrystallized frostwork" (p. 101). In the present Comment Maltsev speculates on condensation-evaporation and seasonal humidity cycles, though in another publication (Maltsev, 1994), he asserted that there is a biogenic

component in the mechanism of formation of these hollow stalagmites, and that they “are not hollow but have aggressive to gypsum biogenic substance inside” (p.96). The question arises then, what particular genesis is described and known from Maltsev’s publications?

In publishing our article we realized that the suggested mechanisms were speculative to a considerable extent and required further theoretical and experimental justification. Some of the aspects of the topic extend beyond the limits of

our direct competence. One of the main goals in writing this paper was to stimulate further discussion and studies of the physical properties of the cave environment and aerosol effects in caves. Regrettably, Maltsev’s comments give no constructive contribution to the problem and obviously have more of a scandalous agenda. The only positive result of this discussion may be that it will draw the attention of serious investigators to the topic.

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# SELECTED ABSTRACTS FROM THE 1995 NATIONAL SPELEOLOGICAL SOCIETY NATIONAL CONVENTION IN BLACKSBURG, VIRGINIA

## ARCHAEOLOGY SYMPOSIUM ON CAVE ARCHAEOLOGY IN AND AROUND VIRGINIA

### CAVES AND CULTURE: HUMAN USE OF CAVE RESOURCES WITHIN THE CONTEXT OF VIRGINIA

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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 are an important prehistoric example. During historic times, the mining of saltpeter 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 uses of caves include 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 is usually 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.

### THE SKELETAL BIOLOGY OF INDIVIDUALS FROM LATE PREHISTORIC MORTUARY CAVES IN WESTERN VIRGINIA AND EAST TENNESSEE

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Over the past four years, extensive and, in some cases, intensive investigations have been conducted of prehistoric Native American mortuary caves in east Tennessee and southwestern Virginia. At least some of these sites appear to date to ~1000 to 500 years ago and some contain the remains of several individuals.

### FOUR THOUSAND YEARS OF NATIVE AMERICAN CAVING IN THE SOUTHERN APPALACHIANS

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Since the seminal work of archaeologists in Mammoth and Salts Caves, Kentucky in the 1960s, it has been known that prehistoric

Native Americans not only buried their dead in these caverns, but also intensively explored and mined this "dark zone" at least 4,000 years ago. When the glyph caves of Tennessee and Virginia were studied in the 1980s, these underground sanctuaries were found to be the scene of non-mortuary ritual as well. It was concluded at that time that Native American cave use over the past 4,000 years may have shifted from exploration to intensive mining of minerals until about the beginning of the common era. At that time, the increasing use of caves as burial places eventually led to their abandonment as sources for minerals, and by ca. 1,000 years ago only a few of these caves continued to be used for ceremonial purposes. The recent discovery of two additional glyph caves in Tennessee, one in Virginia, and two in Kentucky has resulted in a reassessment of this chronological sequence of prehistoric cave use. It also serves notice to modern cavers that the caves of our region still contain important undiscovered archaeological remains.

### INTEGRATING PROTECTION AND INTERPRETATION OF FRAGILE CAVE ARCHAEOLOGICAL RESOURCES: A CASE EXAMPLE FROM CRUMPS CAVE, KENTUCKY

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Since 1989, Crumps Cave (15Wa6), in the karst-rich region of south-central Kentucky that includes the Mammoth Cave system, has been the focus of archaeological research, specifically on the prehistoric Native American mud glyphs that cover hundreds of square meters deep within the cave. One aspect of this project has been the construction of what is claimed to be the second largest cave gate in the world to protect the cave from further vandalism, while at the same time allowing passage of fauna, including at least two species of endangered bats. In 1994, a video news feature, *Saving a Kentucky Time Capsule*, was produced on the archaeology of the cave and the endeavors to protect it. This feature ran continuously at the Kentucky State Fair, and aired a number of times on the Kentucky Educational Network (public television station). In this manner, close to a million viewers were reached about this important resource. An hour long national production is now planned. In this paper, I present a summary of the archaeology of Crumps Cave (vestibule and mud glyphs) and the effect of the video documentation for technical purposes and interpreting this fragile cultural resource.

### 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 had been vandalized to varying degrees. In addition to the burial resource inventory, goals of the

**BIOLOGY SESSION**

## A REPORT ON THE CAVE DIPLURA OF VIRGINIA

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An examination of 87 collections of diplurans from 65 caves in Virginia has revealed the following: one new undescribed species of *Mixojapyx*, family Japygidae, from a cave in Rockingham County; and at least six species of *Litocampa*, family Campodeidae, from the other caves in 12 counties in the southwestern part of the state. The *Litocampa* species in Virginia represent portions of three larger species groups. The most primitive species group and the most advanced species group are represented by two species each. The intermediate species group is represented by at least two species, although differences in the lengths of macrochaetae and body size of individuals of some cave populations suggest that there may be more. Cellulose acetate gel electrophoresis is being used in an attempt to help decide if these observed morphological variations represent specific or subspecific differences.

## OVERVIEW OF THE NATURE CONSERVANCY'S CAVE PROTECTION PROGRAM AND FUTURE INVENTORY NEEDS

Tina Hall, The Nature Conservancy of West Virginia, P.O. Box 3754, Charleston, WV 25337

The Nature Conservancy has a national mission to find, protect, and maintain natural biodiversity. In some states, much of this biodiversity is in caves. Stewardship staff within The Nature Conservancy of West Virginia conducted a national survey of Conservancy offices to determine the degree of protection that the Conservancy has offered to significant bat and invertebrate caves. Cave protection is a high priority in some states but can be increased. Many cave-rich states lack a link to the cave biology community to either identify or inventory potentially significant caves. In some states, bat protection is the priority with little attention given to invertebrates. Cave community classification has only begun in one or two states. The Conservancy would like to work more closely with the cave biology community to increase inventory and classification information.

AN ECOLOGICAL ASSESSMENT OF HARRISONS CAVE  
BARBADOS, WEST INDIES

Horton H. Hobbs, III., Department of Biology, Wittenberg University, Springfield, OH 45501

From 24 July to 01 August 1994, ecological investigations were carried out in Harrisons Cave, St. Thomas, Barbados, West Indies. Biological and physicochemical data were gathered in representative sections of the cave, with special attention directed to the stream(s) of the cave. Traps were placed in drip pools, pool and riffle sections of the streams, and in various terrestrial sites. Much effort was made in the commercial sections but undeveloped areas of the cave also were sampled.

Observations and raw data indicate that Harrisons Cave is impacted heavily by the totality of activity associated with the tour operation of the cave as well as from runoff from varied land uses, including areas in the environs of Welshman Hall, Allen View, and Welshmans Gully. Although no data are available for the cave prior to its devel-

MBCP include site protection and education. Two sites in Lee County and one in the town of Radford have been protected by gates and are chosen for discussion. All three cave sites displayed evidence of recent causal disturbance. Indian Burial Cave was known locally as a burial cave and has suffered desecration for decades. Looting of this site continued after it was initially inventoried, prompting gating. Bone Cave also was known locally as a burial site, although locals thought the burials were of black slaves. Apparently, disturbance to this site was minimal and largely surficial. Bone Cave was scheduled for destruction by a road building project until the MBCP and subsequent inventories revealed its significance as a Native American burial site. Adams Cave had been mined historically for saltpeter and had a long history of casual disturbance by high school and college students. Both the historic and the prehistoric significance of this cave had escaped recognition by the caving and science communities until a student brought a mandible and two long bone fragments to a college professor. Disturbed and exposed human skeletal components were removed, under permits, from all three sites for analysis and study.

## STABLE ISOTOPE ANALYSIS: A TOOL FOR CAVE ARCHAEOLOGY

Carmen C. Trimble, University of Virginia

To more fully understand a past civilization, knowledge about its subsistence strategy is necessary. Traditional methods of diet determination focus on an incomplete and 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 provide information about what may have been consumed. 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. Stable isotope analysis of human remains is an especially valuable research tool in archaeological sites where other dietary evidence may be missing or out of context.

## SCIENCE VERSUS GRAVE DESECRATION: THE SAGA OF LAKE HOLE CAVE

Thomas R. Whyte and Larry R. Kimball, Department of Anthropology, Appalachian State University

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 research 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 in limestone and dolomite formations of the Southern Appalachian region. Efforts should be made by federal and state agencies to discover cave sites and to protect them, as they are considered by the American natives to be sacred places.

opment, the presence of terrestrial and aquatic fauna in the undeveloped Natural Entrance section and their near absence in the tour sections suggest that the commercialization process has resulted in the extirpation of biota from much of the cave. A particularly obvious problem is associated with the erosion of rubber from tires of tour trams along the tourist route. This results in a "black stream," a true eye-sore in an otherwise crystalline white and tan environment, and the benthic habitat is adversely impacted. No aquatic fauna were found in any sections of the stream in the developed portions of the cave. A single organism (a nereid polychaete *Namalycastis* sp.) was found in fine sediments of isolated drip pools and only a few species of terrestrial organisms were noted. The main stream below Cascade Pool is severely impacted by "rubber-calcite" deposition. Numerous recommendations have been made to the government of Barbados to resolve the many historical and current anthropogenic impacts.

#### NEW DATA ON THE INVERTEBRATE CAVE FAUNA OF VIRGINIA

David A. Hubbard, Jr., Virginia Cave Board, Box 3667, Charlottesville, VA 22903 & John R. Holsinger Department of Biological Sciences, Old Dominion University, Norfolk, VA 23529

During a five-year period between 1990 and 1994, macroscopic invertebrate animals were collected and identified from 141 limestone caves in 22 counties in the Appalachian Valley and Ridge and from a copper mine and railroad tunnel in the adjacent Blue Ridge Mountains of western Virginia. Ninety-seven of the caves were biologically sampled for the first time. Approximately 100 different species were collected and identified, approximately 50 of which are troglobites. Taxonomic groups represented in the samples included snails, copepods, amphipods, isopods, millipedes, centipedes, harvestmen, pseudoscorpions, spiders, symphylans, diplurans, collembolans, dipterans, and beetles. The samples include 18 to 22 new (undescribed) troglobitic species, the majority of which are amphipods (*Stygobromus*), pseudoscorpions (*Kleptochtonius*), and beetles (*Pseudanophthalmus*). However, a significant number of new, non-troglobitic species were also included. Aside from the discovery of new species, important new records were established for described species, some of which were either very poorly known or believed extremely rare (such as some species of snails, amphipods, isopods and carabid beetles).

An important result from this study is that even karst regions which have been studied biologically for many years, such as in Virginia, there exist numerous biologically unsampled caves harboring undescribed species or previously unrecorded populations of described species. Similarly, even previously studied caves may have undiscovered new species or unrecorded populations of described species that may be revealed by systematic searching on repeated visits.

#### MARK-RECAPTURE ESTIMATION OF THE POPULATION SIZE OF *STYGOBROMUS EMARGINATUS* IN A STREAM IN ORGAN CAVE

Shannon Knapp & Daniel Fong, Department of Biology, The American University, Washington, D.C. 20016

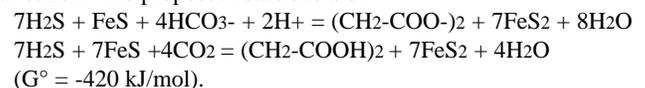
The population size of the troglobitic amphipod, *Stygobromus emarginatus*, in the Sively #2 stream in Organ Cave was estimated using the mark-recapture method. We sampled three sites in the stream channel in the lower half of the stream, and three sites of mud-bottomed pools adjacent to the channel in the upper half of the stream.

Recapture rates ranged from 20 to 50 percent in the stream sites, but ranged from only zero to three percent in the pool sites. Estimated population densities ranged from 10 to 30 per m<sup>2</sup> in the stream sites, and showed clear but not statistically significant differences among sites and over time. Estimated population densities ranged from 250 to 300 per m<sup>2</sup> in the pools sites, but the standard errors were large due to the low recapture rates. Spatial and temporal fluctuations in population densities at the pool sites are also evident.

#### PRIMITIVE METABOLISM IN ARCHAIC HYDROTHERMAL LAVA CAVES

Radu Popa, Department of Biology, The American University, Washington, D.C. 20016

The microspace and macrospace from basaltic lava, invaded by hot reduced water, represented a redox environment called here Hydrothermal Lava Cave (HLC). HLC is proposed as a good environment for a primeval chemolithotrophic metabolism. The redox interfaces from HLC (water/gas, water/mineral surfaces, water/water) were more stable in space and time than redox interfaces in deep sea vents, and hydrolysis was lower due to the subaerial and aphotic conditions. Recent studies suggest a thermal anaerobe progenote, related with sulfur. The proposed reactions are:



The redox catalysis was facilitated by two categories of peptides (some enriched in Arginine and some with iron-sulfur clusters) with a plausible existence in basalt microspace. Proton transport across membranes was coupled with a secondary phosphorylation on the oxidized side. Secondary phosphorylation and condensations of activated monomers occurred inside protocells. The mechanism is proposed as a primeval negetropic biological activity because the increase of the half life of the internal oligomers was dependent on energy derived from an exergonic process (a redox reaction).

#### DISTRIBUTION OF THE ELLETT VALLEY MILLIPEDE *PSEUDOTREMIA CAVERNARUM* COPE, IN VIRGINIA

Kevin Simon, Department of Biology, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061-0406

*Pseudotremia cavernarum*, the Ellett Valley Millipede, has only been found in caves in Ellett Valley, Montgomery County, Virginia. This troglobitic millipede is currently considered a threatened species in Virginia. When this millipede was described, it was known only from Erhart Cave. Erhart Cave was destroyed in the 1970s by quarrying. In recent surveys, the millipede was found in one new cave (Unnamed Cave A) and one previously reported cave (Daves Cave). Based on all cave records, *P. cavernarum* is restricted to four caves (Aunt Nellies Hole, Daves Cave, Heartbeat Cave, and Unnamed Cave A) near the former location of Erhart Cave. In recent surveys *P. cavernarum* was found from May to July, but individuals were more common in May. This millipede apparently emerges in early spring for mating. All specimens were found on damp organic material, usually wood. Damp organic debris may be an important food source for *P. cavernarum*. Although the species probably has a small geographic distribution, lack of intensive field sampling has certainly led to underestimation of both the range of the species and the number of caves harboring populations of *P. cavernarum*.

## CAVE RESCUE SESSION

### USING GIN POLES TO HELP ELIMINATE EDGE PROBLEMS IN RAISING AND LOWERING SYSTEMS

Arthur W. Dodds, Jr., 5029 White Flint Dr., Kensington, MD 20895

Rappelling, ascending, raising and lowering of litters and equipment are a problem at the edge of a cliff, building, or pit. The anchors and haul systems are normally at the same level as the lip, and the rope forms a right angle between the load and the anchors, developing stress and friction. The ideal attachment and/or final change of direction in a system, could be 6 or more feet above and a few inches beyond the edge. The rope does not make contact with the edge or the face, thus eliminating friction and need for rope pads. The object is to create a point, increasing the angle formed by the rope to be greater than 90 and equal to or less than 180 at the edge. This helps overcome problems and dangers associated with edge work. Raising or lower will be safer, quicker, and easier for you, your team, and your patient. You may do this efficiently, safely, and with materials commonly available at wilderness sites that are not necessarily carried with you.

There are a variety of prefab gins and gin pole arrangements for you to buy. They have various configurations, attachment points, and work well for the normal fire/rescue environment. Few, if any will provide you with the tailored, cut-to-length fit that will be required in wilderness or cave rescues. Examples of gins and gin poles can be found at the local blacksmith shop.

### SPECIALTY CAVE RESCUE EQUIPMENT - A FIELD REPORT

Butch Feldhaus, 614 N Valley Dr., Chattanooga, TN 37415

The RES-Q-AIRS Model HT 1000 Inhalate Delivery System and the Germa® Patient Immobilization Mattress have been used with great success by the Chattanooga-Hamilton County (TN) Rescue Service Cave/Cliff Unit.

The RES-Q-AIR® Model HT 1000 Inhalate Delivery System provides the hypothermia patient with warm (410C) saturated air (or air supplemented with oxygen) via face mask. This device was developed, and used successfully, as a tool to reverse the hypothermia which is a result of oil rig workers falling in the icy sea waters. It has made the transition to cave rescue very well.

The Germa® Patient Immobilization Mattress is a body-size vacuum split which has been used successfully in conjunction with the Femo® and SKED® litters. This mattress provides full-body spinal immobilization in the position of injury. It is very comfortable in that it conforms to the patients body unlike hardwood backboards, etc.

### TO TRAIN THE TRAINER

Jack T. Grandey, NREMT-P, ER/NCRC Supervisory Instructor, 862 N Beechwood St., Philadelphia, PA 19130-1437

Three years ago, the Eastern Region of the National Cave Rescue Commission (ER-NCRC) initiated an instructor development program directed at both the novice and experienced instructor. The goal was to provide improved instructional performance and quality control in its cave rescue training curricula.

Key to the program was the identification and promotion of several experienced instructors to the newly created position of supervi-

sory instructor. In addition to their regular teaching assignments, these individuals would be responsible for instructor monitoring at regular cave rescue training programs and instructing at an annual instructor refresher. Attendance at the annual refresher is mandatory for all eastern region personnel to maintain their teaching status.

The annual refresher has two tracks. For the new instructor, or those requiring skills remediation, the core content is fixed and covers principles of adult education, lesson plan development, evaluation & remediation, didactic presentation techniques, psychomotor teaching skills, and creation & use of visual aids.

Instructors with previous training receive lectures on specific areas of instructional technique that have been identified by the supervisory instructional staff and the region coordinator as a priority for the current year. Additionally, they perform mini-lessons in small groups, under the guidance of a supervisory instructor, critiquing one another and sharing instructional techniques. Lastly, the instructor staff is divided into groups according to their areas of special expertise to further work on the ER-NCRC cave rescue study guide or develop and refine audio/visual aids for specific subject areas of the cave rescue curriculum.

### \*REPLACE YOUR HYPOTHERMIA THERMOMETERS WITH A FUNCTIONING HUMAN BRAIN

Jack Hisson, 8716 Quarterhorse Dr., Indianapolis, IN 46256

Measuring and knowing the core temperature of your hypothermia patient in the cave has been important in cave rescue situations. But the necessity of getting a low reading thermometer or more sophisticated measuring and monitoring device on site has been overrated. Rectal probes have fallen into disfavor due to issues of patient tolerance, packaging, unpackaging, availability, and delays. Axillary reading have some of the same problems. We can make accurate guesses bases on signs and symptoms.

## CONSERVATION / MANAGEMENT SESSION

### DIFFERENTIAL CAVE MANAGEMENT IN TWO ADJOINING AREAS IN HAWAII COUNTY, HAWAII

William R. Halliday, Chairman, Hawaii Speleological Survey of the National Speleological Society, 6530 Cornwall Court, Nashville, Tennessee 37205

The world's leading area for studies of lava tube caves lies between Mauna Loa volcano and the East Rift Zone of Kilauea volcano in Puna District, Hawaii County, HI. Here members and cooperators of the Hawaii Speleological Survey have mapped more than 65 km of caves, including the world's longest lava tube cave: Kazumura Cave, which is 47 km long at present. A housing boom is occurring over many of these caves, and the county is planning extensive infrastructure developments in the cave area.

Just across the district line in Kau District is the caldera of Kilauea volcano. In 1994 and 1995 the Hawaii Speleological Survey identified, mapped, and inventoried numerous caves in this much-visited National Park. In addition to obvious management differences inherent in land stewardship in the two areas, major differences in cave management strategies will be needed to maximize protection of cave features, resources, and values. Other examples of marked differences in features, resources, and values exist in adjoining pseudokarstic and karstic areas elsewhere in the world. Such differ-

ences strongly support the concept of cave management by individual prescription rather than management by broad categorization.

TREVOR SHAW'S REPORT ON THE FIRST SPELEAN CINDERELLA  
"STAMPS"

William R. Halliday, 6530 Cornwall Court, Nashville, Tennessee  
37205

In 1994, noted speleohistorian Trevor Shaw published a definitive report on Cinderella advertising stamps, in German, of Austria's Lurgrotte cave system in a volume celebrating the Centennial of Lurgrotte. One set of these stamps was issued in 1906 and constitutes the first known spelean Cinderella "stamps." This material is part of a longer historical article on publicity for the cave. A manuscript copy exists in English, in addition to the German published text.

THE SLOANS VALLEY CAVE SYSTEM AND THE PULASKI COUNTY  
LANDFILL OR CAN AND SHOULD AN "OPEN SYSTEM" BE MANAGED?

Hilary Lambert Hopper, Sloans Valley Conservation Task Force

Popular, accessible, and challenging, the 42 km long Sloans Valley Cave System, located in southern Pulaski County, Kentucky, is a regional natural treasure. With 16 official entrances (and more rumored) on private and public lands, Sloans only protection against overuse has been its complexity, which can overwhelm even experienced cavers using the maps compiled by Louis Simpson, Dave Beiter, and other Ohio and Kentucky cavers and grottoes during the 1960s and '70s.

Adding to the challenge of protecting Sloans health is the Pulaski County Landfill, opened in 1980 on a strip mine site at the top of the cave system's drainage. By the late 1980s, cavers and landowners were concerned about the quantity and quality of sediment running off the landfill permit area, onto private property, and into at least one entrance of the Sloans Valley Cave System, which drains into Lake Cumberland, the region's water supply and recreational resource.

The Sloans Valley Conservation Task Force, NSS, was organized in 1992 with the short-term goals of ascertaining whether or not there was factual proof of a negative environmental impact of the presence of the Pulaski County Landfill on the Sloans Valley Cave System and adjacent karst features and the long-term goals of bringing management and protection to this wide-open system.

Our Task Force has worked in sublime cooperation with prominent cavers, cave scientists, NSS personnel, the Miami Valley and Dogwood City grottoes, and a Kentucky-based citizens action group, to bring about at least some measure of success in reaching both short- and long-term goals.

A REVIEW OF UNITED STATES CAVE PROTECTION LAWS

George N. Huppert, Department of Geography and Earth Science,  
University of Wisconsin - La Crosse, WI 54601

The first state cave protection act was passed in Colorado in 1883; unfortunately it was repealed in 1971. From that modest beginning there are now a total of 22 states, Puerto Rico, and the Cherokee Nation that have specific cave protection acts. Most of these have been legislated during the last 20 years. There are a number of laws on the federal level that can be used for cave protection, however this presentation will concentrate on the laws of specific states.

THE WORLD WIDE WEB AS A CONSERVATION TOOL

Rob Stitt, 1417 9th Ave. W, Seattle, WA 98119-3224

The Internet (sometimes known as the "Information SuperHighway") connects millions of computers throughout the world together into essentially instantaneous communications. The World Wide Web is a graphical hypertext interface that enables Internet users to post information, exchange e-mail, and collect information from users. To take advantage of this as a communications and educational tool, the Cave Conservation and Management Section has established a Web Home Page at <http://www.halcyon.com/samara/nssccms/>.

DIGGING SESSION

DIGGING PUT THE ORGAN CAVE SYSTEM TOGETHER

Robert Handley, West Virginia Association Of Cave Studies, Inc., 647  
Vorpe Rd., St. Albans, WV 25177

Most caves of any size have grown as a result of the extra efforts of explorers. Organ Cave has grown as a result of cave diving and the use of a rope toss, but it was primarily added to and connected together by digging open blocked passages. Reports of large cave passages encountered by water and well drillers and the closeness of Fox Hole Cave, which overlays Organ, whet the diggers resolved.

GEOLOGY SESSION

SPELEOGENESIS OF A GRANITE SOLUTION CAVE AT FORTY ACRE ROCK,  
KERSHAW, SOUTH CAROLINA

Sara H. Baldwin, 2036 Woodcliff Street, Charleston, South Carolina  
29414

Forty Acre Rock is approximately 15 kilometers northeast of Kershaw, South Carolina, near the transition zone between the Piedmont and the upper coastal plain. Covering fourteen acres, the rock consists of a large exposure of the Pageland Granite; a massive, coarse-textured gray granite with inclusions of fine-grained pink granite and felsitic andesite. Near the base of the steep eastern margin of the rock is a cave consisting of two ten-foot-long tunnels which slope upward into a low passage of unknown length parallel to the cliff face. Granite caves in the Lost Creek area of Colorado are reportedly the result of surface streams removing chemically weathered rock along joints. Other caves in granite are usually result from undercutting by streams, wave action, talus accumulation, or tectonic action. The cave at Forty Acre Rock, however, is apparently of true solutional origin. The tunnel roofs are scalloped, the walls smooth, and the tunnels seem to have little relationship to the joints in the granite.

The best evidence for a solutional origin to this cave lies in the existence of a readily available and highly aggressive source of water in the form of solution basins (opferkessel). The solution basins support an abundant growth of mosses, algae, grasses, sedums, and even small trees. The growth and decay of this vegetation produces carbonic and sulfuric acids which keep the water pH generally less than 5.0. Temperatures of the basin waters are usually well above ambient air temperature due to solar heat on the large bare rock surfaces. This hot acidic water is flushed out of the basins with every summer afternoon

rainstorm, where it undoubtedly seeps into the granite and becomes available to dissolve cave passages.

KARST HYDROLOGY AND GEOMORPHOLOGY OF THE BARRACK ZOURIE  
CAVE SYSTEM, SCHOHARIE COUNTY, NEW YORK

Kevin A. Dumont, P.O. Box 802, Troy, New York 12181

The Barrack Zourie Cave System represents an important karst system of the Cobleskill Plateau, east-central New York. Discovered in 1992, over five kilometers of passages have been surveyed at two distinct levels. Passages in the cave display a complex developmental history which is directly coupled with surface hydrology. The present hydrological role of the system is as a conduit for water insuring at Cave Mistake and Browns Depression, and resurging at Doc Shauls Spring after flowing through glacial material which fills a buried valley. Flow routes were proven by qualitative dye traces.

Minimum age of the system is 277 Ka, based on U/Th dates from speleothems. Fine-grained sediments found in the system are potentially stable carriers of the geomagnetic field. The system has survived and functioned through at least one glacial/interglacial cycle. Complex relationships exist between the system and the McFails and Howe systems of the plateau.

PIT CRATERS AND OPEN VERTICAL VOLCANIC CONDUITS OF  
HUALALAI VOLCANO, HAWAII

William R. Halliday, Hawaii Speleological Survey of the NSS, 6530 Cornwall Court, Nashville, Tennessee 37205

Na One Pit on Hualalai Volcano, with a depth of 263 m, is the deepest pit in the United States if water-filled depths of another Hawaiian pit are excluded. It is a compound volcanic structure consisting of an open vertical volcanic conduit opening near the bottom of a pit crater. Other open vertical volcanic conduits and other pit craters exist on this volcano. The deepest pit crater observed to date is about 200 m deep. The open vertical volcanic conduits are less easily observed and studied. Another type is known only in the vent area of the Kaupulehu ultramafic xenolith nodule area. The term pit crater is not clearly defined, at least in common usage, and no consensus exists on whether some or all pit craters should be considered speleological phenomenon or even pseudokarstic.

THE HYDROLOGY AND CHEMISTRY OF COON LAKE DRIPS, MYSTERY  
CAVE, MINNESOTA

Roy A. Jameson & E. Calvin Alexander, Jr., Department of Geology and Geophysics, University of Minnesota, Minneapolis, Minnesota 55455

Coon Lake Drips (CLD) in Mystery Cave, Minnesota, was monitored for drip rate, water temperature, conductivity (continuous data acquisition system), and ions and environmental parameters (grab samples) between February 1993 and January 1995. Drip rates ranged from winter lows of 0.25 l/hr to storm peaks of nearly 14 l/hr. In March 1993, successively warmer days resulted in diurnal snowmelt cycles. CLD drip rates became cyclic with peaks that lagged 7, 4.5, and 7.5 hours behind air temperature peaks. The snowmelt cycles were interrupted when 4.34 cm of rain melted the snowpack, resulting in widespread flooding of the Root River and Mystery Cave. CLD responded with a rise in drip rates to 6.5 l/hr, a

chaotic fluctuation (2-6 l/hr), and a rise to sustained high flows (5-7.5 l/hr).

Additional storm hydrographs and fall-winter hydrograph recessions reveal a complicated hydrologic response. Recharge passes through soil and loess (6-9 m) via matrix flow and preferential flow through macropores and gopher burrows. The flow continues through a possible rudimentary subcutaneous zone and fractured bedrock to emerge as a flowstone flow on a wall about 18 m beneath the surface. Recharge ponds upflow of the drip site induced a piston flow that ejects water at CLD within 15 minutes to several days following the onset of recharge. The ejected water lacks a distinct event signal in temperature or conductivity, though seasonal signals in conductivity and other chemical parameters were observed.

SINKHOLE BACK-FLOODING  
A LOCALIZED KARST HAZARD IN VIRGINIA

David A. Hubbard, Jr., Virginia Cave Board, Box 3667, Charlottesville, VA 22903 & Terri Brown, 1500 E. Main, Suite 312, Richmond, VA 23219

A series of back-flooding sinkholes in the Front Royal area of Warren County, Virginia may represent a significant threat to potential karstland residents. A highway construction project along U.S. Highway 340 resulted in an investigation of a number of epiphreatic sinkholes that flood in response to local groundwater fluctuations. Floodwater levels of up to 13 m have been observed boiling-up in these sinkholes. The local aquifer is partially recharged by two sinking streams draining the Dickey Ridge area of the Shenandoah National Park and adjacent private property. One sinking stream flows north through the Park and sinks near the Park Entrance; the other stream sinks east of Skyline Caverns. During precipitation events, additional hydraulic head is apparently the result of surface runoff channeled from a relatively new subdivision into a sinkhole along Browntown Road. Concerns are that development in the areas containing the back-flooding sinkholes at Riverside may result in: subsidence of sinkhole fills, formation of new sinkholes, and the back-flooding of nearby currently unaffected sinkholes. An additional concern is that further development, adjacent to the affected area, will result in additional karst groundwater inputs enhancing the risk of new karst hazards including: subsidence, flooding, and groundwater pollution in this extremely active karst area.

EARLY RESULTS FROM THE HAWKINS RIVER SITE  
MAMMOTH CAVE, KENTUCKY

Joe Meiman, Div. of Science & Resource Management, Mammoth Cave National Park Mammoth Cave, Kentucky, 42259 & Christopher G. Groves, Center for Cave & Karst Studies, Dept. of Geography & Geology, Western Kentucky University, Bowling Green, KY 42101

Hawkins River is one of the major underground streams draining (and forming) the Mammoth Cave System. Two major tributaries, the Left and Right Forks of Hawkins River, converge within the Proctor Cave section of the system, and the waters then flow on to eventually emerge at Turnhole Spring on the Green River. A continuous, long-term water monitoring program is currently underway to understand storm- and seasonal-scale changes in water chemistry through two 140 m deep wells, one in each fork of the river a short distance upstream from their confluence. Continuously measured variables include stage height, velocity, temperature, and specific conductance,

and complete, short interval water chemistry measurements made during storms of varying magnitudes.

Because the rivers are draining large catchments, much of which lie outside of Mammoth Cave National Park, contaminants pose a threat to the sensitive ecosystem within the cave system. One of the purposes of the project is to evaluate the nature of that impact. The entire area draining to the study site is within a United Nations International Biosphere Reserve. Understanding storm-scale variations in water quality will also provide information on the physical nature of the flow system, as well as aiding the development of strategies for the effective monitoring of karst aquifers in general.

Another major emphasis involves measurement of parameters that describe the behavior of the carbonate system and the nature of the limestone dissolution process. This helps us to understand cave forming processes, as well as to field test dissolution kinetics rate laws, which are an essential component of models describing evolution of karst landscapes and flow systems.

GOVERNMENT PROGRAMS AND THE  
REGULATION OF DYE TRACING: THE FUTURE

Albert E. Ogden, Department of Earth Sciences, 340 Brackett Hall, Clemson University, Clemson, South Carolina 29634

Due to an increasing use of groundwater tracers in the environmental business, government regulators have become concerned with the potential of cross contamination of traces that could lead to false positives, and also with the qualifications of those conducting the work. As a result, some of the states containing significant karst areas are requiring "registration" before conducting a groundwater trace. In Tennessee, this is handled through the Underground Injection Control Program. In Kentucky, you must notify the Division of Water. The Department of Natural Resources in Missouri requires a groundwater professional to become a "Registered Dye Tracing Expert." Arkansas requires that a study plan be prepared and submitted to the Department of Pollution Control and Ecology before conducting a trace. Virginia's Department of Environmental Quality presently considers the use of groundwater tracers degradation of water quality, but state agencies and consultants solving pollution problems are using groundwater tracers. In four other states surveyed, there is no official registration or regulation of groundwater tracing. Since all states consider the discoloration of water an offense, prudence dictates that cavers, consultants, and local environmental field offices should be well informed before conducting a dye trace.

AN EXAMINATION OF SHORT-TERM VARIATIONS IN WATER QUALITY AT  
A KARST SPRING IN KENTUCKY: HOW TO ACCURATELY DETERMINE  
THE WATER QUALITY OF A KARST CONDUIT FLOW SYSTEM

Martin Ryan, ERM Southeast, Inc., 215 Centerview Drive, Suite 110, Brentwood, Tennessee 37027 & Joe Meiman, Division of Science & Resource Mngt., Mammoth Cave National Park, Mammoth Cave, Kentucky 42259

Water quality at many karst springs undergoes very high amplitude but relatively brief degradation following influxes of runoff. Accurately recording transient variations requires more rigorous sampling strategies than traditional methods. A pilot study to determine the usefulness of high-frequency, flow-dependent sampling strategies, combined with coincidental quantitative dye tracer tests, was imple-

mented in the Big Spring Groundwater Basin in Mammoth Cave National Park.

Data recorded following two separate runoff events showed that the concentrations of two nonpoint source pollutants, fecal coliform bacteria and suspended sediment, greatly exceeded pre-runoff event values for very short periods of time. A phreatic conduit segment (calculated at 17 million liters in volume) instantaneously propagated head changes, caused by direct runoff entering the aquifer, from groundwater inputs to Big Spring. The results were a significant delay between the initial increases in discharge and the arrival of direct runoff at Big Spring. The delay showed that even by sampling a karst spring only during peak discharge would be an unreliable sampling method.

Runoff from two different subcatchments was tagged with tracer dye and the timing of the passage of the resultant dye clouds through Big Spring were compared to water quality variations. Distinct lag times between the arrival of direct runoff at Big Spring and the bacteria and suspended sediment waveforms were shown through the concurrent quantitative tracer tests to be related to the areal distribution of land-cover type within the basin.

THE OCCURRENCE OF CAVES ON THE CUMBERLAND PLATEAU  
ESCARPMENT OF KENTUCKY, TENNESSEE, GEORGIA, AND ALABAMA

Ira D. Sasowsky, Nittany Geoscience, Inc., 120 Radnor Road, State College, Pennsylvania 16801

The Cumberland Plateau Escarpment is a persistent topographic feature which separates the Cumberland Plateau from the Interior Lowlands (to the west) and the Valley and Ridge (to the east). Its relief ranges from about 100 to over 300 meters. Thousands of caves are known in the Escarpment, and it is host to many of the long caves of the eastern U.S. The occurrence and form of the caves is strongly controlled by stress release fracturing. Caves form within the walls of the Escarpment, and rarely penetrate beneath the caprock of the Plateau.

The longest caves form parallel to the valley walls of coves which are incised into the Plateau. These "Cumberland Style" caves are characterized by broad, sinuous trunk passages which are developed on distinct levels. The trunks represent former (or active) drainage routes for the entire flow of the basin, and are usually developed on the down-dip side of the valley. Shorter caves form directly on the face of the Escarpment. These include many contact caves, and pits, and some multi-drop systems. All show a stronger control by stratigraphy and have a more limited hydrologic function than the Cumberland Style caves.

The occurrence of caves in other escarpment settings is similar. Caves from New York, West Virginia, and Arizona all show common features, particularly parallelism of the cave with the escarpment.

IMPROVING FLUORESCENT DYE TRACING THROUGH ENHANCED DYE  
RECOVERY FROM PASSIVE ACTIVATED CHARCOAL RECEPTORS:  
DISCUSSION OF TWO EXPERIMENTS AND RESULTS

Mark Turner, 4601 Packard Dr. Apt L-133, Nashville, TN 37211-1212

Methods of detection of fluorescent dyes employed in karst hydrologic tracing have greatly improved over the past thirty years. However, the recovery methods used in extracting dye from activated charcoal detectors have remained fairly static since the 1970s. The author has performed a series of experiments to improve recovery of

dye from activated charcoal detectors. The critical areas of concern identified are: preparing the detector for extraction, volume of eluent to weight of charcoal ratio and choice of eluent for recovery of various dyes. Results suggest that detectors should be air dried after collection and washing; that of the volume to weight ratios tested, a 10:1 ratio yielded best stable peak fluorescence for Rhodamine WT, limiting re-adsorption of the dye and that Smart Solution and a propanol-based sodium carbonate eluent (Turner-1 Solution) were the superior dye extraction agents for the recovery of both Fluorescein and Rhodamine WT, of those eluents tested, from activated charcoal.

A REEXAMINATION OF GEOCHEMICAL KARST DENUDATION  
CALCULATION AND VALIDATION BY STREAM INCISION RATES

George Veni, George Veni and Associates, 11304 Candle Park, San Antonio, Texas 78249-4421

Several methods are used to calculate denudation rates in karst areas. Two primary techniques involve calculations based on measured chemistry of spring discharge and on theoretical expression of carbonate dissolution. Significant variation in results occur where nonspring-based calculations include denudation by surface runoff that does not enter the aquifer. For comparable results, equations must be adjusted to reflect differences in recharge versus runoff. Denudation equations can also be combined to estimate the size of spring drainage basins using measured water hardness and denudation as calculated by methods not relying on known basin size.

Denudation calculations adjusted for recharge-runoff differences and the calculations of drainage basin areas were validated by application to the Lower Glen Rose Aquifer in south-central Texas. Relict geomorphic features were used to estimate denudation by calculating the differences in elevation versus their known age. This method was used in interstream areas and was especially useful in streams. However, adjustments were necessary for a major knickpoint migration through the drainage network. In the Lower Glen Rose Aquifer, denudation was geochemically calculated at 21-24 mm/Ka and at 25 mm/Ka based on the incision rate of the Guadalupe River. Use of these rates to determine the age of aquifer and cave development favorably compares with ages derived from speleothem dating, paleontological material, and paleoclimatic changes. Similarly favorable comparisons occur between the potentiometrically derived size of the aquifer's Honey Creek Cave drainage basin with the size calculated from denudation rates.

THE METEOROLOGY OF HARRISONS CAVE, BARBADOS, WEST INDIES

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During the period 24 July through 01 August 1994, a team of speleologists from the United States, representing the National Speleological Foundation, conducted studies in Harrisons Cave, Barbados, West Indies. Barbados is a small island in the Caribbean Sea about 2500 km (1550 miles) southeast of Miami, just north of Venezuela. The center of the island is near 59.5° west longitude and 13.0° north latitude. The climate of Barbados is mild, breezy, and sunny year-round, with an average surface temperature of about 27°C (80°F). Harrisons Cave, a show cave owned and operated by the government of Barbados, is located near the center of the island at an elevation of approximately 250 meters (820 feet) msl.

Seven sets of temperature, partial pressure (due to water vapor), and relative humidity measurements (64 measurements in total) were

obtained at eight locations within the cave and one location on the surface, allowing spatial variations to be studied. The measurements were clustered at near-noon and near-midnight, allowing temporal variations to also be explored. Statistics of the measurements, shown in the table below, indicate that the cave environment is remarkably constant.

The detailed data show that diurnal variations are minimal; however, variations with elevation and distance from entrances are detectable. What appears at first glance to be a variation with elevation in the cave (higher temperatures occurring at higher elevations) turns out to be caused mainly by cave air flowing over bodies of cooler water. Clouds form in the entrance passage.

| GROUP             | # OF MEASUREMENTS | TEMP.                      | PARTIAL PRESSURE                      | RELATIVE HUMIDITY |
|-------------------|-------------------|----------------------------|---------------------------------------|-------------------|
| In-Cave + Surface | 64                | 78.3 ±0.9°F<br>27.5 ±0.5°C | 0.947 ±0.042 in Hg<br>24.1 ±1.1 mm Hg | 98.1<br>±3.0%     |
| In-Cave           | 55                | 78.4 ±0.3°F<br>25.8 ±0.2°C | 0.962 ±0.007 in Hg<br>24.4 ±0.2 mm Hg | 99.1<br>±0.5%     |
| Deep Cave         | 48                | 78.4 ±0.3°F<br>25.8 ±0.2°C | 0.962 ±0.007 in Hg<br>24.4 ±0.2 mm Hg | 99.1<br>±0.5%     |
| mean              |                   | ±0.1°F                     | ±0.004 in Hg                          | ±0.5%             |
| error             |                   | ±0.06°C                    | ±0.1 mm Hg                            |                   |

THE ELLENVILLE (NY) CREVICE GEOMORPHIC PROCESSES ACTING ON  
STRUCTURAL AND STRATIGRAPHIC FEATURES

Eberhard Werner, P. O. Box 795, Morgantown, West Virginia 26507 & Douglas Medville, 11762 Indian Ridge Rd., Reston, Virginia 22092

Crevice complexes are found in the massive sandstone/ quartzite beds throughout the Appalachian Mountains. The Ellenville Crevice complex, developed in the lower member of the Shawangunk Formation, is unusual in magnitude and development. Most crevices are a few meters in vertical extent and a few tens of meters long; the Ellenville Crevice complex contains several segments which are hundreds of meters long and tens of meters in vertical extent. The other crevices have developed by the opening of prominent regional joints as rock cities located a few tens of meters from an escarpment; the Ellenville Crevice complex has no escarpment directly associated with it, and has not developed along any regional joint set. A large block slide, slipping on the surface of underlying shales, has several crevice-type openings near its upper edge, some of which are roofed by differential slip within the main block or breakdown from the crevice edge which is wedged lower in the opening. A similar, but somewhat larger block slide just to the south of the area containing the crevice complex has been mostly removed by subsequent erosion. Geomorphic indications are that the slides occurred during the last Late Wisconsin glacial events. Different thicknesses of tills indicate that the southern slide was the earlier one, and probably occurred before the last ice advance, and the block forming the crevice complex began moving near the end of the last ice advance, probably when the ice sheet began melting which provided water for lubrication of the underlying shale surface as well as hydraulic push to help move the block.

## GEOLOGY SPECIAL SESSION: KARSTMAP

### INTRODUCTION TO THE SPECIAL SESSION

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

While more caves have been mapped in the U.S. than in any other country, maps defining its karst areas are incomplete, inadequate, and sometimes inaccurate. KARSTMAP is a project of the Section of Cave Geology and Geography, and its purpose is to produce detailed and high quality maps that delineate our nation's karst.

### SELECTED KARST FEATURES MAPPING IN VIRGINIA

David A. Hubbard, Jr., Virginia Department of Mines, Minerals, and Energy, Division of Mineral Resources, Box 3667, Charlottesville, VA 22903

Maps of selected karst features are published (1:250,000 scale) for two of the three sections of Virginia's Valley and Ridge Physiographic Province. Karst features selected to define the relative degree of karstification are sinkholes (karstic closed-contour-depressions) and cave entrances. The term sinkhole refers to: dolines, blind valleys, poljes, uvalas, etc. Sinkhole locations are determined by stereoscopic viewing of low altitude (approximately 4,000 m) panchromatic, aerial photography taken during leaf-off seasons. Cave entrance locations are from published and unpublished sources and the symbology only indicates a single or multiple entrance location. Karst features are plotted on a carbonate bedrock map differentiating sequences of Cambrian-Ordovician limestones interbedded with dolostones, middle-Ordovician limestones, Devonian-Silurian limestones, Mississippian limestones or non-carbonate rocks. The base map contains cultural and hydrological features, but no topographic contours.

Questionable features have been field checked. Problems arose with pseudo-sinkholes such as ancient-landslide sag ponds and old, open-pit mines. Additional problems have been posed by inaccurate TVA topographic maps on late 1940s bases, on which up to 10% of the features shown as sinkholes are misidentified. They are not topographic depressions and include hills. A number of features depicted as hills are sinkholes.

Mapping of the third and final Valley and Ridge Province karst section is in progress. Although sinkhole and cave entrance features may present a fair representation of the degree of karstification in Virginia, these features may not appropriately depict the relative degree of karstification in other areas of the United States.

### REGIONAL MAPPING OF KARST TERRANES IN OKLAHOMA

Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Rm. N-131, Norman, Oklahoma 73019 & James F. Quinlan, Quinlan and Associates, Box 110539, Nashville, Tennessee 37222

The Oklahoma Geological Survey will prepare a map of the State at a scale of 1:500,000 to show karst terrains and associated environmental problems in Oklahoma. Surface and near-surface carbonates (limestone and dolomite) comprise about 6% of the surface area of the State, whereas sulfates (gypsum and anhydrite) comprise about 4% of the State. Areas of carbonates and sulfates will be differentiated and

mapped separately as two zones: in zone 1 they are 0-6 m deep, and in zone 2 they are 6-30 m deep. Areas underlain by bedded salt (halite) within 300 m of the surface comprise 14.6% of the State, and they will be mapped as zone 3.

### THE PENNSYLVANIA CAVE DATA BASE

Keith D. Wheeland, 2191 Mountain View Avenue, State College, PA 16801

The Pennsylvania Cave Data Base was designed to include geological, biological, and hydrological data, cave access information, and the usual name, length, map status, quadrangle, and coordinate information, all in computer accessible form. New cave discoveries are entered as information is received and existing entries are continuously updated. Information contained in the data base can be displayed on a map of Pennsylvania in various ways. A dot map of cave entrance distributions has been prepared.

### A KARST ATLAS FOR THE UNITED STATES: CONCEPT, JUSTIFICATION, FEASIBILITY, AND HOW TO EXPEDITE

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

At present, the only document showing the distribution of karst in the United States is the Davies map published by the United States Geological Survey in 1986. The Davies map displays only areas underlain by karstic rocks with no indication of the type of karst or the intensity of karst development. If the maps were expanded from national to state scale, the types of information that could be displayed include: (a) Geology as outcrop area of limestone, dolomite, gypsum, or other karstic or pseudokarstic rock. (b) Surface landforms, mostly closed depressions, displayed as dot patterns, or mapped as some sort of intensity pattern. (c) Cave distributions either as dot patterns on a state scale or as some sort of cave length/unit area mapping. (d) Patterns of underground drainage. Data for constructing (a) are generally available from State geological maps and for some states there are limestone maps. Data for (b) are readily available on topographic maps but in this case there is too much detail on too fine a scale and the problem is to generalize the information. Most states now have cave data bases generated privately by caving groups. These data bases are computerized to varying degrees and there is also a greatly varying degree of public access to the data. Hydrological maps are the greatest challenge because there is very little systematic data in any form. Rather than a single map or set of maps, an atlas format with provision for text and photographs seems a desirable device for the systematic display of information.

## HISTORY SESSION

### THE HISTORY OF DURHAM CAVE, PENNSYLVANIA

Bert Ashbrook, 1257 Lehigh Parkway South, Allentown, PA 18103-3875

*"The Cave, called the DEVIL'S HOLE, lying in Durham township, Bucks County, Pennsylvania . . . certainly ranks among the natural curiosities of this country, and deserves publicity whilst it has been but barely noticed by historians."* A VISITANT, 1802

Now known as Durham Cave, this cavern was open during the last ice age and was occupied by several species now extinct or locally extirpated. Archaeological and historical evidence suggests Indian occupation until 1728. Eighteenth-century publications manifest that the cave was widely known. During the Revolutionary War, the Continental Congress attained the cave's owner of treason, confiscated the property (which had an iron furnace), and leased it George Taylor, a signer of the Declaration of Independence. In 1802, the cave was the subject of a minute description and temperature study.

In the nineteenth century, Durham Cave was surrounded by new iron furnaces, forges, quarries, lime kilns, railroad tracks, a canal, wharfs, and roads. Quarrying began destroying the cave c. 1850. By the 1870's, half the original 90 m of passages were destroyed, and quarrying under the drip line widened the remaining passage to 20 m in places. The huge room, now opened to daylight, only increased the cave's renown. Meetings and church services were held inside the ever more popular cave.

Several paleontological and archaeological excavations at Durham Cave from the 1840's until the 1980's were done by the likes of Henry Rogers (Pennsylvania's first state geologist), Henry Mercer (early archaeologist and speleologist), Joseph Leidy (vertebrate paleontologist), and Frederick Grady (Smithsonian paleontologist).

THE SEARCH FOR THE CAVE FROM WHICH THOMAS JEFFERSON  
DESCRIBED THE BONES OF THE MEGALONYX

Fred Grady, 1201 S Scott St. Apt 123, Arlington, VA 22204-4655

In 1796, Thomas Jefferson was sent some bones from a cave in Greenbrier County, Virginia. Jefferson described these bones, a femur fragment, ulna, radius, and some foot bones, as a new genus of mammal, *Megalonyx*. Jefferson reported the bones were found by saltpeter workers and gave the cave owner's name as Frederic Crower, an apparent mis-spelling of Frederic Gromer. Correspondence between Jefferson and John Stuart who sent him the bones, indicates the cave was about five miles from Stuart's home and contained saltpeter vats. While Organ Cave has been previously cited as the location of this discovery it can be eliminated as it was never owned by Gromer. The discovery of two letters written by Tristram Patton the next owner of the cave indicates the cave was in Monroe County near Second Creek. Monroe County was separated from Greenbrier County shortly after the discovery of the bones. Patton described the cave and the indicated more bones were there. This information and other material accumulated over several years leads me to suggest that Haynes Cave was the actual discovery site. Two years ago, two fragments of a *Megalonyx* scapula were found in Haynes Cave and tend to support this suggestion.

AN INFORMATIVE PIGEON RIVER, N.C. NITRE DEPARTMENT ENVELOPE

William R. Halliday, Hawaii Speleological Survey of the NSS, 6530 Cornwall Court, Nashville, TN 37205

In 1993, I acquired a stampless envelope addressed to Charlie W. Slagle, Franklin, N.C., with a hand-written "manuscript" postal cancellation stating "Pigeon River NC Paid 10. In the corner appropriate for a return address is the hand-written statement : Nitre Department Official Business.

No caves are known near Pigeon River, N.C. although the Confederate also manufactured saltpeter from passenger pigeons droppings.

THE CAVE OF NEW YORK'S CITY'S CENTRAL PARK: A FORGOTTEN  
MARVEL

Cato & Susan Holler, P.O. Box 100, Old Fort, NC 28762

Caves occur in the strangest places. A once popular but now almost forgotten cave in New York City's Central Park is a good example. Part natural and part artificial, the little cave at one time provided a much-appreciated source of adventure to park visitors. One could visit the cave from the lakefront by either rowing up to the entrance in a boat or by descending a series of steps hewn out of the rock along the shore. At the far end of the narrow passage was another entrance to the north.

Unfortunately, it was necessary to close the cave somewhere around 1930 due to its misuse by tramps. Both the waterfront and landward entrances remain sealed. Today, homeless individuals can be seen occupying the shallow shelter of the lakeside entrance.

There are no immediate plans of reopening the little cave due to safety considerations. We can still enjoy 19th Century photographs and documentations.

CATACOMBS OF YUCATAN: A BRIEF BLINK IN AMERICAN SPELEAN  
HISTORY

George N. Huppert, Department of Geography and Earth Science,  
University of Wisconsin - La Crosse, WI 54601

The Catacombs of Yucatan (also called Black Hammer Cave) is located in southeastern Minnesota in Black Hammer Township of Houston County. The cave was discovered in the late 1870s or early 1880s by local landowners. There were reports of burials and other artifacts found in the cave but, if they ever existed, there is no evidence of it now.

For a short time in the early-to-mid 1930s, the cave was the scene of a thriving commercial enterprise. This short-lived business included not only the show cave (small and of minimal quality) but also tourist cabins and a restaurant/night club. The cave was electrically lit which was unusual for a show cave in a very rural setting in the 1930s. The power source was an on-site generator in its own powerhouse. Barely a trace of the cave improvements remain today. The buildings have been moved to other locations, the road and parking area have been plowed over and, sadly, the cave has suffered great damage by vandals. The business lasted only a few years, a victim of its isolated setting and the "Great Depression".

KARST, CANNON AND CAPTAIN MARSHALL

Hal Joerin, 2828 Red Leaf LN., Southfield MI 48076-2929

A review of the literature detailing events of the Battle of Stones River during the American Civil War allude to the landforms aiding Confederate forces in the capture of Union artillery. These features have been described variously as rocks, boulders, limestone ledges and even mud. An examination of the ground itself reveals features of interest to an observer aware of karst terrain.

THE MASON/DIXON CAVE AND THE SIGNIFICANCE OF ITS  
DOCUMENTATION

Patricia A. Rosevear & Richard E. Rosevear, 1236 Union Street,  
Allentown, PA 18102-4610

During the survey of the boundary between Pennsylvania and Maryland, Charles Mason and Jeremiah Dixon took an excursion to visit a cave. Mason described the cave in his journal entry for 22 September 1765. The late Russ Gurnee thought that this may have been the earliest documentation of a cave in the United States.

William Davies stated in 1966 that Jonathan Carver's 1778 account of his 1766 exploration in Carver Cave, Minnesota was the oldest mention of a large cave in the United States. Durham Cave in Bucks County, Pennsylvania has also been suggested as the earliest documented United States cave because of its inclusion on Schull's map of the Province of Pennsylvania in 1770.

The location of the "Mason/Dixon Cave" was determined and documentation predates even Mason's account. Joseph Spangenberg gave a general location and description of the cave in 1748.

The cave has rich history as a saltpeter and commercial cave. Native American artifacts and the bones of prehistoric animals have also been excavated from the cave.

**INTERNATIONAL EXPLORATION SESSION**

GUNUNG BUDA EXPEDITION, SARAWAK, MALAYSIA

Dave Bunnell & Djuna Bewley, 320 Brook Rd., Boulder Creek, CA 95006

Sixteen American and two British cavers joined guides from Mulu National Park on a two-month expedition to Gunung Buda, a limestone massif just north of the park. From the beginning, we found plenty to explore and surveyed over 29 km in 18 caves. The largest of these, Green Cathedral, connected to the previously mapped Beachcomber complex, netting over 10 km for the system. Climbers pushed a series of phreatic ramps in the Snail Shell system to a height of over 490 m, making it Borneo's deepest (or tallest?) cave. An unusual fissure in a large sink was pushed to a sump at -139 m, the deepest known pit in Borneo. The "Big Feature", an intriguing sink that thwarted earlier exploration efforts, revealed 200 m of grand borehole leading to a sump.

Many of the caves were characterized by unusual corrosional features, including guano-carved potholes and forest of pinnacles up to 5 m high. Cave life included large poisonous spiders and centipede, snakes, white and black crabs, many bat species and large swiftlet populations.

While many leads remain, the expeditions findings thus far may have sparked sufficient government interest to declare Gunung Buda a national park, bringing a halt to destructive logging practices in this sensitive karst region.

CAVE EXPLORATION IN BULGARIA

Charles Crandell, P.O. Box 5193, Sun City West, AZ 85375

Under the former Eastern Block alliance Bulgarian caver pushed the limits of their former socialist government. When everyday Bulgarians could not travel internationally, cavers of this eastern European country were conducting expeditions in Spain, Cuba, and

Armenia. The "National Speleological House", in the middle of the Karlukovo Karst Region, is a testimony to their zeal and craftiness. Today, Bulgarian cavers are on the forefront of entrepreneurship and speleology.

INLANDSIS 1994: GLACIAL SPELEOLOGY INTO  
THE GREENLAND ICESHEET

Diana Gietl & Marc Tremblay, 11700 Avenue Royale, Beaupré,  
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The Greenland ice sheet (inlandsis) margins are subject to a melt-water process making subglacial drainage tunnels. The exploration of those ice caves is generally hazardous at the resurgence level but possible at the inlets, usually vertical shafts that require combining single rope techniques with ice-climbing skills. This enables modern scientists to peer directly into the glacier instead of staring at ice cores. During September 1994, a team of 13 spent 2.5 weeks on the inlandsis exploring ice caves at about 50 km east of Kangerlussuaq, 25 km into the ablation zone. The site is located just north of the arctic circle on the west coast.

In a karst-like fashion, the surface meltwater enters fractures which enlarge into immense shafts. The French call these shafts "moulins" or watermills because of the groaning noise of water cascading down. There is a critical time period for visiting the moulins. Too early in the season, the volume of 00 C water prohibits entry and too late, snowfalls cover the entrances.

Studies of the inlandsis attract scientists like glaciologists researching mechanics and hydrogeology of the immense glacier or biologists looking for the tiny organisms trapped in the ice. The expedition explored and mapped eight moulins which averaged between 20 m and 60 m deep with the exception of Paaqitsoq, which was bottomed to a deep lake at 80 meters of depth. The same moulin was explored down to 175 m the previous year, still the deepest explored in ice.

EXPLORATION AT ARROYO GRANDE, CHIAPAS, MEXICO

David R. West, 13610 Arctic Ave., Rockville, MD 20853

Over a six year period, an international group of cavers explored and surveyed caves and pits in a 25 km<sup>2</sup> valley in this southern most Mexican state. There are both long horizontal developments as well as deep pits.

Early on we began a "resurvey" of Cueva del Arroyo Grande. A demand for two degree accuracy on mandatory backsights and quality sketches assisted with connections, and the cave is currently the state's longest at 10,222 m. It lies within meters of connecting to Cueva Queso Grande, which has an additional 2,267 m of surveyed passage. Many entrances and ease of traverse have made for pleasant surveying.

Many 100 m to 200 m pits have been surveyed, as well as two pits which are 278 m and 283 m deep. We have surveyed more than 30 caves or pits and have covered relatively little of the valley.

**PALEONTOLOGY SESSION**

THE FIRST RECORD OF ARCTODUS SIMUS FROM VIRGINIA

Fred Grady, 1201 S Scott St. Apt 123, Arlington, VA 22204-4655

The discovery of a partial skeleton of the extinct giant short faced bear *Arctodus simus* from Island Ford Cave, Alleghany County is the first discovery of this species in Virginia. The skeleton was discovered in a tight muddy passage and consists of much of the skull, one side of the mandible, vertebrae, rib parts, sternum parts, scapula parts, both humerae, 1 ulna, 1 radius, most of a front foot, pelvis parts, 1 femur, 1 tibia, 1 complete fibula and part of another fibula, 1 complete hind foot, and 2 ankle bones from the other hind foot. The skeleton is of a relatively small individual especially with regards to the dentition. It is a mature adult individual and probably a female.

#### IS THIS CAVE PALEONTOLOGICALLY SIGNIFICANT?

David A. Hubbard, Jr., Virginia Cave Board, P.O. Box 3667, Charlottesville, VA 22903

By 1985, approximately 2,500 caves were recorded in Virginia, 224 (9%) of these caves were included on the Virginia Cave Board's revised Significant Cave List. Only 12 Virginia caves were recognized as paleontologically significant.

Vertebrate skeletal accumulations in caves result from pit falls, anthropogenic activities, animal lairs, roost sites, wash-ins, etc. No less potentially significant are pollen and invertebrate remains incorporated in speleothems. Most of these example deposits are at least partially obscured and their study results in the destruction of the deposits. The study of such deposits must be conducted by or directed by professionals. These deposits are protected in Virginia by State law. In some cases, the fossils themselves may be less important scientifically than the context in which they were deposited. Context determination may require far more knowledge and attention to detail than the comparative work typically required to identify the organisms.

The fossils existing in the rocks in which caves are formed may be paleontologically significant and are typically exposed in rock outcrops. In Virginia's covered karst, the fossils in the carbonate rocks may be more readily observed in caves than in weathered outcrop. The occurrence of some exposed fossils may warrant the listing of a cave as paleontologically significant. Such fossils exposed in caves are protected by state law, but observation and identification can provide pleasure and knowledge to the caver, the speleological community, and the paleontological community.

#### SURVEY & CARTOGRAPHY SESSION

##### FUNDAMENTALS OF COMPUTER-AIDED DRAFTING APPLIED TO CAVE CARTOGRAPHY

Bert Ashbrook, 1257 Lehigh Parkway South, Allentown, PA 18103-3875

Computer-Aided Drafting (CAD) can produce finished cave maps at any scale. Three-dimensional screen projections enable visualization of vertical caves but are cumbersome to use. CAD maps on paper are more practical for horizontal caves.

Traverse lines may be imported into CAD programs or data reduction may be incorporated into the software. Scanning sketches directly into CAD programs is difficult. Walls are more feasibly transcribed as lines and "smoothed" mathematically, or deduced from "left / light / up / down" data. Detail may be custom-drawn or inserted from libraries of standard symbols. Special hatches and line patterns are useful. The scale of the final presentation affects detail inser-

tion.

In CAD, related data are sorted into "layers." Layers may be displayed or hidden at will, producing different maps for different purposes. For example, maps for mop-up surveyors might display survey station layers which would be hidden in publication maps.

Experienced hand- and CAD-drafters draw with equal speed, but CAD is significantly faster when changes are necessary, especially for large caves. "Working" maps are eliminated. New data may be added indefinitely and maps produced at any time, so inked maps no longer signify project milestones. However, closing loops is problematic for some software.

CAD permits neat lettering using many fonts. Map elements may be moved easily to achieve balanced layouts. Although CAD enables sloppy drafters to do neat work, CAD does not replace the artistic talent and attention to detail required of great cartographers.

##### CARE AND CALIBRATION OF THE SONIN COMBO PRO: AN ELECTRONIC DISTANCE MEASURING TOOL

Hubert Crowell, 3105 Mary Dr. NE, Marietta, GA 30066

With proper care and calibration the SONIN Combo PRO can be used in place of a tape for cave surveying. The unit in a cave environment can be used in the single unit mode to measure a flat surface such as a ceiling up to 60 feet (20 m) and in the dual unit mode up to 200 feet (60 m). Other useful features are the ability to keep a running total of the survey length and the temperature at each station.

In the dual unit mode, the SONIN Combe POLO uses a target. The target is activated with an infrared light signal and then sends sound waves back. This enables the distance to be measured through small or narrow openings.

##### NEW FEATURES AND USES FOR CAPS

Hubert Crowell, 3105 Mary Dr. NE, Marietta, GA 30066

CAPS is an available software program that converts raw survey data to a 3-D screen plot with sides, notes and the ability to display pictures at each station. Some of the new features are 3-D with glasses in order to relate to the depth of the cave and a new search feature that shows where the requested information was found by placing small circles at each station where a match occurred. Any ASCII text editor can expand the notes for each station and the editor can be used from within CAPS to edit the notes. One can view the raw survey data in a table and edit the data.

##### STANDARDS FOR SKETCHING

Dale L. Pate, 30 Permian Dr., Carlsbad, NM 88220

The key component of any cave survey is the information that is produced. On most cave surveys that information is in the form of a sketch or series of sketches and the notes. If when a team returns to the surface and the information brought out of a cave is not readable, hard to understand, or lacking in usable data, then the time spent by the team has been wasted and, more importantly, the cave has been impacted without producing any viable results. In the caves of Carlsbad Caverns National Park, this impact to the caves with poor or no usable results is unacceptable. The caves of the park are very fragile and each team entering an area will have an impact. Therefore, it is imperative that good information be gathered. The sketcher is the

most important member of the survey team. Standards have been developed to give sketchers knowledge of what is expected when they return from a survey trip. These standards will be discussed and examples will be given of bad as well as good survey sketches and notes.

THE COMPUTERIZATION OF THE CAVE MAP

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The computerization of many types of activities has tended to occur in identifiable and somewhat predictable stages that can be described nearly independently of the application. Stage-1 (simple)—portions of the activity which were previously performed without

computers are “simply” computerized. Some portions are still done the old way. Stage-2 (enhanced)—the computerized version of the activity is “enhance to provide additional functionality. Capabilities are provided which were seldom done before because they were either too time consuming or too difficult. Stage-3 (complete)—the computerized version is further enhanced by the use of more sophisticated algorithms and added functionality, to the point where all or nearly all operations are performed on the computer. The computerized process completely replaces the previous manual process. Finally, Stage-4 (redefinition)—the functionality of the computerized version greatly exceeds that of the traditional activity. Aspects of the computerized version are recognized as new manifestations of existing ideas, processes, and/or products. The fundamental terms previously used to describe the activity are redefined. The activity of creating and viewing a cave map is undergoing such a “redefinition”.

## ADDITIONAL ABSTRACTS FROM THE 1996 NATIONAL SPELEOLOGICAL SOCIETY NATIONAL CONVENTION IN SALIDA, COLORADO

IS IT CONDENSATION CORROSION OR SOMETHING ELSE?

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Many morphological features of caves have been explained by a sub-aerial process called condensation corrosion. Condensation collecting on cave surfaces absorbs carbon dioxide and becomes corrosive. The subsequent dissolution erodes away ceilings, walls, and speleothems, creating hemispherical domes or cupolas, among other features. The calcite mass is disposed of through the walls by capillary action, traveling to the lower portions of the passages by gravity, and depositing there as seepage coral through evaporation. If condensation collects at orifices, where moisture-laden air emerges from passages below, rims of calcite are formed around barren channels which appear scoured of all secondary deposits. In the United States, these features appear only in caves west of a line roughly drawn from western Texas to the Black Hills of South Dakota. The caves of the Basin and Range Province of western Utah and eastern Nevada present a great diversity of cupolas, rims, vents, coral, and other related phenomenon. While some of these fit the subaerial condensation corrosion model for their origin, many others with identical appearances may be more appropriately explained by subaqueous processes. The morphology of these channels and associated rims, and their locations within the passages would be improbable if air currents were involved.

THE ORIGIN OF FOLIA

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Folia, strange-appearing and relatively rare speleothems, are generally regarded as forming in relation to a fluctuating water surface. While investigating folia in Nevada's Goshute Cave, several clues were found that point to a different origin. In most caves with folia, the lowest exposures of folia ribs are usually covered with water or have been buried by sediments. In Goshute Cave, however, there are three instances where the lowest folia ribs appear midway in the cave's vertical extent, allowing a unique insight as to their origin. When water saturated with calcium bicarbonate ions emerges from an orifice, there is a profuse outgassing of carbon dioxide (and calcite nuclei are precipitated. Carried by bubbles or water that has greater buoyancy because of higher temperature, the calcite nuclei flow upward along down-facing walls. Nuclei adhere to the walls, at first creating small sub-horizontal ribs spaced a few millimeters apart and protruding only slightly. These tiny ribs have limited horizontal extent and interleave with each other. Eventually, enough calcite accumulates on the ribs to form cavities that protrude enough to trap beneath them. When the accumulated exceeds the capacity of the cavity, it bubbles from underneath. The turbulence of bubbling causes deposition of more calcite at the cavity edge. Folia then, are the upside-down equivalent of rimstone pools, except that the upside-down pool of folia is filled with gas. What have been described as folia composed of mud have a different origin and appearance.



Janet Steele is a NSS Fellow and an active member of the Society of Woman Geographers. For over a decade, she has investigated cave archaeological sites in southern Mexico. Her thesis for the University of Texas at San Antonio documented a cave site of the previously unknown Classic Mazatec Period.



Dr. Ira D. Sasowsky is currently Assistant Professor of Geology at the University of Akron in Ohio. He is the *Journal of Cave and Karst Studies* earth sciences editor and compiles its yearly index.



Andrea Stone received her PhD in Art History in 1983 from the University of Texas at Austin. She is currently Associate Professor of Art History at the University of Wisconsin-Milwaukee. Her recent book, *Images from the Underworld*, documents Maya cave art in Belize, Mexico, and Guatemala.

**NO PHOTOS**

James E. Brady received his PhD from UCLA where he wrote his dissertation on the archaeological excavations at Naj Tunich. He is the first Maya archaeologist to specialize in caves and has directed projects at Naj Tunich, Petexbatun, Copan and the Caves of the Talgua Region (Cave of the Glowing Skulls). He has written over 40 articles on cave archaeology and currently teaches at George Washington University.

Ann Scott received her MA from Northern Illinois University in 1993. She has been involved in cave archaeology since 1992 and has conducted related research in Guatemala, Honduras and Texas. She is currently on staff with Prewitt and Associates, Inc., an archaeological consulting firm in Austin, Texas.

**Fabienne Rouvinez**

After studies in archaeology, social anthropology and Spanish at the University of Neuchâtel, Switzerland, Fabienne Rouvinez received a grant from the Mexican government to spend one year in Mexico, studying archaeology relative to the Proyecto Cero Rabon with the Universidad Nacional Autonomia de Mexico. She is working now in the Musée Schwab in Biel, Switzerland, the Museum of Archaeology.

**Roman Hapka**

After Studies in archaeology, history and journalism at the University of Neuchâtel, Switzerland, Roman Hapka, worked in the United Arab Emirates and spent one year in Mexico working on the Proyecto Cerro Rabon with a grant from the Swiss national fund. He is now working for the archaeological office of the Neuchâtel state. He is co-president of the Archaeological Commission of the Union Internationale de Spéléologie.

Mary Kennedy earned her MA in Anthropology at Washington University with a thesis on the radiocarbon chronology for Salts Cave and Mammoth Cave. She has participated in archaeological research in Jaguar Cave, Tennessee, and also supervised the initial seasons of the joint Mammoth Cave National Park/Earthwatch project in Mammoth Cave.

Patty Jo Watson (NSS337) is the Edward Mallinckrodt Distinguished University Professor of Anthropology at Washington University in St. Louis. She is an Honorary Life Member of the National Speleological Society and also holds a Certificate of Merit from that organization. She is a member of the Cave Research Foundation (CRF) and has directed the CRF Archeological Project, which has been investigating the prehistoric exploration of Salts Cave, Mammoth Cave, and other caves in the Midsouth since 1963.

Cyndi Mosch is a long-time caver (NSS 20146), a geology student at New Mexico State in Las Cruces, and one of the discoverers of Hourglass Cave, Colorado. Both Kennedy and Mosch are also CRF Joint Venturers.

**LONGEST CAVES IN THE WORLD**

| CAVE NAME                                       | COUNTRY        | LENGTH (M) | DEPTH (M) |
|---|----------------|------------|-----------|
| 1 Mammoth Cave System                           | U.S.A.         | 563270     | 115.5     |
| 2 Optimisticeskaja(Gypsum)                      | Ukraine        | 183000     | 20.0      |
| 3 Jewel Cave                                    | U.S.A.         | 175,023    | 179.2     |
| 4 Hölloch                                       | Switzerland    | 165500     | 872.0     |
| 5 Lechuguilla Cave                              | U.S.A.         | 143795     | 477.9     |
| 6 Siebenhengste-hohgant Höhlensystem (Muttsee.) | Switzerland    | 135000     | 1324.0    |
| 7 Wind Cave                                     | U.S.A.         | 128800     | 197.7     |
| 8 Fisher Ridge Cave System                      | U.S.A.         | 125529     | 88.4      |
| 9 Ozernaja                                      | Ukraine        | 111000     | -         |
| 10 Gua Air jernih - Lubang Batau Padang         | Malaysia       | 101500     | 355.1     |
| 11 Systeme de Ojo Guarena                       | Spain          | 97400      | -         |
| 12 réseau de la Coumo d'Hyournèdo(e)            | France         | 94843      | 1018.0    |
| 13 Zoluška (Gypsum)                             | Moldavia       | 85500      | 30.0      |
| 14 Sistema Purificación                         | Mexico         | 84992      | 956.0     |
| 15 Sistema ejido Jackinto Pat(Under Water)      | Mexico         | 84545      | -         |
| 16 Hirlatzhöhle                                 | Austria        | 79270      | 1041.0    |
| 17 Easegill System                              | United Kingdom | 70500      | 211.0     |
| 18 Raucherkarhöhle                              | Austria        | 70000      | 725.0     |
| 19 Friars Hole Cave System                      | U.S.A.         | 69997      | 188.4     |
| 20 Toca da Boa Vista                            | Brazil         | 64000      | -         |

**DEEPEST CAVES IN THE WORLD**

| CAVE NAME  | COUNTRY      | DEPTH (M) | LENGTH (M) |
|--|--------------|-----------|------------|
| 1 réseau Jean Bernard                            | France       | 1602.0    | 20000      |
| 2 Lamprechtsofen-Vogelshacht                     | Austria      | 1537.0    | 38000      |
| 3 gouffre Mirola / Lucien Bouclier               | France       | 1520.0    | 9000       |
| 4 Shakta Vjacheslav Pantjukhina                  | Georgia      | 1508.0    | -          |
| 5 Sistema Huautla                                | Mexico       | 1475.0    | 55953      |
| 6 Sistema del Trave (La Laureola)                | Spain        | 1441.0    | 9167       |
| 7 Boj-Bulok                                      | C.I.S.       | 1415.0    | 5000       |
| 8 (Il)laminako Aterneko Leizea (BU56)            | Spain        | 1408.0    | 14500      |
| 9 Lukina Jama - Manual II                        | Croatia      | 1393.0    | -          |
| 10 Sistema Cheve (Cuicateco)                     | Mexico       | 1386.1    | 23500      |
| 11 Sniezhnaja-Mezhonnogo                         | Georgia      | 1370.0    | 19000      |
| 12 Ceki 2 (Cehi)                                 | Slovenia     | 1370.0    | -          |
| 13 réseau de la Pierre Saint Martin              | France/Spain | 1342.0    | 53800      |
| 14 Siebenhengste-hohgant Höhlensystem (Muttsee.) | Switzerland  | 1324.0    | 135000     |
| 15 gouffre Berger - Gouffre de la Fromagere      | France       | 1271.0    | 25975      |
| 16 Cosanostraloch - Berger - Platteneck Hohle    | Austria      | 1265.0    | 30000      |
| 17 Pozo del Madejuno                             | Spain        | 1255.0    | 2852       |
| 18 Torca dos los Rebecos                         | Spain        | 1255.0    | 2228       |
| 19 Abisso Paolo Roversi                          | Italy        | 1249.0    | 4000       |
| 20 Vladimir V. Ijukhina System                   | Georgia      | 1240.0    | 5870       |

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