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Cover Photo: troglobitic millipeds, *Tetracion jonesi*, Crossing Cave, Alabama. Stewart Peck photo.

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# ABSTRACTS OF PAPERS 1978 NSS CONVENTION NEW BRAUNFELS, TEXAS

(By prior arrangement with the Program Editor, abstracts of all papers accepted for the program are reprinted in this issue of *The NSS Bulletin*.)

## SUBTERRANEAN AQUATIC FAUNA OF THE EDWARDS AQUIFER IN TEXAS, AS INDICATED BY SAMPLES FROM WELLS AND SPRINGS

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An extensive sampling program was initiated in 1973 and has been continued to the present on wells and springs along the Balcones Escarpment in Central Texas. This sampling program has produced much new information about aquatic species inhabiting the Edwards Aquifer. Where possible, discharge has been measured and related to numbers of organisms. Estimates of populations have been made where the hydrology is known. Numerous new species of amphipods, isopods, and gastropods have been discovered. Several other taxa will probably produce new material when examined more closely.

New insight has been gained into the food-chain relationships and feeding habits of vertebrates in the Aquifer. Extensive work has been done with the Texas Blind Salamander, *Eurycea rathbuni* and two species of blind cavefish from Bexar County, *Satan eurystomus* (widemouth) and *Trogloglanis pattersoni* (toothless), in the family Ictaluridae. Prior to my studies, few specimens of many of the species had been collected and studied. With the methods I employ, numerous specimens of most forms are now available (Supported by contracts with the U.S.F.W.S.).

## STATUS OF THE TROGLOBITIC BLIND CATFISHES, *TROGLOGLANIS PATTERSONI* AND *SATAN EURYSTOMUS*, IN BEXAR COUNTY, TEXAS

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Prior to this study, only three specimens of *Trogloglanis pattersoni* Eigenmann and three specimens of *Satan eurystomus* Hubbs and Bailey had been collected. A program for sampling the Central Pool of the Edwards Aquifer in San Antonio, Bexar County, Texas, was initiated in 1976 yielding approximately 25

specimens of *T. pattersoni* and 15 specimens of *S. eurystomus*. Ecological factors such as evolutionary background, distinguishing characteristics, distribution, habitat, feeding habits, population dynamics, and predation of these fishes are presented.

## A REMARKABLE AMPHIPOD CRUSTACEAN FAUNA FROM THE ARTESIAN WELL IN SAN MARCOS, TEXAS

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Since 1973, continuous sampling of the Artesian Well in San Marcos, Hays Co., Texas, has revealed an extraordinary assemblage of subterranean amphipods. At present, this fauna consists of 10 species representing six genera and five families. In overall taxonomic diversity, this amphipod fauna is probably the richest in the world, and in number of species, it is rivaled only by those of certain groundwater biotopes in southern Europe.

Among the amphipods recorded from the well are *Stygobromus flagellatus* (first described from the well in 1896) and *S. russelli* of the family Crangonyctidae; two new genera and four species (three new) of the family Hadziidae that are members of the weckeliid generic complex of the greater Caribbean region; a new genus closely allied with *Bogidiella* (family Bogidiellidae) that is composed of two new species; a new family composed of monotypic new genus and species; and a new species of the heretofore monotypic, brackish-water genus *Seborgia* (family Sebiidae).

Four distinct phylogenetic lineages are represented in the Artesian Well amphipod fauna: (1) superfamily Crangonyctoidea, which is an old freshwater group of mostly groundwater-related species without contemporary marine relatives; (2) superfamily

Hadziioidea, which is composed of epigeal and hypogean species living in shallow marine, brackish and fresh water habitats; (3) superfamily Bogidielloidea, which is composed of subterranean species living in habitats that include mesopsammic marine, littoral interstitial, freshwater hyporheic and freshwater caves; and (4) family Sebiidae, which is predominantly marine benthic.

The zoogeographic and ecological ramifications of the diversified amphipod fauna of the subterranean Edwards Aquifer are tremendous. More than 50% of the species have obvious affinities with marine and brackish-water relatives and are presumably derivatives of marine ancestors that colonized newly opened freshwater habitats during the recession of epeiric seas in the Late Cretaceous. Although little is yet known about the population and community ecology of amphipods in the Edwards Aquifer, it is apparent from the large number of species and their relative abundance and also the high degree of differentiation in mouthpart and appendage morphology that these species are well adapted for fine resource partitioning and co-existence. (Supported in part by grants from the National Science Foundation (GB-42332) and the Penrose Fund of the American Philosophical Society.)

## THE DEVELOPMENT OF DIVERSITY IN TEXAS CAVE SALAMANDERS

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The Edwards Plateau is the site of the most extensive radiation of troglobitic salamanders in the world. About 35 populations, representing 5 to 7 species, are distributed along the Balcones Fault Zone from Austin to Del Rio and inland to the undissected Plateau surface. These troglobites range in morphology from populations indistinguishable from the widespread epigeal *Eurycea neotenes* through numerous intermediate forms to the advanced *E. tridentifera* and beyond to the uniquely specialized *Typhlomolge rathbuni*. Troglobitic populations of *Eurycea* originate when failing springs force resident epigeal populations underground. The local repetitive nature of this process results in many independent colonization events, followed by extensive parallel evolution of troglobitic adaptations. Similar forms now occupy widely separated caves, and it is clear that morphological resemblance need not imply relatedness. Reproductive isolation

is weak or nonexistent; hybridization occurs wherever cave and surface populations come into contact. Allopatry, evolutionary parallelism and convergence, and hybridization combine to make the systematics of these salamanders difficult. Of the four species currently recognized, two (*Eurycea latitans* and *E. troglodytes*) appear to be hybrid swarms involving *E. neotenes* and *E. tridentifera*; these taxa are thus invalid. With the addition of an undescribed intermediate troglobite from Travis County, the Texas cave *Eurycea* comprise about 20 populations of *E. neotenes* and six of *E. tridentifera*. Some biologists believe *Typhlomolge rathbuni* to be a specialized species of *Eurycea*. There is now strong evidence that *T. rathbuni* and the advanced troglobitic *Eurycea* are evolutionarily convergent rather than closely related. Analysis of a new, highly advanced troglobitic species from the San Marcos region supports this interpretation.

## ZOOGEOGRAPHY OF THE CAVE FAUNA OF THE YUCATAN PENINSULA

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A total of 565 species of animals have been found in the caves and cenotes of the Yucatan Peninsula, Mexico. Of these, 34 species (23 terrestrial and 11 aquatic) are probable troglobites. The terrestrial fauna consists almost entirely of species with tropical affinities; the aquatic fauna includes elements both of marine and fresh water origin. The distribution of the Yucatan cave fauna is discussed with respect to geologic and physiographic features of the Peninsula. The Yucatan fauna, in a semi-arid tropical region, is compared to the

faunas of a highland tropical region (the Sierra de Guatemala of Tamaulipas), a lowland semi-arid tropical region (the Sierra de El Abra of San Luis Potosi and Tamaulipas), a heavily-dissected temperate region (the Edwards Plateau of Texas), and a homogeneous temperate region (the Mammoth Cave area of Kentucky). These diverse areas are discussed with respect to the comparative number of species present and to the species composition of the troglobite fauna.

## THE FAUNA OF HAWAIIAN LAVA TUBES

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Hawaii is a string of young, oceanic volcanic islands stretching more than 2400 km across the mid-Pacific. The native fauna and flora are composed of those groups which dispersed across upwards of 4000 km of open ocean and became successfully established. Less than 300 introductions gave rise to our entire native insect fauna of 7000+ species. Lava tubes, the major cave type in Hawaii, form almost exclusively in pahoehoe basalt by the crusting over of lava rivers. The resultant caves can be complex. In the past, these were considered too ephemeral, too often polluted with volcanic gasses, and too inorganic (lacking the main energy sources of continental caves) to support troglobites. Further, representatives of the continental cave fauna are absent, and very few terrestrial troglobites were known from the tropics.

Many of Hawaii's troglobites are representatives of the speciating native groups and have close surface relatives still extant. They have invaded caves through a process of adaptive shifts characteristic of island faunas and

are not relictual. The two favorite biomes of evolutionary biologists are oceanic islands and caves. Now, for the first time, these have been combined.

Of the four life zones in caves, the dark zone, where the troglobites live, is of the most interest. The main energy source in Hawaiian lava tubes is tree roots. Other energy sources are slimes and accidentals. At the base of the food web are several rhizophagous troglobites, including cixiid planthoppers, millipedes, and moths. The troglobitic scavengers include several species of crickets, a terrestrial water treader, and a terrestrial amphipod. A threadlegged bug and two blind wolf spiders are troglobitic predators.

Continental cave ecosystems are often likened to islands in their susceptibility to perturbations. A cave ecosystem on an oceanic island is in double jeopardy. Two troglobites, *Adelocosa anops* and *Spelaorchesta koloina* have been proposed for the U.S. endangered species list.

## A PHOTOGRAPHIC SURVEY OF THE MEXICAN CAVE FAUNA

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Some of the more spectacular and interesting cave animals of Mexico will be illustrated by color transparency and briefly discussed. The animals seen will range from

the planarians through the fishes, and cave area will range from Nuevo Leon through Chiapas and Yucatan.

## GLACIATION AND KARST GEOMORPHOLOGY IN SCHOHARIE COUNTY, NEW YORK

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Schoharie County, New York contains a well-developed karst formed on gently dipping (1 to 2°

SSW) Upper Silurian-Lower Devonian limestones. The karst has unique features which resulted

from Pleistocene glaciation. The effects of the Wisconsin glacial episode predominate. Most pre-glacial surficial karst landforms are either quarried, buried, or crushed, with derangement of surficial drainage by glacial deposits at insurgences and resurgences the dominant factor. Insurgences may be either covered, starved, or rejuvenated, depending on their location with respect to the present-day rearranged landscape. Many large, glacially constructed basins exist, which are preserved as topographic lows by solutional processes that remove water and sediment. Resurgences are either glacially occluded locally with immature passages that bypass the blockade, or glacially alluviated on a larger scale with regional base level rise both in the surface and sub-surface.

Active master cave conduits are basically unchanged, but abandoned upper-level conduits are filled with sediment. High loads of glacial sediment are common. These cause local hydraulic inefficiencies which result in floodwater overflow passages. Cave sediments deposited during ice cover are characteristically high in soluble components and low in organics. Postglacially deposited cave sediments are low in soluble components and high in organics. This reflects stagnant, sterile ice cover conditions and aggressive, floodwater-oriented post-glacial conditions. Schoharie County is a nonalpine, undeformed area, and as such is a simple presentation of the effects of glaciation on cave development.

(1:20,000) and high altitude photo-lineaments ( $\leq 1:20,000$ ) for Benton County, Arkansas. A modified version of the Kolmogorov-Smirnov test, compensating for circular ( $0^\circ-360^\circ$ ) data, was used. The area is underlain by nearly flatlying Mississippian carbonates (Boone and St. Joe formations) on the southwest flank of the Ozark Dome.

Eight, two sample K-S tests were used to compare the orientation diagrams. The null hypothesis in each case is a statement of no significant difference in orientations of the two distributions or populations at the chosen alpha level ( $\alpha = .10$ ). The results (Table 1) show that for low altitude photo-lineaments and straight cave passage segments (both 50 ft and

100ft), the orientations are *not* dissimilar. This suggests that large-scale photolineaments may be either discrete fractures or zones of weakness that control cave passage development to a significant degree. The lack of similarity of orientation of lineaments and joints suggests that lineaments may be formed in part by larger-scale processes than those forming the regional joint patterns.

Although not statistically significant, there are certain preferential orientations common to small-scale photo-lineaments and cave-passage segments. This further supports the hypothesis that caves have formed, and are still forming, along major fractures or orientations that are not represented by joint patterns alone.

## NORTH CAROLINA COASTAL PLAIN CAVES

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Coastal Plain cave systems, when accessible (not underwater), are usually quite limited in extent. The two principal cave systems, Rock Houses Cave in Onslow County and Old Blacksmith Cave in Jones County, are rich in several ways. For generations, both caves have been the source of "curios" (human bones), an archaeological heritage that needs to be preserved. Fauna include poisonous snakes, cave crickets, spiders, eyeless fish, bats, salamanders, etc. True cave flora appears limited to fungi.

The geology of the caves may be the source of much valuable data about joint sets, palaeontology, early stages in the evolution of caves, and, perhaps, possible causes for Carolina Bays. Joint sets are quite well developed in Coastal

Plain caves. There appears to be a positive correlation between marly (clay-rich) limestone and the presence of caves. Earlier assumptions by geologists that karst features in coastal North Carolina were negligible to non-existent were obviously not based on adequate field checking; consequently, earlier conclusions that the Carolina Bays were not influenced by solutional processes should be re-examined.

Data on Coastal Plain caves can lead to further research concerning karst development in the Coastal Plain, the preservation and study of Indian burial sites in the caves, and an inventory of the associated flora and fauna in these little-explored sites.

## A STATISTICAL COMPARISON OF JOINT, STRAIGHT CAVE SEGMENT, AND PHOTO-LINEAMENT ORIENTATIONS

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A statistical comparison was made of the orientations of joints,

straight cave-passage segments, low altitude photo-lineaments

Table 1. Statistical comparison of Orientation Diagrams\*

	Joints	Low Altitude Lineaments	High Altitude Lineaments
50 ft Cave Segments	Dissimilar	Similar	Dissimilar
100 ft Cave Segments	Dissimilar	Similar	Dissimilar
Joints	—	Dissimilar	Dissimilar

\* Similarity of orientations at  $\alpha = 0.10$

## ALPINE KARST OF THE MARBLE MOUNTAINS WILDERNESS

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A significant area of alpine karst occurs in the Marble Mountains Wilderness Area of California. The karst is in marble beds that lie at elevations of 5,000 to 7,000 ft. Major surface features were formed by glacial action. The caves reveal two distinct stages of speleogenesis: an earlier, phreatic

development of cave passages in the upper members of the marble, and more recent, subglacial cave development at the lower bedding contact. The latter phase resulted in caves of significant size and depth, including Bigfoot Cave System, deepest cave in the U.S.A. at 1205 ft.

## HOW FOOD TYPE DETERMINES COMMUNITY ORGANIZATION IN CAVES

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The Flint Mammoth terrestrial fauna shows: 1. Groups of species specialized to different foods; 2. Specialization based on calories available / area / time; and, 3. Coevolved species interactions for the most stable foods.

1. *Component communities* are demonstrated by an index (IV) summing each species frequency + density + weight. Of 40 species, 28 have 95%+ of their total IV on one food, 6 on two, 4 on three, and 2 on four of the seven foods. Seasonal stress of flooding or cold-dry microclimate reduces number of species and increases dominance of some, but no new species are added. Addition of a natural food, litter, attracts only expected specialists, but an unnatural food, horse manure, repels normal specialists, attracts new species, and allows rare species to become highly dominant. More species occur and specialist IVs decrease when component foods are mixed in a compound community setting.

2. *Caloric availability* of each food favors different combinations of foraging, life history, and physiology. Calories available / area / time ranges from "hot" racoon feces to "cold" water-leached litter, with cave rat feces, fresh litter, cricket guano, cricket eggs, and mud-silt in between. Species occurring on

multiple foods face the same caloric availability by picking different times in successional decomposition or different places along a gradient of food concentration. Comparing species pairs, hot food specialists are time efficient with highly flexible rates of growth, reproduction and development, whereas cold food specialists are inflexible and resource efficient with additional specializations of foraging, habitat selection and body size-shape. When alone and given no choice they grow poorly on hot foods, so ongoing competition does not explain their restriction to cold food.

3. *Coevolved community organization* is shown for cold foods which are most stable in space-time and so have the most predictable species composition. In sand-silt — which covers large areas, has many replicates and has existed over long geological time — there are multiple levels of prey-predator and competitor-competitor coevolution. High densities of individuals on hot foods makes high intensity interaction possible but food renewal, and thus interaction, is transitory in space-time.

Supported by NSF-BMS 11140 and Cave Research Foundation.

## COMPETITION AS AN ORGANIZING FACTOR IN A COMMUNITY OF CAVE ASSOCIATED SALAMANDERS

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Field manipulation experiments indicate that competition is an important factor influencing the structure of a four-species salamander community associated with caves of the western Ozarks. Available data support the existence of competitive interactions in the larval portion of the life cycle. Predictions concerning community stability will

be based on these data. The failure of predictions, based on larval ecology, to be confirmed by field observation is hypothesized to be a result of interactions among post-metamorphic salamanders. Available data support this hypothesis.

## BAT MANAGEMENT IN THE UNITED STATES: A SURVEY OF LEGISLATIVE ACTIONS, COURT DECISIONS AND AGENCY INTERPRETATIONS

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In 1966, Congress enacted legislation which afforded native animals legal protection. Since that time, this legislation has been twice revised. The 1973 Endangered Species Act provides not only animals but, also, plants with what appears to be a reasonable degree of protection. Recent court decisions support the concept and validity of the 1973 Act.

This paper is the result of a survey conducted through 14 federal departments and agencies in order to obtain their interpretation of this legislation and, more specifically, to learn how bats are protected by these

interpretations. The survey included 4 questions:  
1) What federal laws, regulations, and guidelines govern your agency's actions regarding the protection and/or eradication of bats?  
2) How has your agency interpreted these laws, regulations, and guidelines in the formulation of its internal policies?  
3) What do your protection policies include?  
4) If eradication is necessary, what methods and recommendations are followed, and what chemicals are allowed and in what dosages?

\*Publication of this report does not signify that the contents necessarily reflect the policies of USEPA, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

## THE NEW MELONES CAVE HARVESTMAN TRANSPLANT

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The New Melones Lake project of the U.S. Army Corps of Engineers, Sacramento District, will inundate several caves on the Main and South forks of the Stanislaus River in Calaveras and Tuolumne Counties, California. In 1975, the Corps sponsored a small transplant project of cave fauna from McLean's Cave, Tuolumne County, to the Von Trump Mine, an inactive gold prospect 2.5 km away. Uncertain as to the success of the first effort, the Corps sponsored a second transplant from December 1977 to March 1978. The primary concern of both projects was the cave-dwelling phalagid, *Banksula melones*

Briggs, which is known only from two localities: McLean's Cave, which will be completely flooded, and McNamee's Cave, which is threatened by quarrying.

The second transplant resulted in the transfer of 27 of the 30 or more species which inhabit McLean's Cave, for a total of 1353 individuals. Despite a considerable collecting effort, only 26 adults of *B. melones* were transferred to the mine. Seven other local caves were studied to determine the range of *B. melones* and other cave fauna.

(Supported by the U.S. Army Corps of Engineers, Sacramento District Contract #DACW05-78-C-0007.)

## SPELEOTHEM GROWTH RATE MEASURED FROM A STALAGMITE IN ADMIRAL'S CAVE, BERMUDA

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In 1819, Admiral Sir David Milne removed a large stalagmite from Admiral's Cave, Bermuda to be placed in the Museum of the University of Edinburgh, Scotland. Sir Alexander Milne, visiting the cave in 1863, determined that five cubic inches of calcite had been deposited on the stump during the 44 years since the original speleothem had been removed by his father. David Milne Home concluded from his brother's observations that, assuming a constant rate of deposition, it

would have taken 600,000 years to form the original stalagmite. Sir C. Wyville Thomson, director of the H.M.S. 'Challenger' oceanographic expedition, entered Admiral's Cave in 1873 to observe the stump. Under Thomson's direction, a slice was removed containing the material deposited in the last half century. Current measurements indicate that although drip rate and calcite deposition at the stump have decreased, the calculated age of the stalagmite may not be too far off.

## WATER BALANCE, MASS BALANCE, AND TIME SCALES FOR CAVE SYSTEM DEVELOPMENT

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It is reasonably well established that most cave systems, or at least individual passages in cave systems, are fragments of drainage conduits that have acted to transport water and clastic sediment from well-defined catchment areas to specific discharge points where the underground drainage returns to surface routes. The evolution of such systems involves a transition from a fracture aquifer to a conduit aquifer and there are three thresholds that must be crossed during the cave system development (1) a critical passage size at which the flow becomes localized along a single route and thus a transition from diffuse to conduit flow (which is also associated with a transition from laminar to turbulent flow); (2) a critical velocity in the system at which the clastic sediment load can be moved. At lower velocities, infiltrating sediments merely clog the fracture permeability but at velocities above the threshold, sediment is swept out and the channel kept open; (3) a critical

through-put that permits undersaturated water to penetrate the aquifer system thus initiating a large increase in the rate of solution attack of the water on the wall rock. It is a curious coincidence that all three thresholds occur at a passage size of 1 to 10 mm which may then be taken as the boundary between fracture permeability and conduit permeability. Past these thresholds, the cave system will evolve on a time scale dictated by available recharge. CO<sub>2</sub> uptake, and clastic load.

Constraints on the system can be calculated from considerations of kinetics of solution, overall water balance in the catchment, mass balance of dissolved load, and mass balance of clastic load. Model calculations under somewhat idealized conditions show that it is possible for a flow path to evolve from the initial mechanical fracture (assumed width, 25  $\mu$ m) to the threshold size of 5 mm in about 3000 years. Enlargement of the critical pathway to a full-scale cave passage with a diameter on the order of 1 m

can take place in less than 10,000 years. The calculations are in agreement with field observations of caves in glaciated areas (e.g., the Helderberg Plateau Karst of New

York) which indicate that some caves have formed since the retreat of the Wisconsin ice sheet—10,000 to 15,000 years ago.

## CAVERN DEVELOPMENT VIA H<sub>2</sub>S DISSOLVED IN HOT SPRING AND NATURAL GAS FIELD WATERS

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Several hot spring caves located in 4 areas of Colorado and Wyoming may be classified in three categories; 1) single main horizontal passage caves with little or no side passage development, 2) multiple, parallel main horizontal passage caves with smaller cross passages connecting the main passages, and 3) spongework-like caves with multiple interconnected passages. Cave development resulted from or was enhanced by the H<sub>2</sub>S gas dissolved in the hot spring waters. There is in all three of these types naturally some mixing of the hot spring waters with variable amounts of ordinary ground water.

Caves of the first two types develop where hot spring waters flow horizontally through fissures in the carbonate rock toward a nearby surface stream. When the hot spring waters simultaneously flow through a number of closely spaced fissures, interconnecting side passages form. The Kane Caves near Lovell, Wyoming, are examples of the first type, whereas Hubbard's Cave near Glenwood

Springs, Colorado, is an example of the second type. Spongework-like caves form where the hot spring waters mix with large quantities of slowly moving ordinary groundwater. Fairy Cave near Glenwood Springs, Colorado is an example of this type of cave.

Most cave development in all three types proceeds a short distance below the top of the water table. Therefore, a dropping water table often produces one or more vertical fissure passages connecting different cave levels.

H<sub>2</sub>S is also commonly found with natural gas accumulations. There, the H<sub>2</sub>S dissolved in the water, which either contains or underlies the natural gas, should function as it does in the hot spring waters, forming the same three types of caves. One area that may illustrate cave development at least partly enhanced by water containing dissolved H<sub>2</sub>S is the Guadalupe Mountains of southern New Mexico. Further work may show H<sub>2</sub>S-related cave development is a much more widespread occurrence.

## HYDROGEOLOGY OF THE SPRING MOUNTAINS, NEVADA

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The Spring Mountains are located in southeastern Nevada, 16 km west of Las Vegas. They are 72 km long and 29 km wide, rising to an elevation in excess of 3600 m. The range is composed primarily of dense Paleozoic carbonate rocks up to 4500 m thick. Structures are dominated by east-directed thrust faults. The Spring Mountains receive up to 65 cm precipitation per year as summer thunderstorms

and winter snows. Water movement is primarily along solutionally enlarged fractures and brecciated zones. Part of the recharge emerges as local springs throughout the range, and part becomes recharge to the regional carbonate flow systems. Approximately 60 springs issue from the mountains, with discharges varying from a few liters per minute up to 1000 l/sec. Only

eight springs are known to have discharges greater than 6 l/sec and, in general, most are less than 1 l/sec. Springs tend to be localized by faults and joints, with several emerging from cave entrances. Six known caves in the range exceed 30 m in length. One

of these, Trout Spring Cave, 1000 m long, has an active stream that emerges at Trout Spring with an observed minimum discharge of 14 l/sec and a maximum of 250 l/sec. Electrical conductivity averages 300 mhos at the spring.

## SPELEOGENESIS IN THE BERMUDA ISLANDS

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The Bermuda Islands are located 650 mi east of North Carolina, in the Gulf Stream of the Atlantic Ocean. The islands consist of marine and aeolian limestones overlying a submerged and inactive volcanic peak. The bulk of the islands consist of aeolian calcarenite hills rising up to 257 ft above sea level. Solutional features are well developed, including small-scale solutional fretwork on outcrops, residual soils, paleosols, caves, and dolines. A lack of impervious catchment material precludes the formation of surface streams, and meteoric waters sink directly into the porous limestones.

Most Bermuda caves have a similar morphology: they lead downward from collapse dolines as passages formed between breakdown on the floor and a bedrock ceiling, both dipping

around 45° and leading to terminal chambers ending in collapse or sea level pools. The water is saline and fluctuates with the tides, causing currents in submerged caves that agitate the fresh water lens, limiting lens development. True solutional conduits are rare, and most enterable caves represent the upward collapse of portions of solutional conduits formed at a lower sea level during continental glaciation episodes. Collapse prograding above present sea level, but below the landspace surface, forms the typical Bermuda cave. Complete stoping to the surface produces structures analogous to "blue holes". A few small, perched solutional conduits 20 ft above present sea level follow a horizontal datum across bedrock structures, indicating a possible earlier, higher interglacial sea level.

## CAVE CONSERVATION IN THE UNITED STATES

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The conservation of caves has been practiced in the United States since Mammoth Cave and Grand Caverns first opened to admit tourists in the very early 1800s. Commercial caves continue to be very important in the protection of many caves in this country. However, the real story of American cave conservation does not begin until the middle of the 20th Century. This move to protect caves accompanied the development of organized caving and the great proliferation of caves, which by some estimates

may number in the hundreds of thousands. Some of the problems caused by this increase are litter, vandalism, pollution, biotic disturbance, and the disruption of archeological, paleontological, and historical evidence. The most subtle of all damage is done by using the cave beyond its carrying capacity to absorb the impact. The story of modern cave conservation is largely that of small groups of concerned, dedicated individuals with a drive for hard work and the patience to wait for results.

## REPAIRING BROKEN CAVE FORMATIONS

Martin Wiggins

*(address unknown)*

Commercially available adhesives were investigated to determine which would be most appropriate for use in the repair of

broken speleothems. Certain epoxies and urethane glues were found to yield the most satisfactory results.

## RESTORATION OF A SPELEOTHEM—A CASE HISTORY

John Tinsley

*1040 Oakland Avenue, Menlo Park, California 94025*

A stalagmite 0.5 m tall, dubbed the "Ice Cream Cone" and suffering from two fractures, was reconstructed and reinstalled in Santa Claus Cave, California in March 1978, by members of the San Francisco Bay Chapter, NSS. Materials employed included a 3/8-inch diameter aluminum rod, a modest quantity of stucco-patching compound, epoxy glue, a soup can (#303), an immodest quantity of water, drop cloths, a pair of surgeon's gloves, a 3/8-inch drill, and a cordless electric drill. Two 3/8-inch diameter holes were bored

parallel to the vertical axis of the speleothem. One hole extended 8 cm into the 4 cm diameter basal stalk, and the second hole was bored 9 cm downward into the subjacent flowstone. Stucco-patching compound was applied to the base of the speleothem to mask the aluminum rod and to restore the original appearance and taper to the pedestal. We are monitoring the repair to observe the durability and hence the suitability of the technique and materials employed.

## VIRGINIA COMMISSION ON THE USE AND AND CONSERVATION OF CAVES—HISTORY

John Wilson

*7901 Dalmain Drive, Richmond, Virginia 23228*

The Virginia Commission on the Conservation and Use of Caves was established in March 1978, by the Virginia General Assembly to make recommendations to the Governor and the General Assembly by 1 October 1978. This is the first commission ever established by any state government to study the use and conservation of caves in general. It should provide an overview of the problems of cave use and conservation in Virginia, and, it is hoped, a more

all-encompassing solution to the problems of cave use and conservation will be developed. This paper will (1) discuss the rationale for the commission and the limitations of other approaches to cave conservation, (2) present the methods by which the commission was established, the progress made so far, and the goals to be obtained, and (3) list a few needs of the commission for data in various cave related areas.

## CAVE RESOURCES AND THE ARCHAEOLOGICAL RECORD: SOME ADDITIONAL CONSERVATION ANALOGUES

Mark Grady

*(deceased)*

A number of presentations and papers in the recent past have emphasized the value of cave

conservation approaches derived from those already demonstrated to be effective in conservation



archaeology. In an effort to further this perspective, a series of more refined parallels between the preservation of archaeological manifestations and the conservation of cave resources is drawn. Some successes and failures on the part of conservation archaeologists in dealing with the general public, land managers, and the archaeological profession are

considered, and recent conservation research in caves threatened by the New Melones Reservoir is used as an example of the specific application of aspects of this perspective. The NSS is singled out as the organization having the most potential to promote cave conservation in a broad-based and reasonable fashion.

## THE EDWARDS STORY (film)

Edwards Underground Water District  
1200 Tower Life Building, San Antonio, Texas 78205

This 24 min sound-and-color film provides an overview of both the Edwards Underground Water District and the Edwards Aquifer—the sole source of water for over one million persons in an area stretching 175 mi from Brackettville in Kinney County to Kyle in Hays County, Texas.

The responsibilities and projects of the District since its creation by the Texas Legislature in 1969 are interwoven with the story of the uniquely rechargeable limestone aquifer. Five hundred sixty-two thousand acre-feet of water are pumped from it each year for agricultural, industrial, municipal,

and miscellaneous uses. It also supports major recreational uses at Comal Springs, New Braunfels, Texas and at Aquarena Springs, San Marcos, Texas.

The unique process of artificial recharge, carried on by the District, is portrayed by word, film, and animation. During the year of its release, "The Edwards Story" was judged one of four outstanding entries in the Hemisfilm Festival and received the Texas Water Quality Board's "Chairman's Award" for outstanding effort in explaining to the public the workings of this unique regional water resource.

## NATURAL BRIDGE CAVERNS, TEXAS

Jan Knox

*Texas Dept. Water Resources, Austin, Texas*

Natural Bridge Caverns is a commercial cave in Comal County located on the uplands above Cibolo Creek, adjacent to the Bat Cave Fault. The cave is a prominent feature of the Edwards Solution Zone. Cavern development is strongly guided both by variations in rock type and by joints and faults. The five levels of passages, generally trending northwest-southeast, have been joined in places by solution dome development in the vadose zone.

The bedrock floors of the cave

passages are commonly covered with mud, guano, and/or breakdown, upon which speleothems have locally developed. Natural Bridge is still active, with solution enlargement and speleothem deposition occurring simultaneously. Current studies include detailed mapping of the cave with accompanying stratigraphic cross-sections, study of the distribution of joints and fractures, and documentation of intervals of flooding.

## CAVERN DEVELOPMENT, STREAM PIRACY AND AQUIFER EVOLUTION IN THE EDWARDS LIMESTONE, SOUTH-CENTRAL TEXAS

C.M. Woodruff, Jr. and Patrick L. Abbott  
(address unknown)

Geometry of stream nets and of drainage basins indicates that stream piracy occurred within the

Guadalupe and San Antonio River systems near the Balcones fault zone. Further evidence includes

relict fluvial features existing on drainage divides near presumed "elbows of capture;" all these relict fluvial features occur on upland karstic plains. At one time, these karstic plains were probably lowlands adjacent to recharging streams, but they were left as relict landforms after rapid downcutting by pirate streams graded to a new, lower base level. Because of this deep incision in the Guadalupe and San Antonio watersheds, the Edwards Limestone was breached

at the lowest topographic levels in the entire region, thus providing loci for spring discharge from the aquifer. Farther west, in the Nueces watershed, the geometry of trunk streams suggests no major piracy. Because of the absence of piracy, and because of less fault displacement and less rainfall, the major streams of the Nueces system cross the Edwards Limestone at higher topographic levels and, thus, recharge the aquifer.

## SOLUTION SCARP AND RELATED FISSURE SYSTEM, YESO HILLS, CULBERSON COUNTY TEXAS AND EDDY COUNTY, NEW MEXICO

A. Richard Smith

8310 Hazen, Houston, Texas 77036

The Yeso Hills, lying across the southern border between Texas and New Mexico, are part of the Gypsum Plain. A pronounced, west-facing scarp about 3½ mi long and up to 140 ft high bounds the western Yeso Hills. Along the upper slope of the scarp and subparallel to its trend are fissures up to 60 ft deep of apparent tensional origin, modified by solution, collapse, and filling.

Bedrock in the Yeso Hills is the Castile Formation, predominantly gypsum at the surface and in the shallow subsurface. Laminae of brown calcite give the Castile a varved appearance. The lowland west of the scarp (Border Flats) is covered with gravel, cobbles, and boulders of Permian limestone and dolomite carried from the Guadalupe Mountains by flood flow of McKittrick Draw.

Thickness of the gravel is at least 100 ft near the foot of the scarp.

The scarp was formed by relatively fresh (aggressive to gypsum) floodwater issuing from the Guadalupe Mountains. Once an initial low area came into being, it filled with gravel which served to hold water against the gypsum, further dissolving the toe. Distributaries of McKittrick Draw have moved back and forth in front of the scarp, contributing to its relative straightness. Sulfur and petroleum test wells show no evidence for faulting as a control for the scarp. The tensional fissures result from solution of the toe and rotational subsidence of the scarp front toward the gravel-filled basin.

A similar fissure system exists at Lake McMillan, north of Carlsbad, New Mexico.

## DEVELOPMENT OF GYPSUM KARST FEATURES OF LA HOYA ALARDIN AREA, ZARAGOZA NUEVO LEON, MEXICO

Thomas M. Byrd and Walter R. Helmick

Box 4361, Austin, Texas 78766

In the fall of 1976, a reconnaissance study was made of a gypsum karst in the semi-arid region between Zaragoza and Aramberri, N.L., Mexico. The gypsum crops out in a north-south trending valley (elev. 1400 m) between the Sierra de San Francisco (2700 m) and the Sierra

de Aramberri (2500 m). The gypsum is part of the Jurassic Olvido Formation, which is exposed along the axis of the valley. During the early part of the Laramide Orogeny, imbricate thrusting carried Jurassic and Lower Cretaceous rocks eastward over Upper Cretaceous Mendez,

San Felipe, and El Abra formations. The gypsum formed the base of the thrust along which slippage occurred. Tensional faulting near the close of the Laramide Orogeny resulted in the formation of this graben valley. Pediments extend from the mountains into the 2.5 to 4 km wide valley, which is drained by the northward flowing Rio Blanco.

The gypsum is predominantly alabaster with a thin soil mantle of gypsite. Rainpits and Rillenkarren are common on exposed surfaces. The center of the outcrop contains a small polje with caves arranged

around the periphery. These caves are of two types: solution-widened joints and collapse sinkholes. Older sinkholes are filled with soil and appear to coalesce with the polje. Speleothems are scarce and composed of CaCO<sub>3</sub>. Rainfall in the mountains flows into the valley by sheetflow over, or seepage through, pediment gravels. Subsurface solution of the gypsum is directed along joints and other planes of weakness. Unlike those in limestone, these result from plastic deformation caused by local tectonic activity and unloading.

## LATE PLEISTOCENE DEER TRACKS IN CUEVA DE LOS PAJAROS, OAXACA, MEXICO

Roy Jameson

(address unknown)

Cueva de los Pájaros and Cueva San Agustin (Oaxaca, México) have yielded remains of *Navahoceros fricki*, a large, Late Pleistocene deer. On the basis of adaptive morphological features, including thick-set bones and short metapodials, and a mountainous habitat, Kurtén (1975) suggested an alpine or climbing mode of life. The occurrence of deep tracks in Cueva de los Pájaros offers unusual supporting evidence for Kurtén's interpretation. Cueva de los Pájaros was probably a shelter and certainly a natural death trap for *N. fricki*. Several individuals

apparently fell down the entrance pitch of 13 m and survived. They then negotiated a 17 m breakdown slope and left their tracks on a mud floor en route to a 13 m flowstone drop and final 19 m pitch into a room measuring 20 by 50 m. In this last chamber, floored by mud, popcorn, and flowstone, are perhaps a hundred tracks, all of a size commensurate with *N. fricki*. A steep mud bank contains "skid marks" terminating in tracks. One fully articulated and several partially articulated skeletons of *N. fricki* are present.

## SOME PALEO-BIOLOGICAL IMPLICATIONS FOR SPELEOCHRONOLOGY

Merydith D. Turner

Box 8536, U. T. Station, Austin, Texas 78712

Problem: A major cave containing a large chamber with deposits of a material (apparently ancient guano) has no natural entrance.

If the material is guano, what can be learned of the bats, and what might be implied of past speleological sequences? A multidisciplinary study of the biology, paleontology, chemistry,

and stratigraphy of such situations should yield substantial data of interest. A pilot project along these lines was undertaken in Natural Bridge Caverns, Comal County, Texas. The author feels justified in concluding that the "material" was guano from a large *Tadarida* nursery colony. The dates of paleo-speleological events could be determined from such studies.

## CAVE MANAGEMENT AT BUFFALO NATIONAL RIVER: PHASE II

Milford R. Fletcher, L. Lorraine Mintzmyer and Keith A. Whisenant

Buffalo National River, Harrison, Arkansas 72601

The National Park Service has recently acquired lands on the Buffalo National River in Arkansas which contain some outstanding karst features, including a number of caves. During the past year, the NPS has contracted to have a number of these caves inventoried and classified according to the dual classification system evolved by the U.S. Forest Service, the Bureau of Land Management, and the National Park Service. Well over 40 caves and springs have been so

classified to date, and more than a dozen of these have been opened to general public use. Plans for the future include a continuation of the value and hazard evaluation of caves, the establishment of photo points and cave registers, and investigation of the karst and hydrological features of the park. Within the next year, we plan to begin establishing critical habitat for several species of animals including three species of bats.

## CAVE MANAGEMENT—THE VIRGINIA EXPERIENCE

John Wilson

7901 Dalmain Drive, Richmond, Virginia 23228

The success of efforts in Virginia to manage or control caves for a given purpose, such as conservation, have been directly related to the degree of management skill, time and capital applied to accomplish those goals.

Several different approaches to cave management have been tried with four significant caves in Virginia: Butler, Perkins, Paxton's, and Porter. Limited efforts to gate the back portion of Paxton's Cave were marginally effective; very little more was done to manage the cave. Porter had a better gate installed, but follow up was inadequate to effectively deter cave vandals, and thus gating only marginally achieved its goals. Butler Cave is controlled by the Butler Cave Conservation Society

(BCCS), which not only seeks to preserve the cave but has also given priority to exploration and mapping of the cave. The success of BCCS is impressive, although there has been some unintentional deterioration of the cave in a few places. Based upon these experiences, the sensitive Perkins Cave is now controlled and managed by the Perkins Cave Conservation and Management Society (PerCCAMS) under even more protective controls.

Moratoriums can be effective, but they have limitations. Data from cave registers, historical sources, direct observations, cave management organization documents, and interviews provided the information for this study.

## NATURAL BRIDGE CAVERNS

Clara Wuest Heidemann

Route 3, Box 515, Natural Bridge Caverns, Texas 78212

Natural Bridge Caverns was discovered on March 27, 1960, by four students from St. Mary's University in San Antonio. The spelunking students were Preston Knodell, Orion Knox, Jr., Al Brandt and Joe Cantu.

A closed corporation was formed in 1962 and plans were begun for

development of the caverns. Development began on March 25, 1963 by Jack Burch, Harry Heidemann, Reginald Wuest and Orion Knox, Jr. While excavating, spearpoints dating back to 5,000 years were found near the entrance. Also found was the jaw bone of a grizzly bear that became extinct

over 8,000 years ago. Below the bear bones were an Indian's leg bone and spear point.

The caverns were opened July 3, 1964, and were officially dedicated by then Governor John Connally on August 5, 1964. In 1967, Lt. Governor Ben Barnes dedicated the caverns as a State Historical Site. In 1971, the Department of the Interior registered the cavern as a National Natural Landmark. In 1973, the Discover America Travel Organization (DATO) conferred the honor of Travel Attraction of the Year on Natural Bridge Caverns.

## CHOOSING BETWEEN ROPE AND LADDER WHEN MINIMIZING WEIGHT IS IMPORTANT

Kirk MacGregor

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On some caving trips, it is important to minimize equipment weight, but it may not be obvious whether ropes or ladders will be lighter for the cave to be visited (for example, where a cave with a few short pitches is approached by a long hike). This can present a complicated problem, and it may be desirable to consider unconventional techniques and/or to do detailed calculations of relative weights.

However, when reasonably conventional techniques are used (11 mm nylon rope with one average-weight vertical rig per caver versus Pierre Allain ladders with sufficient 11 mm rope to belay all members of each party), an adequate decision can usually be made by comparing the total depth of pitches in the cave to 7.5 n m (or 25 n ft.), where n is the number of cavers on the trip. Deeper caves require less weight on rope. Shallower caves require less weight

As for my philosophy towards tourism, recognition of the essentiality of the travel industry should be emphasized. Travel and tourism, which used to be a privilege of the well to do, is now within reach of most Americans. It is an important growing segment of the U.S. economy. It supports over 4 million jobs. Tourism is one of the three largest employers in at least 30 states. By the turn of the century tourism will be one of the largest industries in the world, if not the largest.

on ladders. These depths can be halved for lightweight vertical rigs or doubled for "overweight" rigs. Thus, a trip consisting of three cavers with lightweight rigs would save weight by using rope in caves with over 11 m (37 ft) of pitches, but a trip with 12 cavers with "overweight" rigs would need a cave with at least 180 m (590 ft) of pitches before it would save weight by using rope.

Two hybrid techniques are also considered: 1) using ladders on some pitches and ropes on others. Using the techniques described above, this is never the lightest approach. 2) rappelling in on a rope, and climbing out on a ladder, using an autobelay. If the rappel/autobelay rigs used are light enough, this technique can save weight over a limited range of total depths, the maximum saving is at 7.5 n m (25 n ft) and amounts to perhaps 10 or 20% (compared with pure rope or ladder).

## LOGISTICAL CONSIDERATIONS IN DEEP MULTI-DROP CAVE SYSTEMS

Bill Steele

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In recent years, members of the Huautla Project of the NSS and Association for Mexican Cave Studies have explored caves in Mexico nearing 3000 ft in depth. Unlike the Europeans, who have explored their deep caves with use

of large parties, the American approach has been with small numbers of personnel. Basically, the procedure has been: (1) rigging ropes (in the case of the Sotano de San Agustin, 45 in number) then exiting, (2) entering the cave with

camp provisions and rappelling down, (3) establishing a camp and exploring from the camp for up to

12 days, (4) exiting with camp packs, and (5) re-entering to retrieve ropes.

## SAWED-OFF GIBBS ASCENDERS

Kirk MacGregor

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In a few applications, it is desirable to have a Gibbs ascender with a short shell. Three tensile tests of such "sawed-off" Gibbs show that loss of strength is not a problem.

However, other problems may arise. If the Gibbs must ride on top of a pulley or another ascender, enough metal must be left on the bottom of the shell to ensure that the cam does not protrude sufficiently to catch on the device below, hindering locking. The amount that can be cut off the bottom of a shell ranges from about 3 mm to 15 mm, depending on the use of the Gibbs. If the top of a Gibbs shell is made very short (for

example, by cutting 45 mm off it), the breaking strength of the rope at the Gibbs is slightly reduced, and both the tendency of the Gibbs to slip and the "fallback" of the Gibbs are substantially increased. For practical use, up to about 32 mm can be cut off the top of a Gibbs shell with essentially no effect except increasing the fallback by about 1 cm.

Two benefits of the sawed-off Gibbs, besides its shorter length, are a reduction in weight by up to about 20%, and a tendency for these ascenders to catch sooner than regular Gibbs when they are dropped loosely down a rope.

## FLARING PIN HOLES IN GIBBS CAMS

Kirk MacGregor

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If the pin-entry end of the pin hole in a Gibbs cam (not the hole in the shell) is flared to 12 mm (1/2 inch) in diameter, using a countersink, the Gibbs becomes substantially easier to assemble on to a rope. Two Gibbs with this modification were tensile tested to over 1100 kg (2500 lbs.) with little damage except bent clevis pins. (In an ill-advised economy move, spring-wire Gibbs were used in this

test. The clevis pins used in these typically bend around 900 kg. Had the much-stronger quick-release pins been used, both Gibbs would have been in working condition after the tests). Combining these results with information from Gibbs Products Company, it is clear that this modification has essentially no effect on the strength of Gibbs ascenders.

## EARLY EXPLORATION IN MEXICO

T.R. Evans

*4905 Vly Oak Drive, Austin, Texas 78731*

An enlightening insight to the first caving trips to Mexico by Texas cavers and the organization of the Speleological Survey of Mexico . . . later to become the

Association for Mexican Cave Studies. T.R. talks of early reconnaissance trips and a few of the deep pits they found — among them, the "Big G."

## THE EXPLORATION OF SOTANO DE JOYA DE SALAS

Orion Knox

*305 Chippendale Avenue, Austin, Texas 78745*

In 1965, three caves were making headlines in Mexico: Ventana Jabali, with its 154 m skylight drop, had just knocked down record 123

m Surprise Pit in Fern Cave. A new cave near Xilitla, Sotano de Tlamaya, was starting to get deep. But the one everyone was watching

was a great fissure which split the valley floor in a remote lumbering camp named Joya de Salas.

## BLACK HOLES

Jeff Horowitz

Box 7672 U.T. Station, Austin, Texas 78712

Mexico has long been known for its spectacular, deep, open-air shafts. Jeff takes you on a whirlwind tour of the best: Hoya de

las Guaguas, Sótano de la Cuesta, Sótano de las Golandrinas, Hoya de la Luz, Sotanito de Ahuacatlán, and El Sótano del Barro.

## THE CAVES OF ACATLAN

Andy Grubbs

Box 7672 U.T. Station, Austin, Texas 78712

Not everything is vertical in Mexico. Andy talks about the

significant horizontal systems in the lowlands of Puebla.

## A NEW AREA — SAN JOAQUIN

Roy Jameson

(address unknown)

Several long-distance hikes have netted an exciting new karst area high atop San Joaquin Ridge.

Large arroyos disappear into deep caves, which also take air. Resurgences are 1200 m lower.

## HIGH ELEVATION CAVING — THE XILITLA PLATEAU

Patty Mothes

727 James St., Morgantown, West Virginia 26505

Cavers have for years visited the lush tropical area around the town of Xilitla, S.L.P., but few have

bothered to hike up above the rain forest and into the alpine meadows . . . until now.

## THE CAVES OF YUCATAN

James Reddell

Biology Department

Texas Tech University, Lubbock, Texas 79409

Amidst the land of Mayan ruins, sacrificial cenotes, and thick

jungle, James describes caving in the flatlands.

## MEXICAN CAVING GROUPS

Jorge Ibarra

(address unknown)

Many Americans caving in Mexico are unaware that there are two active national caving groups in

Mexico. Jorge Ibarra, from Ciudad Mexico, D.F., talks about these groups and what they are up to.

## CAVING IN CHIAPAS

Bill Steele

1506 Waller Street, Austin, Texas 78702

The potential of caving possibilities in the Mexican state of Chiapas has only begun to be

realized. In caves such as Sumidero Yochib, considered the most technically difficult cave ever

explored, American explorers have developed new techniques to match

the obstacles of a steeply descending river cave.

## THE RIVER CAVES OF ZOQUITLAN

Jerry Atkinson

(address unknown)

In December, 1976, cavers located two sinking rivers 20 km north of Huautla, Oaxaca. Jerry

tells of the return expedition in October, 1977.

## CUEVA DE DIAMANTE

Mark Minton

Box 7672, U.T. Station, Austin, Texas 78712

Until quite recently, everyone thought the Sierra de el Abra had a maximum elevation of 1500 ft. An AMCS team spent four years

proving this to be incorrect in a most unusual manner. Mark tells the story.

## THE HUAUTLA PROJECT

Bill Stone

1505 Kirkwood, Austin, Texas 78722

During the past year and a half, five major expeditions have been directed to this area in eastern Oaxaca, exploring the three deepest caves in the Western

Hemisphere. The sixth expedition left Austin, Texas on May 13, 1978 to return to Sotano de Agua de Coarrizo—778 m deep with thirty rigged drops.

## SPRING CAVE, COLORADO

Jim Pisarowicz

Psychology Department, University of Denver  
Denver, Colorado 80208

The dry entrance series of Spring Cave, located in northwestern Colorado, has been known for many years. In the early sixties, exploration was pushed by a swim through 40°F water into a river gallery. Lead by Donald Davis, nearly a mile of gallery was traversed, but exploration was stopped by a sump. In 1975, Colorado cavers Al Collier and Tom Taylor dove this sump (76m underwater) and found more large stream gallery. Not carrying caving gear, they noted that the large, bore-hole passage continued further than their SCUBA lights could penetrate. In 1976,

caver-divers Collier and Taylor were joined Norm Pace, and the passage beyond the First Sump was traversed. The passage sumped again. Collier, Taylor, Pace, and Jim Pisarowicz dove the First Sump and surveyed their way to the Second Sump (823 m sump to sump) in 1977. The Second Sump was then passed by Collier and Taylor. A swimming passage was found which sumped a third time after 30 m. Here, the gradient of the cave changed and waterfalls were encountered. Climbing two waterfalls, Collier and Taylor encountered Sump Four.

## BIGFOOT CAVE, MARBLE MOUNTAIN WILDERNESS, CALIFORNIA — A NEW UNITED STATES DEPTH RECORD

Steve Knutson and Mike Sims

505 Roosevelt, Oregon City, Ore. 97045

In 1974, an alpine karst in the Marble Mountain Wilderness in extreme northern California was rediscovered. Subsequent explorations by personnel of the Klamath Mountains Conservation

Task Force showed caves there to be of national significance. On 9 September 1977, Meatgrinder and Bigfoot Caves were linked, giving a combined depth of 369 meters, a new United States record.

(Program Editor's note: this connection was made five years to the day after the Flint-Mammoth

connection — the longest cave in the United States).

## EXPLORATION OF THE FRIARS HOLE SYSTEM, WEST VIRGINIA

Douglas M. Medville

11762 Indian Ridge Road, Reston, Virginia 22091

The Friars Hole System in Pocahontas and Greenbrier counties, West Virginia is a large and complex cave currently undergoing active exploration and survey work by cavers from several eastern grottos and from McMaster University, Canada. Until 1976, two sizeable but separate caves were known in the area; Friars Hole Cave, with 7.2 km of passage and Snedegars Cave, with about 4.8 km of passage. While several streams sink in the area between the two caves, none were traced into either. Digging in one of these sinking streams in early 1976 resulted in the discovery and exploration of a third substantial cave, Rubber Chicken Cave, which lay between the other two and which took some of the water sinking between them. Exploration of this cave soon resulted in 9.7 km of surveyed passage and in connections, first to

Friars Hole Cave and then to Snedegars Cave. Subsequent exploration and mapping resulted in over 25.7 km of surveyed passage by September 1977. At the same time, cavers from McMaster University were working in a separate cave just to the north of the system, Canadian Hole. In mid-1976, they made a major breakthrough at the known end of the cave and discovered over 6.4 km of large passage, including the largest underground chambers in West Virginia. Finally, in September 1977, the McMaster cavers, pushing a low but blowing lead in Canadian Hole, connected it to the northern end of Rubber Chicken, creating a single system having a surveyed length (as of April 1978) of over 35 km, a depth of 142 m, and a linear extent of 5182 m.

## EXPLORATIONS IN THE SILVERTIP CAVE SYSTEM, MONTANA

Mike McEachern

1404-B Kirkwood, Austin, Texas 78722

An exploratory reconnaissance of Silvertip Mountain, Montana during the summer of 1972 lead to the discovery of a major alpine karst cave system. Since that time, exploration has continued every year during the late summer, following the snow-melt run-off. Most of the 2000 man-hours logged underground have been devoted to mapping and connecting together the numerous entrances which have been located on the mountain. To date, over 11 km of cave passage in several different cave passage in mapped and a number of entrances have been connected together. Entrances occur as much as 425 m above the resurgence, although attempts to break the U.S. depth record have been thwarted. At the

present time, the Getout, Easyout, Stairwell, and Bell sections of the cave comprise the largest interconnected portion of the system and reach over 300 m in depth.

Major obstacles to exploration include the 27 km hike over rugged trails to reach the system, 1°C cave temperatures and water temperatures, thermally fractured cave walls which make hand- and footholds unreliable in addition to creating a severe hazard of rock fall, extremely tight and jagged passageways which slow travel to a snails pace, numerous drops and traverses requiring rigging, and, finally, the limited time during the year in which the cave is accessible.

## EXPLORATIONS IN THE JANUS PIT SYSTEM STONE COUNTY, ARKANSAS

Mike Warshauer

2621 E. Monroe Terrace, Springfield, Missouri 65802

The Janus Pit System is developed principally in the gently dipping Plattin limestone of Ordovician age. Approximately 2.4 km of passage has been mapped, out of an estimated 4 km of explored passage. Explorers face a number of physical difficulties,

among which are the 45 m principal entrance pit, mud, cold water, and lengthy sumps separating the resurgence, Cave River Cave, from air filled passages in the Atlantic Avenue section and from Flitterin' Pit (44 m deep).

## TAG AREA MULTI-DROP CAVES

Marion Smith

5624 Magazine Road SW, Knoxville, Tennessee 37920

Almost every weekend since 1974, vertical cave enthusiasts from the Tennessee, Alabama and Georgia (TAG) area having carried on exploration in ridge caves of Tennessee and Alabama. Systematic walking has located

many new caves. Previously entered caves have been extended with determined pushing and by the use of wetsuits and electric lamps where wet conditions persist. Many of the caves are among the deepest in the United States.

## THE WORLD'S LONGEST GLACIER CAVE: A DECADE OF EXPLORATION IN THE PARADISE ICE CAVE MOUNT RAINIER, WASHINGTON

William R. Halliday, Charles H. Anderson and Mark Vining

1117 36th Avenue East, Seattle, Washington 98112

Until 1966, neither the Paradise Ice Cave, nor glacier caves as a whole, were considered to be of speleological importance. Approximately 13 km of passage are now shown on the map of the Paradise Ice Cave, with much remaining unmapped. This is by far the longest mapped glacier cave

in the world. The size, location, pattern, and features of the cave have changed extensively during the period of study, and numerous new concepts of glaciocaveology have resulted. Similar investigations have now been begun elsewhere in the world.

## THE EXPLORATION OF THE SCAPEGOAT MOUNTAIN KARST SCAPEGOAT WILDERNESS, MONTANA

Jim Chester

410 East Aspen St., Bozeman, Montana 59715

In 1971, a vast alpine karst was found on the plateau encircling Scapegoat Peak (9206 ft). Literally hundreds of shafts, swallets, and resurgences riddle the area. Since 1971, the karst has been systematically investigated in summer and winter expeditions of up to two weeks duration. More than 22,000 ft of passage have been mapped in Green Fork Falls

Cave and other caves in the associated system. Exploration is progressing from the resurgence level upward, with a potential system height of over 1400 feet. Its remoteness, wilderness quality, large river galleries with 35°F rivers, lakes requiring boats, and technical climbs all combine to make the Scapegoat System one of "the classics."

## CAVES OF WHITE RIDGES VANCOUVER ISLAND, B.C., CANADA

Paul Griffiths

*Box 733, Gold River, B.C., Canada V0P 1G0*

The White Ridges are the site of the deepest known caves on Vancouver Island. Recent exploration has been concentrated on a 1200m-high karst plateau which has regularly yielded vertical systems. One of these possesses the deepest free drop in Canada (80 m) and a unique subterranean glacier of considerable thickness. The deepest point reached presently stands at -220 m. Seven hundred meters below is an extensive

resurgence cave ascending to a height of 140 m with a total passage length of 1050 m. Local cavers are hopeful that they will ultimately make the connection between the resurgence and plateau caves, and evidence certainly points to a master system. Rigorous weather conditions, including 380 cm/year rainfall have led to experimentation in equipment and techniques for this particularly challenging alpine caving.

## FLINT MAMMOTH CAVE SYSTEM, KENTUCKY — Progress since the connection of 1972

anonymous

The Flint Mammoth Cave system, in the central Kentucky karst, is by far the world's longest cave. When the connection between the Flint Ridge Cave System and Mammoth Cave was made on 9 September 1972, the total length was 232.4 km. Today, the system has over 314 km of surveyed

passage. Eighty kilometers of passages have been added in less than six years. The potential for further discoveries remains great, and the integration of the Joppa Ridge Cave System to the south with the Flint Mammoth System is a future goal.

## THE 1978 NSS EXPEDITION TO THE ASTRAKA PLATEAU, GREECE

Wil Howie

*749 Gardner Street, Jackson, Mississippi 39206*

During the three-and-a-half-week trip, over 80 new caves were added to the survey. The first extensive and detailed surface survey was done, as well as complete subsurface mapping. The first truly accurate survey of Provatina was

made, several new significant caves were discovered, and much work unfinished by previous expeditions was completed.

All major goals set for the expedition were met.

## THE MYSTERY OF THE MACOCHA ABYSS

Karel B. Absolon

*University of Illinois Medical Center, Urbana, Illinois*

This historic movie on speleology presents the discovery of the central-European Punkva caves in the area of Macocha, one of the largest sink hole abysses in the world. The dramatic discovery of the geographic and paleontologic secrets of this classical karst locality is united by the underlying musical theme of its people, the

"Dear Moravia Theme". The motion picture was presented recently at the International Speleological Congress meeting in Sheffield, England, held in honor of Professor Karel Absolon's 100th anniversary, where it received a special citation as the best documentary film on the subject.

## THE WORLD'S LONGEST UNDERWATER CAVE

Sheck Exley and Ned Deloach

*1591 So. Ln. Avenue, 118 Coventry  
Jacksonville, Florida 32210*

The 22-year exploration of the Peacock Springs Cave System is unique not for length attained (5.85 km) or depth attained (67 m), but for the mode of exploration employed to survey the cave: cave diving. It is Florida's longest cave, but more impressive is the fact that it is the longest known underwater cave in the world — *by far*. No underwater cave outside of Florida has been explored or surveyed for more than a third of Peacock's surveyed length.

Peacock has also played a significant role in the development of cave diving equipment in the United States, having long been employed as a "proving ground" for new equipment and procedures. From the crude single tank, double hose regulator and flashlight in a

plastic bag employed by Vasco Murray in 1956 to catch the first glimpse of the cave entrance, equipment has gradually evolved to enable NSS explorers to push silt-filled underwater squeezeways almost 700 m from the nearest entrance and to water depths up to 67 m. Double 100 cf tanks, dual valve manifolds, quartz halogen lights and stage diving procedures are now being employed by NSS divers to attain safe cave bottom times of over 2.5 hours and still retain a 100% safety margin. During the evolution of this equipment, all of the seven passable entrances of the Peacock system were connected, all of the passage explored, and all but approximately 650 m of the passage surveyed.

## BLACK CAVERS

John M. Wilson

*7901 Dalmain Drive, Richmond, Virginia 23228*

Speculation has long existed about why there are so few contemporary Black cavers in the United States. There are Black cavers, but the percentage is small; even the fact that Blacks make up only 12% of the U.S. population cannot account for this phenomenon. Possible causes include: (1) the generally racially

separate social life in the U.S., (2) location of caves with respect to demographic distribution of Blacks, and (3) economic and cultural factors of the Black community. The nature of caving, both as a recreation and as a science, and the intrinsically conservative nature of organizations may be significant.

## MINORITIES IN CAVING

Janet L. Fitzsimmons

*1506 Waller Street, Austin, Texas 78702*

This statistical analysis of the participation of minority races and women in United States caving was conducted during the Spring of 1978. Self-addressed survey cards were sent to all listed internal organizations of the National Speleological Society. These cards requested information concerning the proportion of minority race and

women members of each grotto.

The demographic presentation includes geographic considerations. The author hopes this survey will serve as groundwork for a future sociological study of Black participation in non-materialistically rewarding leisure-time activities.

## THE GREAT SOLO CAVING MYTH

John M. Wilson

*7901 Dalmain Drive, Richmond, Virginia 23228*

People often seek absolutes to simplify communication and

understanding and to help establish unity of belief. Possibly,

other reasons exist as well. One of the dominant themes in caving safety has been an absolute prohibition against caving alone. This paper examines the prohibition against solo caving as an important concept for novice cavers and one of decreasing importance for experienced, skillful cavers who use good judgment.

## PHYSICIANS AS CAVE EXPLORERS

Karel Absolon (deceased) and Karel B. Absolon

*University of Illinois Medical Center, Urbana, Illinois*

The Moravian Karst, near Brno, Czechoslovakia, is centered around the Macocha Abyss. The earliest detailed explorations of the Karst and the Abyss were made by two physicians: J.F. Hertod von Totenfeld (1648-1714) and J. Wankel (1821-1897).

Wankel, whose clientele included miners in nearby Blansko, was an archaeologist, geographer, and speleologist in addition to being a physician. He is generally credited with having been the "father" of Central European archaeology, and his scientific work is relatively well-known to modern scholars.

Von Totenfeld was interested in the contribution of mineral waters to good health. He also sought a local replacement for imported "unicorn" powder, which formed an essential ingredient of his remedies. According to Paracelsian theories of previous centuries, the "good mother earth" *ipse facto* made remedies available to her inhabitants.

Fossilized mammoth bones from cave and surface deposits, when ground up, became his substitute for "unicorn" powder. The search for bone lead to von Totenfeld's cave explorations and, finally, to Macocha. He measured the depth

Several solo caving situations are ranked according to possible inherent dangers. A system is proposed for evaluating trade offs between risk and cost in time, money, and reduced goal achievement. A call is made for open discussion on this type of issue. The advantages of a more credible safety policy are identified.

of the Abyss by comparing the time required to recite the "Pater Noster" to the time required by a dropped stone to reach the floor of the Abyss.

Von Totenfeld became "Protophysicus" — first physician of Moravia, physician to the Austrian Emperor and King in Vienna, and even the "selector" of the bride for the future King Charles VI. Professional jealousy lead to a controversy over the efficacy of his procedures and remedies. Although certainly not a medical innovator, he made significant contributions to the medical science of his day and became a member of the prestigious "Academia Naturae Curiosorum" in Schweinfurt. His suggestions regarding hygienic principles were progressive.

Von Totenfeld's "Tartaromastix Moraviae" (1669) did not have the scope and influence of A. Kircher's (1602-1680) "Mundus Subterraneus" (1664). However, he deserves to be remembered as an early father of speleology.

This study was based on unpublished material from the archives of the senior author (formerly: Professor of Geography, Charles University, Prague).

Juxtlahuaca has been a semi-commercial cave since 1932. A 43-page booklet on the cave, published locally in 1961, described the three main paintings. The 1964 edition of "Mexico's Caves and Caverns," a 32-page booklet in

English widely distributed by the Pemex Travel Club, devoted a half-page to them. NSS charter member Charles Mohr visited the cave and photographed the paintings even earlier.

## DR. CALL AT MAMMOTH CAVE

Harold Meloy

*Box 454, Shelbyville, Indiana 46176*

One of the very top Mammoth Cave authors was Richard Ellsworth Call, M.D., Ph.D. (1856-1917). His writings flashed across the sky of Mammoth Cave literature during the 1890s with all the brilliance of an unexpected comet. His descriptions of the

famous cave outshone all other accounts then in print, including the works of Horace C. Hovey. Hovey joined with Call in 1897; thereafter, Call's prose gave new life and refreshing luster to Hovey's books.

## THE SKELETON OF LURAY CAVERNS VIRGINIA

Russell H. Gurnee

*231 Irving Avenue, Closter, New Jersey 07624*

On October 4, 1878, Andrew J. Campbell discovered a skeleton at the bottom of a chasm 800 ft from the entrance of Luray Caverns. The skeleton was partly covered with calcite; only the skull, jaw, ribs, and leg bones were visible.

Identified by local medical authorities as a "young person," it was a point of curiosity for visitors for several years. The loose bones were quickly taken by souvenir hunters, however; although there were sufficient parts available for Professor Joseph Leidy to identify them in 1880 as a "young human

male." Leidy saw them again in 1887 and said they were then almost unrecognizable.

In 1921, Col. T.C. Northcott, then owner of the cave, had the bones excavated by Smithsonian Institution archaeologists. Taken to Washington, they were identified as those of a "sub-adult female."

Many tales were told of the skeleton. A book published in 1887 and titled *Legend of the Luray Caverns*, by Pauline Carrington Rust, tells in poetic form a fanciful story of a young Indian brave who was sealed up in the cave.

## A DISCUSSION OF GRAPHIC TECHNIQUES AS RELATED TO SPELEAN HISTORY

Emily Davis Mobley and William F. Mobley

*Box 333, Walbraham, Massachusetts*

The earliest prints were woodcuts related to the Bible. Although there may be early (15th century) Biblical cave prints, the authors have not found any. Man progressed through copper etchings and engravings, mezzotints, aquatints, lithographs, wood engravings and

has completed the cycle with photography. The paper discusses each of these techniques and how to recognize them, so that speleohistorians may be able to date and recognize prints which have been separated from books or which were never bound.

## THE OLMEC CAVE PAINTINGS OF JUXTLAHUACA CAVE AND THEIR HISTORY

William R. Halliday

*1117 36th Avenue East, Seattle, Washington 98112*

The April, 1967 issue of *Natural History* announced the "find of what are believed to be the oldest paintings discovered in the new World", in la Gruta de Juxtlahuaca, Guerrero, Mexico. They were and still are attributed to

the Olmecs, the first high culture known in the Americas.

Since these are the only cave paintings known in the western hemisphere which are comparable with those of Europe, it is important to clarify their history.

natural enemy to be conquered. More commonly, it is a physical setting around which hardship, quest, romance, and various other life struggles are played out. Caves may also serve symbolically in fiction; never really as tangible places, but rather as figurative images. In this context, the mind may be an intricate cavern, or the interplay of human experiences may be excursions through the labyrinth of life. Whether the cave is used realistically or figuratively, the variety of fictional works in which it is found is surprisingly diverse. Fiction using caves includes classical works, historical novels,

### GEORGE WASHINGTON CAVE JEFFERSON COUNTY, WEST VIRGINIA

Jack H. Speece

711 E. Atlantic Avenue, Altoona, Pennsylvania 16602

George Washington Cave near Charles Town, Jefferson County, West Virginia contains a signature of George Washington dated 1748. Although this inscription appears to be authentic and similar to those in Madison's Cave and at Natural

science fiction, fantasy, gothic romance, westerns, pure adventure, children's fiction, the occult, and others. The role of caves in fiction is indeed fascinating and ranges from the proverbially ridiculous to the sublime. As speleologists, we derive something extra from these works, beyond what the authors had intended: many ways caves are used are downright amusing. This light-hearted overview of spelean fiction is in part a progress report on the compilation of an annotated English-language cave-fiction bibliography.

Bridge, it cannot be verified by historical accounts. The cave is also reported to have been used by him for Masonic purposes. The commercialization of this landmark was short-lived, but it remains today in good condition.

### SCIENTIFIC, POPULAR, ROMANTIC, AND ENTERPRISING INTERESTS IN BALL'S AND HOWE'S CAVES, SCHOHARIE COUNTY, NEW YORK, 1831-1900

Ernst H. Kastning

Department of Chemistry and Geology  
Murray State University, Murray, Kentucky 42071

Ball's and Howe's Caves received substantial early recognition in scientific, popular, and romantic literature of the mid-nineteenth century. Early accounts were authored by renowned and influential persons of that time and have significantly enriched spelean history of the period. Continuing historical research has unearthed several interrelationships among various visitors, authors, scientists, and cave owners and managers.

Local newspaper accounts of the discovery and first visits to Ball's Cave were communicated to editors of established scientific journals such as the *Monthly American Journal of Geology and Natural Science* (1832) and *The American Journal of Science and Arts* (1835). These writings may have inspired Charles Fenno Hoffman to create the Cavern of Waneonda in his romantic novel, *Greyslaer* (1840). So real was his description of this

Schoharie Cave that it later inspired a young lady named Geraldine to see Ball's Cave and write about it in *The American Literary Journal*.

Meanwhile, Howe's Cave was discovered (1842) and opened to the public by Lester Howe, creating a sensation in newspapers, geological reports, and in several American and English magazines. Simeon North's "Visit to Howe's Cave" first appeared in the *Knickerbocker* (1851). The account was pirated in the same year by *Sharpe's London Journal*, the *New York Evening Post*, *The North American Miscellany*, and *Littel's Living Age*. Two years later, W.H. Knoepfel published his prospectus for developing nearby Ball's Cave for public view, claiming it was rivaled only by the great Mammoth cave in Kentucky. Surely Knoepfel was influenced by the publicity given to Howe's Cave. These plans

never came to fruition, and what may have been America's first "cave war" was squelched.

The popularity of Howe's Cave continued to grow. The enigmatic "Pip Morgan" account appeared in the *Continental Monthly* (1863). The first guidebook to Howe's Cave was published in 1865 and contained the celebrated "Greatest

Wonder of the World" map of Howe's Cave, later used by Horace Hovey in *Celebrated American Caverns* (1882). Howe's Cave was later subjected to financial vagaries of railroad reorganization and the cement industry. The first phase of its development came to an abrupt halt at the end of the Nineteenth Century.

### REVIEW OF SAFETY AND TECHNIQUES SEMINAR

Don Davison, Jr.

319 Kilbourne Avenue, Appalachia, Virginia 24216

The basic cave pack—useful multi-purpose equipment in a small space. How to keep your body warm before it gets cold. How to keep a body warm in survival or hypothermic situations. How to get the most lift for the least effort, with the least equipment, the fewest men, etc. in a hauling

situation. The shortcomings and hazards of recently introduced equipment. See lots of failed gear and the STC Display Boards. Get the most up-to-date information. Ask probing questions which can inspire new research. Bring your pad and pencil.

### THE BRECCIA-FILLED CAVERNS OF THE TRANSVAAL, SOUTH AFRICA: INSIGHTS ON THE ECOLOGY OF EARLY HOMINIDS

C. Garth Samson

Dept. of Anthropology, Southern Methodist University  
Dallas, Texas 75275

Research on five breccia-filled caverns in the Transvaal dolomites of South Africa is providing new insights into the origins of Man. Not only have new fossils come to light recently, but multi-disciplinary studies on stratigraphy, paleomagnetic-dating, pollen content, and mammalian fauna have all helped to place the earliest hominids in their ecological setting. These new facts have led to an improved

understanding of the ecological pressures which brought about the origins and speciation of the early hominids. Intensive studies of the human fossils, themselves, have continued apace, revealing new evidence for demography, physical capacity and diet. Most fascinating are the new group of theoretical models for predator-prey relationships between the hominids and other large mammals, in the vicinity of the cavern entrances.



## PURIFICACION A

Peter Sprouse

Box 8424, Austin, Texas 78712

Two large caves above Ciudad Victoria, Tamps, are heading for each other. Cueva del Brinco is 800 m above Cueva de Infiernillo.

During the spring of 1978, AMCS cavers spent two and a half months working in the system. Peter tells about the results.

## LA SYSTEMS DE CHICHICASAPAN-ATISCHALLA

Peter Lord

(address unknown)

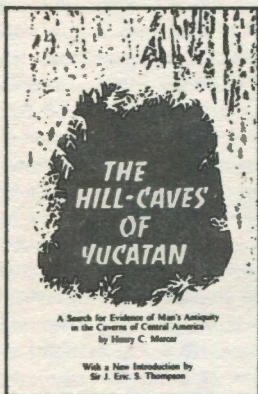
In early 1978, cavers spent three months working in the Cuetzalen, Puebla area, finally discovering the big connection between Cueva

de Chichicasapan and Sumidero Atischalla. The system is now Mexico's longest, at 16 km.

Order from: NSS Bookstore

Cave Avenue, Huntsville, Alabama 35810  
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## THE HILL-CAVES OF YUCATAN



**The Hill-Caves of Yucatan:**  
A Search for Evidence of Man's Antiquity in the Caverns of Central America

by Henry C. Mercer, with a new 44-page introduction by J. Eric S. Thompson  
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1975

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This classic account of Mayan archaeology, jungle travel, and cave exploration derives from Mercer's Corwith Expedition of 1895 to the Yucatan, where he had hoped to find evidence in caves of paleolithic man in America. He found no trace of early man, but much else of perennial interest about the Yucatan Indians and their world.

This reprint edition is enhanced by the 44-page introduction by the late noted Mayan scholar J. Eric S. Thompson, which includes reproductions of rare wall paintings of Maya gods and hieroglyphs here published for the first time.

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## THE SCIENCE OF SPELEOLOGY

The science of speleology has in recent years been advancing at a phenomenal rate. Previous summaries, notably *British Caving* published by the Cave Research Group, have long been out of date. *The Science of Speleology*, published under the aegis of the British Cave Research Association, provides a current survey of "what the other sciences can tell about the nature of caves and their contents, throughout the world." Though the editors are English, the scope of the book is international, with contributors from Canada, the U.S., and Australia as well as from Ireland and the United Kingdom. Each chapter has a bibliography of the classic as well as current literature on its subject.

"I would guess it will appeal to every serious caver be he scientist or straightforward adventurer." — *New Scientist*.

"Belongs in all university, college, high school, and public libraries." — *Choice*.

**Contents:** Cave Surveys, The Geology of Caves, Geomorphology and Caves, Caves in Rocks of Volcanic Origin, The Erosion of Limestones, The Hydrology of Limestone Terrains, The Chemistry of Cave Waters, Cave Minerals and Speleothems, The Physics of Caves, Cave Faunas, Bats in Caves, Cave Palaeontology and Archaeology, The Computer in Speleology.

**The Science of Speleology**

ed. T. D. Ford and C. H. D. Cullingford

6 by 9 inches. 607 pp. Photos.

1976 LC 75 46330

Cloth only: ISBN 0-12-26550-1

# RECENT ANHYDRITE AND BASSANITE FROM CAVES IN BIG BEND NATIONAL PARK, TEXAS

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## ABSTRACT

*Recent anhydrite (CaSO<sub>4</sub>) and bassanite (CaSO<sub>4</sub> · H<sub>2</sub>O) occur as white crusts on the walls and ceilings of three small caves in Big Bend National Park, Texas. Originally precipitated from groundwater as gypsum (CaSO<sub>4</sub> · 2H<sub>2</sub>O), these crusts subsequently changed to bassanite and then to anhydrite in the absence of a liquid phase. High cave temperatures (up to 35°C) and low relative humidities (10 to 60%) caused dehydration of the gypsum. This is the first reported occurrence of bassanite and anhydrite as cave minerals.*

**A**NHYDRITE FORMED from gypsum (via bassanite) in the absence of a liquid phase has been reported from the Death Valley region of Nevada (Moiola and Glover, 1965) and California (Hunt, *et al.*, 1966). This report discusses a new occurrence of recent anhydrite and bassanite which formed as white crusts on the walls and ceilings of three small solutional caves located in Big Bend National Park, Texas, USA. (For details on the specific location of the mineral occurrence and collecting restrictions, contact Big Bend National Park, Texas, 79834). The caves are developed in the Lower Cretaceous (Comanchean) Santa Elena Limestone, which is a gray, cherty, escarpment-forming limestone, thickly bedded and fossiliferous (Maxwell, *et al.*, 1967). The Big Bend exposure of Santa Elena Limestone is 60 to 70 m thick and contains about a dozen caves in all.

The climate of Big Bend is similar to that of the Death Valley region. The precipitation at Panther Junction, Big Bend National Park, is 2.8 cm a year (a 14 yr average) and the precipitation at Death Valley National Monument is 4.5 cm a year (a 30 yr average). Summer daytime temperatures commonly exceed 35°C for both areas. Humidity ranges between 10 and 60% in Big Bend; the lowest humidities occur in the spring and summer months, when temperatures reach their maximum. Because the Big Bend caves are small and dripping water is absent, cave temperatures and humidities correspond closely to daily outside temperatures and humidities.

## MINERAL DESCRIPTIONS

### *Dead Spider Cave*

Dead Spider Cave contains two short, dry, dusty passageways extending from the main entrance room. A 20 cm long, 5 cm wide, 2 cm thick crustal seam was found approximately 0.3 m above the floor, on the right wall near the end

of the left-hand passage. The surface of the crust is discolored a dusty brown while the white underside has a pitted, spongy appearance. A cross-section of this crust reveals (1) microscopic (0.01 mm), short acicular to equant crystals of bassanite, some in parallel arrangement, (2) anhydrite crystals (0.1 mm) surrounding the bassanite crystals and (3) subhedral, tabular gypsum crystals (2 mm) which have been embayed or engulfed by the smaller anhydrite crystals. About one-third of the crystals are gypsum, one-third are bassanite, and one-third are anhydrite. Mineral identification was by X-ray diffraction and by optical techniques (oil immersion). Principal X-ray lines obtained were 3.0 (100), 2.8 (90), and 6.0 (80) for bassanite and 3.5 (100), 2.85 (40) and 2.33 (20) for anhydrite.

The textural relationship of the calcium sulfate crystals indicates that the bassanite and anhydrite postdate the gypsum. The bassanite crystallized first, within the gypsum matrix, and formed nuclei for subsequent radial anhydrite crystal growth. The calcium sulfate in the Dead Spider Cave crust does not occur in layers (anhydrite overlying bassanite overlying gypsum) as does the Death Valley calcium sulfate reported by Moiola and Glover (1965).

### *Pin Cushion Cave*

In Pin Cushion Cave, bassanite and anhydrite occur on the rear wall as thin (1 mm) crusts tinged light pink by underlying red, iron-rich kaolinite clay seams in the Santa Elena Limestone. Most (85%) of this crust is composed of microscopic bassanite. Clearly defined bassanite crystals change to "ghost" bassanite crystals at their junction with the larger, birefringent anhydrite crystals. No gypsum crystals were identified.

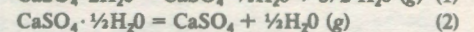
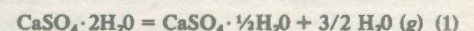
### *Flower Cave*

In Flower Cave, white bassanite and anhydrite crusts (0.5 cm thick) occur on the ceiling of a rear

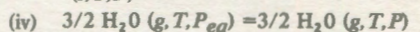
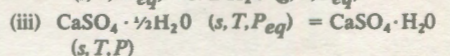
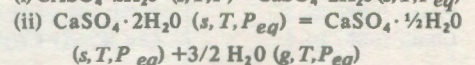
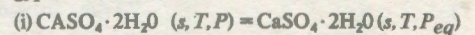
solutional alcove. The crust is composed of approximately 95% bassanite and 5% anhydrite.

## DISCUSSION

Stability relationships in the binary system CaSO<sub>4</sub>-H<sub>2</sub>O have been a subject of considerable debate (for a literature review, see Hardie, 1967). In the presence of a liquid phase, gypsum will change to anhydrite at 42°C and to bassanite at 97°C. In the absence of a liquid phase, the gypsum invariably is dehydrated first to the metastable hemihydrate, bassanite, before changing to the anhydrite.



The free energy  $\Delta G$  may be computed for the dehydration process from consideration of a sequence of reversible processes resulting in the same net change in state. For reaction (1), gypsum to bassanite:



$\Delta G$  (i) and  $\Delta G$  (iii) are very small compared with  $\Delta G$  (iv), and  $\Delta G$  (ii) is zero. Therefore, to a good approximation,  $\Delta G$  for the process of interest is given by (iv):

$$\Delta G = nRT \ln \left( \frac{P}{P_{eq}} \right)^{3/2} \quad (3)$$

Similarly, for reaction (2), bassanite to anhydrite:

$$\Delta G = nRT \ln \left( \frac{P}{P_{eq}} \right)^{1/2} \quad (4)$$

where  $P_{eq}$  is the equilibrium water vapor pressure (dissociation pressure) over the solid phase and  $P$  is the partial pressure of water calculated from the relative humidity (RH) of the air.  $\Delta G$

becomes negative when  $P_{eq} > P$ . Since  $RH = \frac{P}{P_v}$

(where  $P_v$  = the vapor pressure of water at a given temperature,  $T$ ), the reactions will proceed when

$$RH < \left( \frac{P_{eq}}{P_v} \right)$$

The relative humidity at which dehydration of gypsum to bassanite occurs as a function of temperature was calculated using (3). ( $P_{eq}$  was obtained from Kelley and Southard [1940], Figure 13, curve F-F' for  $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$  ( $\beta$ ), where  $\beta$  = the stable hemihydrate under dry conditions.) The dehydration curve of gypsum to bassanite lies well within the range of Big Bend cave temperatures and humidities (Fig. 1). For the reaction bassanite to anhydrite (4) to proceed, relative humidity should be less than 1% (Kelley and Southard, 1940), curve I-I' of Figure 13); however, since bassanite is a metastable phase, it spontaneously changes to anhydrite with time. Moiola and Glover (1965) reported a time period of 11 months for the transition of gypsum to bassanite to anhydrite.

Thermodynamic considerations and textural evidence suggest that the Big Bend cave crusts were precipitated from groundwater as gypsum and then dehydrated in the absence of a liquid phase to anhydrite via bassanite. There is no textural evidence for the rehydration of the crusts, even though cave humidities are higher in the winter months.

## ACKNOWLEDGEMENTS

This work was supported by the Cave Research Foundation. Big Bend National Park permitted sample collection. The manuscript was reviewed by R.C. Ewing and G. P. Landis.

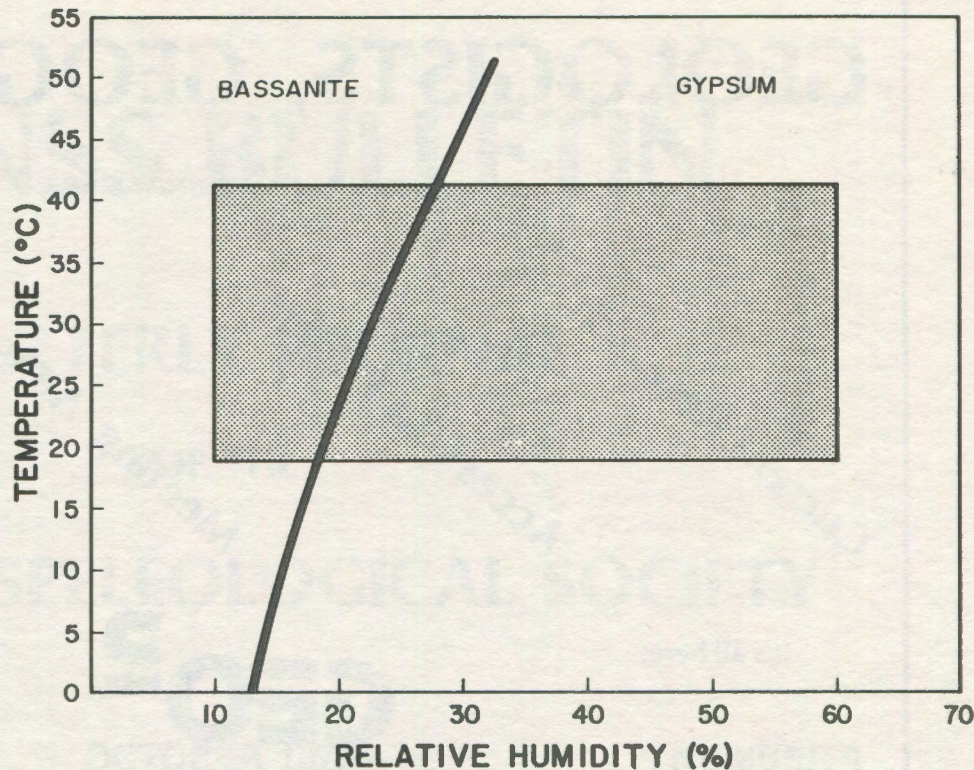


Figure 1. Dehydration curve of gypsum to bassanite. Stippled area represents the range of temperatures and humidities in the Big Bend caves.

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