

SELECTED ABSTRACTS FROM THE 2001 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN MOUNT VERNON, KENTUCKY

ARCHAEOLOGY

WHERE THE BUFFALO ROAM: ROCK-ART AT GUSTAFSONS CAVE IN ARKANSAS

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There are seven panels of aboriginal rock art in the upper chamber of Gustafsons Cave located in the Sylamore District of the Ozark-St. Francis National Forest in Arkansas. The images are predominantly black pictographs. There are also several red pictographs and at least one fine line incised petroglyph. The figures include a panel of six bison, a panel of numerous anthropomorphs, some with evident genitals, and other panels with animal figures, including one turtle and several resembling centipedes. Other pictographs are geometric or unrecognizable. Our recorded efforts included a detailed map of the upper cave chamber.

THE PREHISTORY OF OWL CAVE, MAMMOTH CAVE NATIONAL PARK, KENTUCKY
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Archaeological excavations in Owl Cave occurred between December 1975 and January 1976. Excavated deposits were grouped into three cultural zones ranging from 8000 BC to 1000 BC, or essentially throughout the Archaic Tradition.

ARCHAEOLOGY IN MAMMOTH CAVE

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Mammoth Cave, Kentucky, is one of the most historically visited caves in North America. Archaeological remains in the cave date from prehistoric mining of gypsum and other sulfate minerals (ca. 3000-2200 year ago), historic mining of calcium nitrate around the War of 1812, use of the cave as a tuberculosis sanatorium in the 1840s, and construction of various amenities for the tourist business throughout the 19th and 20th centuries. Beginning in 1993, we conducted a systematic inventory of archaeological resources along a three-mile section of upper Mammoth Cave. Using volunteers coordinated by Earthwatch Institute, we have recorded more than 9700 prehistoric and historic artifacts in the cave to date.

PICTURE CAVE: THE STUDY, DATING, GATING, AND SACRED MEANING OF A PREHISTORIC AMERICAN INDIAN SITE

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We described preliminary study and preservation efforts at Picture Cave in eastern Missouri. This cave is considered the most important site of its type in the Eastern Woodlands. Native Americans left drawings on the walls that appear to reflect Siouan oral traditions. In 1996, a grant was obtained to date the pigments in the drawings. Accelerator Mass Spectrometry radiocarbon dating was used on four samples. The weighted average date for these samples is A.D. 1025 (calibrated). The dates and the striking Mississippian graphics have generated considerable discussion among researchers concerned with the origins of the Southeastern Ceremonial Complex. Realistic portrayals of several important characters known from 19th and early 20th century Siouan oral traditions contribute a great deal to our understanding of Mississippian cosmology in the greater Cahokia area. A target of looters and vandals for over a century, the cave was finally gated in 1996.

KENTUCKY CAVE ARCHAEOLOGY - UNDERGROUND AND UNDER-REPORTED

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We examined the Kentucky Office of State Archaeology site inventory to explore the state of documentation for those caves where prehistoric and historic peoples had left their marks. Some of these archaeological sites have been the focus of spectacular archaeological discoveries, but most cave sites are not recorded in the Kentucky Office of State Archaeology. Despite the potential for Kentucky caves to yield important information about a wide range of prehistoric and historic activities, no statewide inventory of archaeological sites in caves has been undertaken. Using the recently completed statewide GIS database of archaeological sites, we documented the extent of omissions from the inventory, and suggested some ways in which cave archaeology and caving could be mutually beneficial.

ARCHAEOLOGICAL INVESTIGATIONS OF HUBBARDS CAVE, WARREN COUNTY, TENNESSEE

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Hubbards Cave, located in Warren County, Tennessee, contains evidence of a prehistoric gypsum mine. Archaeological investigations conducted thus far have focused on the systematic documentation of all prehistoric material found within the cave.

BIOLOGY

BIOLOGY OF SPRING CAVEFISH (*FORBESICHTHYS AGASSIZI*): NOTES ON DEMOGRAPHY, HABITAT USE, REPRODUCTION, AND EARLY LIFE HISTORY

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Spring cavefish, *Forbesichthys agassizi*, are locally abundant in surface springs at LaRue-Pine Hills Ecological Area, Illinois, that flow less than 100 m before entering a lowland swamp. We initiated a study of the Pine Hills populations and a state endangered population in Missouri to provide much needed information on their biology and status. Spatial and temporal variation in fish abundance, size-frequency distribution, condition, and habitat use in five surface springs were examined by sampling fixed locations along a longitudinal gradient on a seasonal basis. In all five springs, cavefish abundance was highest during the spring season and in upstream stations near the resurgence. Large adults were not present in samples during summer and fall, suggesting mortality or movement underground. Cavefish remaining on the surface during daytime used a variety of cover items, including large boulders, logs, and leaf litter. Gravid females with mature ova were found during winter in two surface springs and in the cave. Larval cavefish with yolk appeared in the surface springs during late winter and were susceptible to capture by drift nets and light traps. Additional data and observations on reproduction and early life history will be presented.

DIFFERENCES IN BEHAVIORS, PHYSIOLOGICAL RESPONSES AND NEURAL STRUCTURE OF CAVE CRAYFISH TO THOSE OF EPIGEAN SPECIES

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Cave crayfish serve as a good model organism to investigate cave adaptations since much is known about epigeal species in their social behaviors, physiological responses and neural anatomical features for comparisons. We

compared the repertoire of social behaviors of cave crayfish to those previously reported with interacting sighted crayfish. The blind crayfish did not exhibit behaviors usually associated with visual displays and posturing. Additional investigations were conducted to determine how cave-adapted blind crayfish responded to novel territories of various sizes. We also used the cave crayfish and to examine their responsiveness to stimuli while monitoring their heart rate as a measure of an internal state. Heart rate is a reasonable measure of the responsiveness of blind cave crayfish to given stimuli even in the absence of observable behavioral changes. This enables the observer to determine if an individual is responsive to and making an assessment of particular cues. Alterations in the crayfish internal physical state, such as when the animal autotomizes its chelipeds, will cause the larger sized animals to tail flip when before they would not. Comparing adult crayfish in an epigean species to a cave species revealed that the cave crayfish are more likely to tail flip to a given stimulus. Neural modifications in the cave crayfish visual and chemosensory structures were also examined. Troglotic crayfish have a disorganized neuronal ganglion within the eye stalk. In addition, neurons associated with olfaction that arise in the central brain are more numerous in cave crayfish, suggesting that they have more neural processing devoted to olfaction, as an adaptation to cave life.

CAVE DIPLURA OF KENTUCKY

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The world's first named cave campodeid dipluran, *Campodea cookei* [now placed in the genus *Litocampa*] was described from a specimen from Mammoth Cave in 1871 by A.S. Packard. This species is widespread in the caves of southern Kentucky, Tennessee, and southwestern Virginia. *Plusiocampa jonesi* [now also placed in the genus *Litocampa*], originally described by B. Condé in 1949 from a specimen collected in Dunbar Cave in northern Tennessee, has also been found in neighboring Christian County, Kentucky. In eastern Kentucky there is an undescribed species that is closely related to *L. cookei*. This new species is known from caves in Pulaski and Rockcastle counties. Another new species of *Litocampa* has been found in the extreme eastern Letcher County, Kentucky. These specimens appear to be the same as a species first discovered in Rye Cove in Scott County, Virginia. This currently presents a zoogeographic range that is difficult to explain. In all, 64 collections of campodeid diplurans from 44 Kentucky caves were examined. As for the japygid diplurans, *Japyx subterraneus* [now placed in the genus *Metajapyx*] was described by A. S. Packard from Little White Cave [White's Cave, Jr.], near Mammoth Cave, in 1874. The only other record of a japygid from a cave in Kentucky is an unidentified species from Barnes Smith Cave in Hart County.

NEW GENUS AND SPECIES OF CAMPODEID DIPLURAN FROM CAVES IN EASTERN TENNESSEE

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A new genus and species of campodeid dipluran has been identified from Tuckaleechee Caverns and four neighboring caves in Blount County in eastern Tennessee. The new species displays troglomorphic characters indicating a highly adapted cavernicole, with possible affinities to the *henroti* species group of the cave-inhabiting *Litocampa* of Tennessee, Georgia, and Alabama. Morphologically the new genus is somewhat intermediate to the *Plusiocampa* of the Mediterranean region and the *Litocampa* of North America and elsewhere. However, its affinity appears to be closer to the *Litocampa*, from which it is possibly derived. Since the *Plusiocampa* may have evolved from ancestral *Litocampa* as well, the similarity of the new genus to *Plusiocampa* is believed to be an example of parallel evolution.

ANALYSIS OF rRNA GENE SEQUENCES TO STUDY DIVERSITY OF MICROORGANISMS IN MAMMOTH CAVE

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Geochemical factors in streambeds inside Mammoth Cave cannot account fully for the observed rates of limestone dissolution. Microbial effects such as production of acids and acid-forming gases are implicated, but attempts to culture cave bacteria for their identification have had limited success. In this study we use 16S rRNA gene sequences as a means for identifying bacteria in cave

sediment without the need to culture environmental bacterial strains. DNA was extracted directly from cave sediments and bacterial 16S rRNA genes were selectively amplified by PCR. PCT products were ligated into the pGEM cloning and sequencing vector and circular molecules, thus produced were used to transform *E. coli* cells to create a cave clone library. Plasmid DNAs carrying 16S rRNA gene sequences from cave bacteria were isolated and used as templates for automated DNA sequencing. Sequences were compared to online databases and closest genetic matches to the cave bacteria were tabulated. Genetic matches to the cave bacteria include most notably soil inhabitants associated with the atmospheric and aqueous nitrogen cycle, plus some exotic strains and ecological red flags. Clues to the mechanisms by which bacteria promote cave formation are emerging, and applications of biotechnology as a tool for cave research are becoming apparent.

REEVALUATION OF THE TAXONOMIC STATUS OF AN "ALBINO" SCULPIN (ACTINOPTERYGII: COTTIDAE) FROM SUBTERRANEAN WATERS OF THE GREENBRIER RIVER DRAINAGE OF WEST VIRGINIA.

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We reexamined the single known specimen of a depigmented sculpin from Buckeye Creek Cave in the Greenbrier River drainage of West Virginia. This specimen has previously been considered to represent an aberrant albino individual of the banded sculpin, *Cottus caroliniae*. The specimen differs from all known species of *Cottus* in the possession of a frenum. In addition, the specimen differs from epigean mottled sculpin (*Cottus bairdi*), as well as both epigean and troglomorphic populations of Kanawha sculpin (*Cottus* sp. cf. *caroliniae*) in meristic counts, body shape, prickling, development of the cephalic lateralis system, and other characters. This suite of character differentiation is inconsistent with the hypothesis that the specimen is an albino displaying pleiotropically induced anomalies associated with albinism. We urge cavers in the New River drainage, and especially the Greenbrier Valley, to be alert for additional specimens of this unique member of the Appalachian ichthyofauna.

EXPERIMENTAL ANALYSIS OF METABOLIC ADAPTATION OF *COTTUS CAROLINAE* IN RESPONSE TO PHOTOPERIOD AND FOOD AVAILABILITY

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Variation commonly exists between organisms inhabiting epigean (surface) and hypogean (cave) environments due to the differences between the two habitats. As organisms move from surface to cave environments, they adapt to cave conditions: constant darkness, relatively constant temperatures year-round, low food availability, and high humidity. Fish adapted to cave life often experience reductions in pigmentation, eye size, pelvic fin ray count, and metabolic rate. The focus of this study was to understand metabolic changes in cave-adapted *Cottus caroliniae* (banded sculpin) in response to photoperiod and food availability. Metabolic rates of sculpin were measured after brief acclimation to laboratory aquaria. Soon after initial metabolic measurement, sculpin were placed into one of four treatments for a period of eight weeks before final metabolic tests were run. Treatments included: 1) 24 hours dark, low food availability; 2) 24 hours dark, high food availability; 3) 12 hours light; 12 hours dark; low food availability; and 4) 12 hours light; 12 hours dark, high food availability. Results indicated no statistically significant differences existed in fish as a result of photoperiod, food availability, or the interaction of the two. Also, no significant differences existed between laboratory measurements and field measurements from cave and surface environments. However, many variables were identified that may have influenced fish metabolism in the laboratory. Further study is necessary to determine the influences of photoperiod and food availability on metabolism of banded sculpin.

UNPARALLELED EVOLUTION: BLINDNESS, DEPIGMENTATION, AND SCALELESSNESS DO NOT RUN HAND IN HAND AMONG TROGLOMORPHIC FISHES

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Anecdotal evidence have suggested in the past that blindness, depigmentation, and simplification or loss of scales may be an example of parallel evolution among troglomorphic hypogean fishes. We investigated the level of blindness, depigmentation, and scalelessness among 423 families of fishes. Among those with troglomorphic features, blindness was categorized as eyes

present, eyes sunken, microphthalmic, and eyes not visible; pigmentation level was categorized as fully pigmented, mostly pigmented, mostly depigmented, and totally depigmented/albino. For all families of fishes, scalelessness was categorized as "have scales," "do not have scales," or "mixed" (some species have scales, some do not). We could not find reliable information on the scales for 22 of them, usually small, little known families, none of them with hypogean representatives. Of the rest, 257 (64.0%) have scales, 117 (29.2%) do not have scales, and 27 (6.7%) were mixed. There are 18 families of fish with troglomorphic representatives. Of those, seven (38.8%) families have scales, seven (38.8%) do not, and four (22.2%) contain both scaled and scaleless species. Our results suggest that levels of blindness, depigmentation, and scalelessness is different even among species of the same family and that simplification and/or loss of scales are common features among troglomorphic fishes, but that the lack of scales in the family as a whole cannot be considered a preadaptive feature. Different phylogenetic histories, selective pressures, and genetic independence governing these features account for the explanation of these results.

ONE EYE BUT NO VISION: TROGLOMORPHIC *ASTYANAX FASCIATUS* (PISCES: CHARACIDAE) WITH REGENERATED EYES DO NOT RESPOND TO LIGHT

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One of the most intriguing questions in evolutionary biology is the degree to which behavior can be viewed as a consequence of morphology. We explore this issue by examining behavior associated with the loss of phenotypic structure and its presence, using responses to light by characid blind cave fish, *Astyanax fasciatus*, that are eyed and eyeless. Our experiments examine subjects that are epigeal (eyed surface) and troglomorphic (blind cave) forms. We compare their photoresponsiveness with blind cave fish with restored eyes. These are produced transplanting the lens from an epigeal fish into the optic cup of a blind cave form. The lens from the surface fish stimulates growth and development of the eye, restoring optic tissues lost during cave fish evolution. Fish were placed in an aquarium with one half illuminated with dim or bright white light or infrared light, the other half dark. Their photoresponsiveness was examined by scoring their presence in the illuminated or dark half. Our results strongly suggest that both the blind subjects and those with restored eyes are indifferent to the illumination whereas the surface forms are not. Deactivation of the genes responsible for scotophilic behavior and/or lack of appropriate neurological connection may account for these results.

DIFFERENCES IN FEEDING BEHAVIOR, PREY SIZE, AND DIETARY COMPOSITION AMONG BANDED SCULPIN POPULATIONS IN PERRY COUNTY, MISSOURI

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In the early 1990s, unique populations of banded sculpin (*Cottus caroliniae*) were discovered in Missouri, showing troglomorphic adaptations typical of many cave species. Banded sculpin are traditionally crepuscular feeders. We were interested in investigating the differences in feeding behavior of these unique cave sculpin populations from typical surface populations. Stomachs were removed from samples collected for a previous study and analyzed for content. At the study sites, contents were flushed, using a non-lethal method, from the stomachs of fish found and taken to the laboratory for analysis. Initially, results indicated surface sculpin had an average stomach content weight ~6x that of the cave populations, while there was not a significant difference (ANOVA, $p < .05$) in total body weights. Surface sculpin total body weight was only 1.1 times the weight of the cave sculpin. Surface sculpin stomachs contained an average of 21% Diptera and 72% digested material. Organic debris (5%) was also found in the surface sculpin stomachs. In the cave sculpin, the stomachs contained 55% partially digested invertebrate material, 10% Amphipoda, and a higher percent (11%) of organic debris compared to surface sculpin. The cave sculpin stomachs also contained 70% acanthocephalon parasites occurrence, which were not found in the surface populations.

FRESHWATER OLIGOCHAETES (ANNELIDA) IN FINE SEDIMENTS OF CAVE STREAMS AND SEDIMENT CHEMICAL COMPOSITION

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We report on quantitative collections of aquatic oligochaetes from fine sediments of 8 cave streams in Illinois and Missouri, USA. Four of these streams were sampled monthly for one year. Eight annelid genera (*Haplotaxis*, *Dero*, *Pristina*, *Pristinella*, *Limnodrilus*, *Rhyacodrilus*, *Tubifex*, *Varichaetadrilus*) were collected. Some of the species identified are associated with more pristine conditions and others with organic enrichment. Measuring slide mounted specimens, we estimate the minimum volume of worms per unit volume of fine sediment in the cave streams. Examination of monthly samples did not reveal any statistically significant seasonal patterns in worm density or diversity. Sediment samples were analyzed for a variety of chemical constituents. We expected these would be positively correlated with the same constituents in water samples, but no such trend was detected for calcium, magnesium, sodium, and potassium. Metals in sediment samples showed some tendency to co-vary. For example, elevated iron levels in sediment samples were typically associated with increased lead and nickel levels in the sediments. Mercury was detected twice as often (6 of 12 monthly samples) in sediment samples from one wild cave that experiences heavy visitation as it was in three less frequented caves (3 of 12 monthly samples each). Lead was present in most sediment samples but only a few water samples, while Atrazine was detected in few sediment samples, but was more common in water samples.

STUDY OF A CONVERGENT CAVE BEETLE/CAVE CRICKET PREDATOR PREY SYSTEM

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Darlingtonia kentuckensis is a cave dwelling trechine beetle found in caves of the Cumberland Plateau (MP-II) (Barr 1985) that has evolved specialized foraging behavior that allows it to prey upon the eggs of the cave cricket, *Hadenoeus cumberlandicus*. *Neaphaenops tellkampfi*, a trechine beetle found in caves of the Pennyroyal Plateau (MP-I) in west-central Kentucky (Kane & Poulson 1976; Kane & Ryan 1983; Griffith & Poulson 1993), has also evolved similar specialized foraging behavior that allows it to prey upon the eggs of *Hadenoeus subterraneus*. The predator-prey interaction between *N. tellkampfi* and *H. subterraneus* has been previously studied (Kane and Poulson 1976; Griffith and Poulson 1993). Unlike the *N. tellkampfi*/*H. subterraneus* system, the dynamics of the *D. kentuckensis*/*H. cumberlandicus* system are unknown. Due to the fact that caves are similar in selective pressures but discontinuous in space, the comparison of *D. kentuckensis*/*H. cumberlandicus* to *N. tellkampfi*/*H. subterraneus* may give evidence for convergent evolution.

COMMUNICATIONS AND ELECTRONICS

CAVING LIGHT USING 24 SERIES/PARALLEL WHITE LEDs

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A caving light design using four parallel strings of six Nichia White LEDs in series does not need as many LEDs to match the strings as when they are all wired in parallel. The circuitry is based on the MAXIM 1698 integrated circuit, which has provisions for efficient dimming and switch mode operation using an external MOSFET. By carefully selecting the inductor and other components for low loss, it is possible to achieve efficiencies greater than 90% using surface mount components. The electronics and 24 LEDs are mounted on a 1.25 x 1.75 inch printed circuit board.

SIMPLE WHITE LED LAMPS FOR PRIMARY AND EMERGENCY LIGHTING

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An array of 24 (or more) LEDs can be mounted in a red "Easter Seals" headpiece along with a simple adjustable linear current source that can be powered from any 4-6 volt battery pack. The result is a waterproof lamp, using 4 AA alkaline batteries, which can be adjusted from very dim (25mA current, 100 hours life) to very bright (440mA, 3-4 hours life). The light pattern, with 20° half-beam width LEDs, is similar to a carbide cap lamp (with a large polished reflector), with a large bright area and plenty of side-light. The "rings" and sharp cutoff of halogen lamps are absent. In a 2-week test, the white, even

light made caving easy and the light remains white even at the dimmest settings, while the efficiency rises! Cavers can dim the lamp to suit conditions, greatly lengthening battery life. I could usually get away with 200mA when moving, and much less when stationary (surveying, resting, eating), getting 10 hours from 4 AA batteries.

The small, waterproof white LED flashlights are great backup lights, but the LEDs are grossly overdriven because they are directly connected to the 3 AA cells. This makes for a bright light (initially), but greatly reduces both LED and battery life. I wired a 1.5V/25mA bulb (Radio Shack 272-1139) in series with each of the 3 LEDs in a flashlight to regulate the current. The initial current dropped from 120 to 60mA, falling to 20mA with .08V across the bulbs near the end.

EXPLORATION-INTERNATIONAL

BONES BENEATH THE DUNES

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Dahl Murubbeh, located in the desert 200 km north of Riyadh, was the first place cavers found thousands of well-preserved animal bones from camels, gazelles, porcupines, gerboas, etc., apparently carried in by hyenas. These bones were found to be around a thousand years old and provide valuable information on animals inhabiting this area in the past. In recent years, human skulls and artifacts were also discovered and are thought to be just as old. Other parts of this cave contain beautiful boxwork and delicate calcite-frosted feathers.

During the last few months, Saudi geologists have been trained in horizontal and vertical caving techniques and a project is now underway to locate and study caves all over the country. One of the first results has been the discovery of new caves in northern Saudi Arabia that contain large caches of animal bones and naturally mummified foxes and bats. In these caves, it appears that modern-day wolves are continuing a process that was begun by hyenas centuries ago. Serdal Ab Al Aqrah Al Aswad (Black Scorpion Cave) is an example. This cave also contains eroded, stratified piles of bat guano that might be extremely old, as well as small but attractive gypsum formations resembling swords, needles, spaghetti and wood shavings.

Vigorously blowing holes were recently discovered in this area, suggesting that there may be many more cave passages awaiting exploration in the limestone hard pan located north of the Nafud Desert.

PROYECTO CERRO RABÓN 2001

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The Cerro Rabón is a limestone massif located in the southeastern margin of the Sierra Madres in a region called the Sierra Mazateca and is well known for its potential for deep caves. It is situated in the northern region of the state of Oaxaca, 300 km ESE of Mexico City, and rises 2000 m above the tropical lowlands of the Gulf of Mexico.

Systematic speleological research on a semi-annual basis began in 1985. This heavily karstified uplift of limestone has since yielded hundreds of kilometers of caves. The Kijahe Xontjoa system has been pushed to a depth of ~1209 m, well below one of its speculated resurgences, the Nacimiento del Río Oropán. An unexplored region on the southeast corner named Terra Incognita is now thought to be part of the catchment area for the Río Oropán. Its rather high flow rate of 20 m³/sec may be an indication of a large and deep cave system.

In February 2001, a team of 13 cavers from America and Germany, led by Cerro Rabón veteran Mike Frazier, ventured into Terra Incognita to search for insurgences to the Río Oropán. Despite some harassment from local authorities, the team was able to perform an initial evaluation of the Terra Incognita landscape. Several caves were discovered and mapped and the team retreated with a valuable amount of knowledge to assist further expeditions.

YUCATAN 2000

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The Yucatan 2000 Expedition took place in the town of Mucuyche, Yucatan, Mexico, bringing together an international group of cavers and cave divers. The primary goal of the project was exploration of some of the 2400 described cave entrances in the Northern Yucatan Peninsula. Exploration was aimed at developing a database of these caves to help geologists determine the influence of the Chicxulub impact on cave development and hydrology in the

area. Additional studies to monitor the impact of local farming on pollution within the caves were also carried out.

The majority of the caves in the State of Yucatan are underwater, with depths averaging 60 m and maximum explored depths exceeding 160 m. These depths require technical cave diving techniques and equipment. In order to make such exploration possible, a base camp was established with an elaborate air mixing station for the blending of specialized dive gasses (including nitrox and trimix) on site. Several caves were explored and mapped during the expedition, including Sabak Ha, Dzonot Nohoch, E-Babuel and Yaal Utzil.

Whilst the majority of caves surrounding Merida are submerged, the Tekax area (150 km south of Merida), contains over 100 dry caves. Members of the expedition traveled to this area to offer geologic suggestions to the local government about why these caves are dry. The majority of caves in this area are formed in an uplift, corresponding with a sudden dip (>30 m) of the water table, allowing depths of now dry cave development in the area to approach 200 m.

CUBAN-AMERICAN EXPEDITION TO CENTRAL CUBA

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Six Americans and 1 Swiss caver spent two weeks in Cuba working with 2 Cuban caving groups. Our first 2 projects were in cooperation with members of SAMA, based in Sancti Spiritus, and were centered in the Escambray Mountains. Survey and photography was begun in the Boqueron system, which contains a large river passage and extensive fossil levels accessed through a spectacular collapsed borehole. One segment contained large numbers of shields, including unusual curtain-like forms. A second project was undertaken at Cueva de la Guira, the resurgence of the multi-drop Caja de Agua system, Cuba's deepest at over 400 m. A scaling pole was used to access upper levels seen near an upstream sump, but unfortunately these did not afford a bypass.

A third project was to begin a detailed survey of Cueva de Santa Catalina, near Matanzas, in conjunction with the Comité Espeleológico de Matanzas. Located near the coast, the cave hosts unusual speleothems thought to be a mixing-zone phenomenon. These include "hongos piedras," or mushroom-shaped formations, in association with folia, some of it on a macro scale observed in few other caves. Other sections of the cave where folia are absent contain long clusters of snake-dancer helictites. While none of the surveys were completed on this trip, groundwork was laid for future cooperation with the congenial cavers of these 2 groups.

CAVES OF THE WADI DEGLA PROTECTED AREA, CAIRO GOVERNATE, EGYPT: INITIAL RECONNAISSANCE

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The Egyptian Environmental Affairs Agency (EEAA) is beginning a systematic survey of significant caves throughout Egypt. Its "Protected Areas" are essentially the equivalent of national monuments in the USA. In April 2001, I accompanied a staff geologist to 6 caves in the new Wadi Degla Protected Area in the outskirts of Cairo. Others exist nearby. To date all are small, but because EEAA so far has absolutely no caving equipment, we had to stop at a 8 m pit in 1 of the 5 we mapped. In still another, we ran out of time after 35 m in a tight, seemingly endless phreatic tube floored with fragments of broken rock. We also visited a much larger cave in the Wadi Sannur Protected Area in the Eastern Desert. Other caves are mentioned in various publications and several visits are scheduled in the next 12 months.

GUNUNG NGALU SERIBU: THE MOUNTAIN OF 1000 CAVES, SUMATRA, INDONESIA

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In July 2000, a reconnaissance to the Gunung Ngalau Seribu (Mountain of 1000 Caves) region of West Sumatra was conducted. The focus consisted of exploration for caves in a 90 km² limestone massif bordered on the north by Sungai (river) Sangkiamo and on the west by Sungai Kuantan and sampling of water for characterization analyses. During the trip, 1488 m of cave passage were surveyed and mapped in four separate caves. The longest cave, Ngalu Moeko Moeko, yielded 988 m of river passage. A number of cave leads remain to be explored. Significant caves were discovered in the Sungai Kuantan valley. Routes to insurgences and resurgences have been located. Depth potential is ~400 m for caves found near the top of the massif. Five water samples were collected and analyzed for calcium, total hardness, total alkalinity, chloride,

sulfate, nitrate, phosphorus, temperature, pH, and conductivity.

MULTIYEAR PROJECT TO MAP CAVES FOR THE DEPARTMENT OF ARCHEOLOGY OF BELIZE

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In March 2001, a group of 10 US cavers spent 2 weeks in Barton Creek Cave in the Cayo District, Belize. This was the third mapping trip to the cave, which had been used by the Maya 1000 years ago and which is used today as a popular show cave. Archeologists under the direction of Jaime Awe excavated in the cave last summer and will be tying their highly detailed maps into our map when it is complete. The first 940 m of stream passage, shown to tourists in canoes, is beautifully decorated. The cave was reputed to be a simple stream passage that continued for a distance of as much as ~10 km. Our exploration showed that it is much more complex than previously thought. Instead of being a simple stream passage it is a complex cave. During the last days of the trip many leads were discovered which will have to wait for next year.

A SHORT TOUR OF SAUDI ARABIA'S DESERT CAVES

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In 1983, cavers discovered a small hole on a hard-pan plateau alongside Saudi Arabia's Dahna Desert. Warm, moist air blowing out of this hole encouraged them to widen the opening until they could just fit through. The labyrinth of decorated passages below is now called Dahl Sultan and it was just the first of many outstanding caves discovered and explored over nearly 20 years. These caves include:

The Whistling Teapot, named for a mysterious wailing sound that baffled its first visitors.

UPM Cave, which boasts three levels, cave pearls, and a small rimstone dam growing beneath the desert. This cave was discovered by speleologists from the Austrian Academy of Sciences and the University of Petroleum and Minerals, in Dhahran.

Dahl Abulhol, which means Father of Fear, a large, single chamber at the bottom of a 75 m drop.

Surprise Cave: Home of the most beautiful formations found so far, with passages still going.

Most of these caves were found while investigating only a small fraction of countless holes dotting the Summan Plateau. The exploration of Saudi Arabia's desert caves may be only in its infancy.

EXPLORATION – U.S.

SURVEY AND EXPLORATION OF THE FARMERS CAVE SYSTEM, KENTUCKY

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The Farmer Cave System of Pulaski County, KY, has been an ongoing project of the Central Ohio Grotto of the NSS since 1989. This is a long-term project in a system that has yielded over 21 km of surveyed passage.

The system is contained within a single valley with no passages yet discovered that pass through the ridges. There are 21 entrances within the valley, 12 connected to substantial passage. Many of these required significant digging to gain access. The history of the project involves numerous connections between these entrances, creating a substantial system that continues to yield exciting discoveries. Recent efforts have centered on several connections in the center of the system. All efforts within the system are limited by the pool level of Lake Cumberland, with many passages accessible only during low winter pools.

The Farmer System may be a classic long term project with the challenges of personnel, leadership, data management, landowner relations, and enough new discoveries to keep us interested and coming back.

GOING WEST FROM NW NORTHTOWN RIDGE IN FISHER RIDGE CAVE SYSTEM

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The survey in Fisher Ridge Cave System in Hart Co., KY, was 159 km long in April 2001. Some of the most remote areas from the entrances on Fisher Ridge are in the northwest reaches of Northtown ridge, the northernmost point in the cave. On five trips in 1993, 1994, and 1995, 2.9 km of pas-

sages called the Other World, the Chasm, and the Chasm Drain were surveyed in this section of ridge. In 1998 members of the Detroit Urban Grotto completed the construction of the Quick Exit, an artificial vertical entrance on Northtown ridge, which facilitated access to the cave under Northtown ridge, including the northwest corner containing the Other World area and another significant passage. Fourteen more survey trips taken from December 1999 to the spring of 2001 turned up an additional 4.4 km of passage in this area. Of this survey 1400 m came from loops and piracies from the southwest-northeast-trending Other World trunk to the Chasm and the Chasm Drain. A wet, windy passage draining from the northwest, south to the Chasm Drain was not exhaustively explored. A dry phreatic infeasible to the Other World having good airflow meandered for 754 m before pinching. Since October 2000, 2233 m more were mapped after another portal into the northwest corner of the ridge was found near the junction where the Other World took off from the main cave. Leads remain, 1.6 km apart on either end of what are known as the Rough Route and Pencil Sharpener passages.

SURVEY AND EXPLORATION OF JUGORNOT CAVE, PULASKI COUNTY, KENTUCKY

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Jugornot Cave in Pulaski County, Kentucky is a well-known cave used by locals and visitors since the 1800s. It was located along the primary route of travel connecting Cumberland Gap to Sublimity Station on the Rockcastle River and to Elihu just south of Somerset and points further west. At that time, the cave was known as Old Kentucky Cave. The first survey took place during 1974 by the Dayton Area Speleological Society. This survey mapped over 1400 m during one trip in one canyon passage. In January 2001, members of the Central Ohio Grotto, Blue Grass Grotto, and local cavers began a project survey of the cave. In one 8-hour trip, 1200 m had been re-surveyed in the canyon. This canyon trends linearly, with a flow direction southwest through the ridge separating Jugornot Hollow from Pumpkin Hollow. Other surveyed passages within Jugornot follow this trend and consist of breakdown strewn, highly decorated upper levels, and tall canyons in lower levels. The spatial location and orientation of passages in Jugornot continue the trend found in the Richardson Bore, Big Room, and Easter Passage sections of the Coral Cave System. Photographic, statistical, and geologic evidence gathered from within Jugornot Cave and from nearby surface features support the hypothesis that regional speleogenesis has been influenced by ancient Cambrian faulting propagated upward through Mississippian and Pennsylvanian strata as fracture swarming. To date, 3000 m of cave have been mapped with a cave depth of 73 m.

MARTIN RIDGE CAVE SYSTEM, EDMONSON COUNTY, KENTUCKY

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Southwest of Mammoth Cave, the Martin Ridge Cave System is composed of Whigpistle, Jackpot, and Martin Ridge Caves. Entrances are on private land and access is tightly controlled by the owners and respective projects.

Whigpistle Cave was discovered by Quinlan employee Rick Schwartz in 1976. Through the late 1970s and early 1980s, Quinlan's explorers mapped an extensive flood-prone cave between the Mill Hole and Cedar Sink karst windows. Beyond grueling entrance crawls and eardrums, explorers found some of the most continuous trunk passage in the region. They also discovered the Big Womb (240m long, 35m wide, 18m tall), which is likely the largest underground chamber in Kentucky.

A digging project several kilometers to the east led to important discoveries in 1995. In Jackpot Cave, through a series of tight domes and drains, explorers found a beautiful, gypsum encrusted trunk, the Celestial Borehole. Smaller, wetter leads continued in the cave's lower reaches. Ridgeworking in April 1996 between Whigpistle and Jackpot, Alan Glennon discovered a swallow leading to numerous narrow canyons and stream passages. In several locations, these passageways intersected large trunks, and an extensive cave was revealed.

The connections of the three caves, which took the system length beyond 50 km, occurred in the summer of 1996 by Glennon, Jon Jasper, and Chris Groves. Since that time, exploration has continued with the goal of pushing northeasterly toward Mammoth Cave and discovering downstream sections of the underground river that flows from the Mill Hole karst window.

LECHUGUILLA CAVE CULVERT REPLACEMENT PROJECT

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The Lechuguilla Cave breakthrough was in May 1986. During the first week of exploration, a 61 cm diameter road culvert with a locking gate was placed through the rubble to make entry into the cave safe and to add security. Due to the high velocity of winds entering and exiting the culvert, the locking gate was later replaced by the Sandia Grotto with a counter balanced lid with a seal. The interior of the culvert was alternatively wet or dry depending on whether the cave was exhaling or inhaling. This constant variation caused by changes in barometric pressure created a very hostile environment for the metal ladder and culvert. During the years, the mild steel ladder and the culvert was in a state of severe corrosion. For safety purposes, the management of Carlsbad Caverns National Park, Cave Resource Office, decided that the culvert needed to be replaced with a combined non-corrosive airlock and culvert. The project started in February 1999 with the combining of ideas and the writing of an environmental assessment. Along with combined long hours, frustration, and hard work, the construction phase of the project is complete and the restoration phase is in progress.

THE BLACK HOUSE MOUNTAIN CAVE SYSTEM, TENNESSEE

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Efforts since 1998 have focused on extending the numerous caves toward each other. Lugannani and others discovered a fourth entrance to the longest segment, 8.9 kilometers long Cornstarch. Todd Bryan and Nikki Woodward extended 0.8 kilometers long Little Jack to a sump that is likely the same as a sump in 3.2 kilometer long Red Bud. Bryan, Lugannani, and others repeatedly braved the grueling Water World crawl in Red Bud to map the long crawls beyond Viagra Dome and did a wet dig named "It Sucks" under "Offending Valley" where a connection to 2.4 kilometers long Temple Falls seems likely. Nashville technical digging experts helped get into Blowing Fern Cave right on top of this connection area, but the next dig looks grim. In 2001, we have dug into more cave in 300 m long Green Bottle Cave and hope to connect to the Viagra Dome area of Red Bud, thus avoiding the Water World crawl.

THE CAVES OF REDMOND CREEK, WAYNE COUNTY, KENTUCKY

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Redmond Creek flows north out of Tennessee into a very large sinkhole where it disappears into the ground in southern Wayne County, KY. The largest known cave in the sinkhole is Redmond Creek Cave. The Central Ohio Grotto began examining the cave during the autumn of 1997 with the policy of surveying as it was explored. Surveying and exploration are limited to late summer, autumn and early winter because the cave is flooded during much of the year. The cave consists of a primary north-south stream passage, significant east-west canyons, and high, old phreatic passages that are rich in fossils. It is this east-west-trending part of the cave that has been most interesting and has received the most exploration and surveying. The Redmond Sinkhole is rimmed with waterfalls, cascades, and streams exiting from caves in the Bangor Limestone, all of which enter caves in the Kidder Limestone. We have many leads yet to explore and survey including the main stream passage, which should go for at least 2.4 km where Redmond Creek enters the cave.

GEOLOGY AND GEOGRAPHY

KARST EDUCATION AT WESTERN KENTUCKY UNIVERSITY: THE CENTER FOR CAVE AND KARST STUDIES

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The first international conference that dealt with environmental problems of karst regions was sponsored and hosted by the Department of Geography and Geology at Western Kentucky University in the spring of 1976. The Center for Cave and Karst Studies, established in 1978, was the first center in the United States to emphasize karst and its environment problems. Although the NSS and other organizations were concerned about cave conservation and protecting caves, the Center was the first organization to emphasize the hydrogeologic environmental problems associated with development upon karst terrain.

BI-MODAL CONDUIT DISTRIBUTION, WELLS CAVE, KENTUCKY: IMPLICATIONS ON REGIONAL HYDROGEOLOGY

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Wells Cave, contained within the Silvers Branch sub-drainage of Buck Creek in southeastern Pulaski County, Kentucky, is a diverse cave system with ~19 km of surveyed passage. The survey of the cave took place during the 1970s and 1980s by the Dayton Area Speleological Society. From in-cave and surface evidence, the geomorphology of Wells Cave can be shown to be the result of a significant hydrologic transition separating two phases of conduit development. Wells Cave began as a phreatic maze cave when Silvers Branch downcut into Mississippian carbonates. Following this period of development, the isthmus of a large meander of Buck Creek was truncated. This meander contained the outlet for Silvers Branch and the paleo-springs for Wells Cave. The isthmus truncation provided an increased hydraulic gradient and an extra 2.4 km of horizontal distance to a new discharge point along Buck Creek. During this transition period, floodwater pulses filled conduits depositing layers of sediment. As Buck Creek entered a phase of rapid downcutting, Wells Cave responded through the development of lower level vadose canyons, including the River Passage (a large trunk conduit reaching sizes of up to 30 m wide by 15 m high). These vadose passages reworked sediment from filled phreatic passages and utilized them as piracy routes. This pattern of cave development is common for caves along southern Buck Creek and may be related to a past change in regional hydrogeology. Understanding the Wells Cave karst aquifer is important as human demands on the aquifer increase.

WATER QUALITY THREATS FROM OIL PRODUCTION ADJACENT TO MAMMOTH CAVE NATIONAL PARK, KENTUCKY

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In the early 1990s, a small oil boom began in the Arthur Community along the southwestern edge of Mammoth Cave National Park. In January 1997, a spill occurred, dumping over 2,000 L of crude oil into the park. An emergency effort prevented the oil from sinking into the karst aquifer. However, the spill highlighted the threat posed by these wells, and demonstrated the need for a better understanding of the area's hydrogeology.

Much of the watershed exhibits alternating surface and karst (subsurface) water flow. However, results from dye tracing also show that subsurface water flow within the Glen Dean limestone karst aquifer is able to breach the Hardinsburg Sandstone in the subsurface, and flows into the underlying Haney limestone karst aquifer.

In order to prepare for potential threats, scientists and students of Western Kentucky University's Hoffman Environmental Research Institute and Mammoth Cave National Park are cooperating in the development of a geographic information system database that depicts the hydrogeology, oil well location, karst features, access roads, and water flow routes adjacent to these oil facilities. The resulting database and map will be distributed to various emergency response agencies, to speed planning and response in the event of future environmental emergencies.

HYDROGEOLOGY OF SPENCER MOUNTAIN, VAN BUREN COUNTY, TENNESSEE: INVESTIGATION UPDATE

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A consortium of karst scientists conducted a hydrogeologic study of Spencer Mountain, Van Buren County, Tennessee. This study expands Crawford's research presented at the 1983 National Speleological Society convention. In 1999, the City of Spencer proposed to discharge sewage effluent into the karst system beneath Spencer Mountain. Dry Fork, the proposed stream to receive effluent discharge, is a High Quality Stream (Tier II). Issuance of an effluent discharge permit to Dry Fork required an exemption to Tennessee's Antidegradation Regulations, which was granted by the Tennessee Water Quality Control Board. The hydrogeologic study delineated and confirmed groundwater flowpaths and identified human and environmental targets susceptible to the proposed effluent discharge.

The study shows that the western edge of Spencer Mountain, including

Laurel Cove and Molloy Hollow, is in the Pennywinkle Spring groundwater drainage basin. The study delineated that McKeever Cave is in the Big Swamp Spring basin. The data confirm that groundwater from Dry Fork, Indian Camp Branch (Windy River Cave), Turkey Cot Cove, and Millstone Branch flows through caves under Spencer Mountain to Big Swamp Spring. Haston Spring and Thunder Run Cave are overflow conduits for Big Swamp Spring; however, the source of Haston Spring's base-flow is not established. The drainage from Green Monster Cave was not detected during the six-month study and will require additional investigation.

STREAM FLOW IN KAUMANA CAVE

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Kaumana Cave is a lava tube located within the 1881 lava flow originating from Mauna Loa. Situated in the lowermost reaches of the flow, Kaumana Cave typifies the morphology of Mauna Loa tubes within long, linear flows. However, it does display one unusual character for a lava tube: during medium to heavy rains, it carries a stream that floods some of the middle sections of the tube.

Stream flow in Hawaiian lava tubes is highly unusual because of the high permeability of basaltic rock which normally favors rapid infiltration. In Kaumana Cave, a combination of factors may contribute to the observed stream flow including:

- extremely high rainfall on the east side of the Big Island;
- floodwaters redirected via man-made drainages into the upper entrances of the tube;
- the 1881 flow, between the town of Kaumana and the western outskirts of Hilo, is underlain with an impermeable ash deposit that perches the stream through most of the cave.

The high stream flow during heavy rains moves floodwaters through the system extremely quickly (within a couple of hours). Waters exiting the lowermost entrance are redirected to a storm sewer located 60 m away. The exact course of the floodwaters once they exit the lava tube is not known. However, it is probable that the water eventually resurges in fresh water springs in Hilo Bay.

PACKRAT URINE PATHWAYS: AN UNUSUAL BIOSPELEOTHEM IDENTIFIED AT FAIRY CAVE-GLENWOOD CAVERNS, GLENWOOD SPRINGS, COLORADO USA

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Packrat urine pathways, which are found in both Fairy Cave and Glenwood Caverns, are linear deposits of indurated calcite that are along the top edges of bedrock breakdown and flowstone. The deposits are up to 4 cm high and 2 cm wide. The pathways are generally subparallel to cave passages and are level. However they can form bumps several centimeters long, called "Mickey Mouse" ears because of their uncanny resemblance to said mouse's famous ears (E. Anderson, pers. comm.). Petrographic examination of thin sections indicate that the pathways consist of very thin layers of microcrystalline calcite. Modern dried packrat urine, which was along the sides and top of a pathway, was identified as a mixture of calcite and monohydrocalcite by XRD. SEM microphotographs of the dried urine showed grain sizes of 0.1 to 3 microns. Fresh packrat urine is a viscous, milky liquid, which contains dissolved urea and calcite crystals. The elevated nitrate content (a byproduct of urea breakdown) of pools in Fairy Cave and Glenwood Caverns indicates that the urea is leaching away, leaving behind the calcite crystals, which with time become indurated. Packrats are apparently marking their trails with urine as an aid for locating their nests and water.

CAVE AND KARST DEVELOPMENT ON SAIPAN

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Saipan, part of the Commonwealth of the Northern Mariana Islands (CNMI) in the western Pacific Ocean, is a 125 km² island made up of a core of Eocene and Oligocene volcanic and volcanic-derived sedimentary rocks mantled and surrounded by interlayered limestones ranging from Late Eocene to Pleistocene. Significant deformation, mostly as high angle normal faults,

has created a complex landscape and outcrop pattern. As a result, Saipan falls into the Composite Island classification of the Carbonate Island Karst Model (CIKM), as both allogenic and autogenic recharge control cave and karst development.

In the island center, streams rising on volcanic and volcanic-derivative rocks sink upon reaching the limestones, in cases forming stream caves of appreciable length. Flank margin caves are found on interior and coastal scarps, their elevation above modern sea level caused by the interplay of tectonic uplift and glacio-eustasy. In the east-central area, faulting has placed limestone blocks against volcanic units such that paleo-recharge was confined and formed large lift tubes to create Vauclusian springs. The northeastern end of the island contains many caves that appear to be progradational collapse features, where dissolutional voids formed at the limestone/volcanic contact stopped upwards, similar to what is observed in Bermuda. Permeability in this northeastern area is sufficient that the fresh-water lens is thin to non-existent.

ELEVATION CONTROL OF CAVE MORPHOLOGY ON TROPICAL ISLANDS

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The Carbonate Island Karst Model proposes that, in a simple carbonate island, the caves near past sea levels are horizontal in shape and the caves significantly above past sea levels are vertical. To test this model, an area on San Salvador Island near Flamingo Pond was examined to discover new caves and see how they fit the model, as part of an overall GIS program for the island. Using a machete, the ridge was walked at certain past sea levels to try to find caves. Once found, a cave was located using GPS. Caves were then surveyed using a Suunto compass, a Suunto inclinometer, and a metric fiberglass tape measure. The data were reduced and maps drawn.

Two caves close to past sea levels were surveyed and were more horizontal in shape than vertical. This was due to the ocean coming in against the land and making a fresh water table at the sea level, and the caves formed in that water table. The caves significantly above sea level had a mostly vertical profile. This is the case because the vertical caves formed by water flowing from the surface to the water table. The results would be more conclusive if more caves had been found.

TEMPERATURE VARIATION OF TROPICAL ISLAND CAVES

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Majors Cave, San Salvador, Bahamas, was studied to see if the temperature in a tropical cave changed dramatically with the weather or day/night cycle. Hobo temperature data loggers were placed in vertical profiles in the back, middle, and front of the cave, with a control placed outside of the cave. In the back of the cave, data loggers were placed in a tidally fluctuating pool of water at depths of up to 1.5 m; one data logger was placed at a depth of 4 m in a pool just inside an entrance at the front of the cave. The data loggers were set to take the temperature once every minute of the day. They were left in the cave for three days, removed on the fourth day and downloaded onto a laptop computer.

During the experiment a series of cold fronts from the North American continent passed over San Salvador Island, creating temperatures below the average temperature for the island. As a result this cool air entered the cave entrances and flowed over the cave floor to the low spots containing the tidal water. The data loggers on the ceiling recorded warm temperatures but the ones on the floor recorded cooler temperatures. The data loggers in the tidal pools showed progressively warmer temperatures with increasing depth and therefore distance away from the cool air. The shallow data loggers recorded the tidal cycle as cool at low tide and warmer at high tide.

GROUNDWATER TRACING RESULTS AT A NEW PUBLIC SCHOOL AND AN INVENTORY OF CLASS V INJECTION WELLS (SINKHOLES) IN PARTS OF RUTHERFORD COUNTY, TENNESSEE

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Dye tracing was conducted around a new Rutherford County middle school site to determine the fate of runoff water planned for diversion to a very large sinkhole called Hooper Bottom. Two traces established that drainage into Hooper Bottom will move nearly 4 km in a northwest direction to a stream in the bottom of a karst window. From there, the subterranean stream moves through a series of karst windows to emerge at Nice Mill Spring along the

West Fork of the Stones River. The estimated size of the Nice Mill Spring groundwater basin, which includes the Middle School, is 17 km². Two other traces were conducted to different springs to help delineate the divides of the Nice Mill Spring basin.

A pilot study of sinkholes that have been modified to accept storm water runoff was conducted throughout a 72 km² area with high sinkhole density. A total of 125 Class V injection "wells" (sinkholes) were located by utilizing 2-foot contour maps provided by Murfreesboro and Smyrna. The locations of the sinkholes were placed in a GIS database. In addition to locating the 125 sinkholes, a broad type of drainage to each was designated. These included: 1) street/major highway; 2) rural road and/or agricultural; 3) industrial; and 4) subdivision/parking lot. Nearly all of the designated sinkholes drain streets, roads, and parking lots where the expected contaminants would be primarily grease and oils from cars or possibly fertilizers and pesticides from lawn and field application.

ORIGIN AND REGENERATION OF NITRATES IN MAMMOTH CAVE SEDIMENT

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Few subjects have been the source of more confusion than the origin of nitrates in cave sediment and regeneration reported in the literature over the past three centuries. The purpose of our investigation was to determine the mechanism/s by which nitrate accumulates/regenerates in Mammoth Cave sediments.

Sediment samples were collected from a leach vat (LV) at Booths Amphitheater, leached sediment piled across the trail from this vat, and undisturbed sediment near Bunker Hill. Nitrate concentrations were determined, and samples were leached with deionized water to remove nitrates. The leached sediments were subsampled and replaced in the cave such that the samples were in contact with sediment, bedrock, or cave air. Samples were then periodically collected during the past six years and nitrate concentrations determined.

After six years in the cave, all of the samples (except LV bedrock) had nitrate concentrations less than 10% of original concentrations. Temporal changes in nitrate concentrations were extremely variable and in many instances no trend was apparent. These results suggest that proposed mechanisms such as transport/deposition of nitrates via percolating groundwater, and mineralization of atmospheric nitrogen through biotic or abiotic mechanisms are likely not responsible for regeneration of nitrates in these sediments.

Recent investigations indicate that former bat, woodrat, and raccoon populations in the cave were highly significant. With this realization, and the failure of our samples to significantly accumulate nitrate during the project period in the absence of these populations, the most likely dominant source of nitrate was guano.

THE GEOLOGIC FRAMEWORK OF KARST IN THE OZARK PLATEAUS OF SOUTH-CENTRAL MISSOURI

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A regional geologic framework is required to understand the environmental impact of mining of lead and zinc proposed on large springs in the karst area of the Ozark Plateaus of south-central Missouri. Information about lithologies, faults, joints, and karst features (sinkholes, caves, and springs) contributes to the development of a conceptual model of karst hydrogeology of the Ozarks. Conduits and caves along bedding planes and joints provide avenues for groundwater recharge, movement, and discharge. The trend of joints was studied to determine if they controlled the orientation of cave passages and conduits. The data show that cave passages are curvilinear and do not correlate well with measured joint trends. Instead, stratigraphy, bedding-plane dip, and local base level affect conduit and cave development. The majority of caves in south-central Missouri have developed within stromatolitic dolomite horizons beneath sandstone beds. We hypothesize that the sandstone beds act as confining units allowing artesian conditions and mixing to occur beneath them, thus, enhancing dissolution. Additionally, joints and the high primary porosity of the stromatolitic dolomite beds form openings in the bedrock that initiate solution. Where a solution-widened joint intersects a bed-

ding plane, lateral movement of groundwater is controlled by the bedding plane.

NOTCH MORPHOLOGY AS A PALEOHYDROLOGICAL INDICATOR

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Distinctive "c-shaped" features known as notches exist on tropical rocky carbonate coasts, and are often interpreted as bioerosion notches. Inland notches have been interpreted as fossil bioerosion notches from a previous sea level highstand. However, many of these inland notches have morphologies similar to exposed flank margin caves, and contain speleothems, suggesting a speleogenetic origin. Fossil bioerosion notches contain important information on past sea level position, but fossil notches of speleogenetic origin offer important paleohydrological information.

Notches were examined on Guam, San Salvador, and Isla de Mona, both in and out of the modern intertidal. Linear notches with nearly horizontal roofs were observed in all of the modern intertidal settings and some inland settings. Notches that have undulating floors and ceilings are commonly observed outside of the intertidal in all three localities, and at rare locations within the intertidal. This latter morphology has been termed "beads-on-a-string" by previous workers, and is believed to be indicative of flank margin caves exposed by cliff retreat.

The degree of anisotropy in the flow of the fresh-water lens is presented by the degree of chamber enlargement. If flow is to specific discharge points along the lens margin, large separated dissolutional chambers are produced. Uniform, isotropic flow produces a low, continuous chamber. With sea level fall, the breaching of these chambers reveals the nature of the paleohydrology that produced them. The degree of anisotropy shown by these breached flank margin caves may reflect current anisotropy in island and coastal carbonate aquifers.

LOCATING AND MAPPING CAVES FROM THE GROUND SURFACE USING ELECTRICAL RESISTIVITY AND MICROGRAVITY

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The Center for Cave and Karst Studies has been using geophysical techniques to locate caves from the ground surface since 1985. Although several geophysical techniques have been employed, the best results have been obtained using microgravity and electrical resistivity. The general trend of the cave is estimated by using a combination of lineament analysis, dye traces and potentiometric surface mapping. Microgravity is then measured at a 10-ft interval along traverses established perpendicular to the hypothesized general trend of the cave. Electrical resistivity using the new Swift/Sting resistivity meter is also measured along the traverses using a dipole-dipole array. Once a low-gravity anomaly and/or a high resistivity anomaly has been confirmed to be a cave, usually by an exploratory boring, the general route of the cave passage can be determined by proceeding in a "leap frog" fashion with short parallel traverses. A spring or a known section of cave can also be used as the starting point for the "leap frog" traverses. This technique is particularly useful in well-developed karst, where the caves are relatively large and shallow. Use of this technique located the Lost River Cave under Bowling Green, KY.

A PROPOSED PROGRAM TO REGULATE GROUNDWATER WITHDRAWAL TO MINIMIZE THE IMPACT ON ENDANGERED SPECIES HABITAT DURING DROUGHT IN THE BALCONES FAULT ZONE PORTION OF THE EDWARDS AQUIFER OF SOUTH-CENTRAL TEXAS

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The Edwards Aquifer in south-central Texas is the primary source of water for over 1.7 million people. It is also the largest source of water for an irrigated agricultural economy as well as industrial demand in the region. Over 425,000 ac-ft/yr are withdrawn from the aquifer to meet these demands. The Edwards Aquifer is also the water source for the two largest springs in the southwest, providing critical habitat for a number of endangered species. In

May 2000, the Edwards Aquifer Authority's board of directors passed Emergency Drought Management Rules for 2000 (EDMR) to help reduce declining rates of springflow during the projected drought for the summer 2000. The EDMR specified reductions in pumping of groundwater based upon index wells in the region. Flow at Comal Springs reached "Jeopardy" levels for endangered species (as defined by the US Fish and Wildlife Service) for 3 days in September until relief was provided by cooler temperatures and moderate rainfall.

Hydrologic data from the 2000 drought along with other historical data on springflow and aquifer levels were used to develop a more technically based Critical Period Management Program (CPMP) with the goal to create an equitable method to allow reductions in pumping in the region. The plan is intended to optimize pumping from the aquifer while still providing sufficient springflow for endangered species habitat and downstream water users. The proposed CPMP is currently under committee review to determine if it will be proposed as a regulatory program to the Authority's board of directors.

AGRICULTURAL LAND USE AND PESTICIDES IN KENTUCKY KARST AQUIFER DRINKING WATER SOURCES

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Western Kentucky University is working with the Environmental Protection Agency to investigate methods to improve source water quality for small, rural water systems. One year of monthly sampling from seven demonstration watersheds in Kentucky, including five from karst flow systems, shows that levels of several pesticides and herbicides, particularly atrazine and simazine, can occur in high levels. The highest levels found in raw water are from the Hawkins River, which drains 75 km² of the south-central KY karst and forms one of the major underground rivers of the Mammoth Cave System. Atrazine levels in treated water at Marion, KY, exceeded federally mandated Maximum Contaminant Levels (MCLs), in one case by a factor of 7. Data suggest that farmers applied atrazine during fall 2000 in several of the watersheds, which is prohibited by law.

A new, 1-year program is underway to understand how atrazine and simazine are transported through the watersheds and how geology, soils, and hydrology impact transport and storage of these chemicals. This is in cooperation with the state Department of Conservation, which is working with farmers to plan a "no-atrazine application" spring season in 2001. The goal of this research is to develop land use strategies that can improve water quality at these and other water supplies, to improve public health.

RADIOACTIVE AND STABLE ISOTOPES IN DEEP CAVES OF CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

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Lechuguilla Cave (-478 m) and Carlsbad Cavern (-316 m) are the two deepest known caves in Carlsbad Caverns National Park. While the two caves are nearby and of similar depth, host rock, and origin, they differ markedly in one respect. While Carlsbad has a large natural entrance, Lechuguilla has no known natural entrance, and the artificial entrance is equipped with an airlock to minimize atmospheric exchange. We have analyzed water samples from both caves for radioactive and stable isotopes. In Lechuguilla, we have found elevated Cl-36 levels associated with global nuclear fallout both in near-surface pools and in deeper pools located near mapped lineaments and surface catchments. These results indicate topographic and structural control on fast pathways for vadose-zone flow. Elevated fallout-associated H-3 occurs throughout the cave (including pools with no nuclear-era Cl-36 signal), suggesting a strong component of vapor-phase transport. Stable-isotope measurements in Lechuguilla are relatively homogeneous. There is some evidence for slightly heavier isotopes in deeper, presumably older pools, indicating a historic shift in recharge patterns, perhaps due to climate or land-use changes. Compared to Lechuguilla, the stable isotopes in Carlsbad Cavern vary widely, showing the increased impact of evaporation in that cave.

HYDRAULIC CHARACTERIZATION OF CARBONATE AQUIFERS FOCUSING ON WATER LEVEL DATA

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A major problem with understanding flow in carbonates is the lack of test methods to assess karstification. One useful approach is to compare hydraulic properties in a proven karst area to those in an area one wishes to understand. We use the Mammoth Cave area as the type area since there is abundant hydraulic data available and there is consensus that the area is karstified. Six specific testable properties that we use to differentiate karst aquifers from porous media aquifers are tributary flow to springs, turbulent flow in conduits, troughs in the potentiometric surface, downgradient decreases in hydraulic gradient and increases in hydraulic conductivity, and substantial scaling effects in hydraulic conductivity.

There are many carbonate aquifers where the role of the karstification and the presence of conduits has not been well addressed. Examples tested for the 6 above properties include the Edwards Aquifer in Texas, the Floridan aquifer in the Ocala area, the Yucatan aquifer in Mexico, and the dolostone aquifer in the Niagara Falls area. In each case, the data show that aquifer behavior is much more similar to the Mammoth Cave karst aquifer than to a porous medium. This accords with lab experiments and numerical modeling, which indicate that these aquifers should indeed behave as karstic rather than as porous media aquifers.

EVALUATION OF EQUATIONS ESTIMATING MASS OF DYE NEEDED FOR SINK TO SPRING TRACER TESTING IN KARST

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There are at least 17 published equations for estimating the quantity of dye needed for a successful groundwater trace in carbonate rocks. The pertinent variables in these equations are input discharge, spring discharge, distance, velocity, mass of dye injected, peak recovery, and time from injection to peak recovery. Surprisingly, there is a lack of empirical evaluation of these equations in the literature.

Data from more than 150 quantitative tracer tests were used to statistically evaluate the equations. The tests included a wide range of spring discharges (0.002-47 m³/s), distances (30 m - 30 km) and mass of dye used (2 mg - 250 kg). Tests with slow velocities often have poor tracer recoveries, so the few tests with peak velocities <0.005 m/s or recoveries <25% were rejected.

The most useful equation is

$$m = 17 (LQc)^{0.93}$$

where m is the mass of dye, L is distance, Q is discharge, and c is concentration, using standard SI units. Use of the equation gives a high probability of successful sub-visual detection of dye in water samples, and thus addresses one of the major problems of tracer testing.

HISTORY

CAVES AS CURIOSITIES: THE LOCATION OF CULTURAL VALUES WITHIN AMERICAN CAVES IN THE NINETEENTH CENTURY

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During the 19th century, one way Americans conceived of caves was as natural curiosities, interesting spaces that were expressions of the sublime. Americans located spiritual, religious, romantic, and patriotic cultural values within caves, giving them an importance beyond their utilitarian and commercial worth. By attaching these values to caves, Americans created ambiguous and contradictory interactions with the cave environment, reflecting differing impulses towards the natural world. The tension between commercial and utilitarian exploitation of caves and the cultural values of caves was an important factor in the period's nascent efforts to conserve the cave environment.

NORWAY'S TORGHATTEN: THE CAVE AND THE LEGEND

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The natural history of Norway, including its caves, is steeped in fascinating tradition and folklore. Off the rugged northwest coast lies the island of Torgset, the Omarket hat. Rising from the center of the island is the granite peak of Torgatten, pierced completely through with a huge paleo-sea cave of

the same name. This historic natural tunnel measures 160 m long, 20 m wide, and over 35 m high. According to local folklore, the peak of Torghatten was pierced through by an arrow shot by the Horse Man, Hestmannen. The arrow was being aimed directly at the woman Lekamoya, but was blocked when King Somnafjellan intervened by throwing down his hat to distract the jealous archer. The woman was spared, the king's pierced hat fell upon the island just as the sun rose, and everything immediately turned to stone!

NUCLEAR FALLOUT SHELTERS IN MAMMOTH CAVE NATIONAL PARK

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Between 1963 and 1978, Mammoth Cave National Park had four Civil Defense nuclear fallout shelters in the Mammoth Cave System and Great Onyx Cave. Supplies included food, water, a medical kit, sanitary supplies and devices to check radiation.

Though these spelean sites probably would have been as safe as other fallout shelters, usually basements in homes or public buildings, caves in general are not suitable for this use. Most caves are not in highly populated areas, do not have roads leading to them and lack easy access entrances. A well-ventilated cave could let fallout in, while a cave with little ventilation could be unsafe for large groups over long periods of time, and the cool temperature of most American caves would be uncomfortable for inactive people.

After 15 years in the cave, the shelter supplies were removed, not always with care. The water was poured out of the barrels before removing them from the caves, washing away sediment and leaving gullies in the floor in Mammoth Cave's Audubon Avenue. Workers destroyed gypsum flowers in Crystal Cave. Most of the supplies were disposed of, but the carbohydrate supplement candy, 15 years old and "hard as rocks", was given to National Park Service employees to eat.

The Office of Civil Defense has long been closed and fallout shelters are not now common. The Mammoth Cave fallout shelters are no longer a survival strategy, but an interesting chapter that covers extensive history.

SCIENTISTS PREFER THEM BLIND: A HISTORIOGRAPHY OF HYPOGEAN FISH RESEARCH

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The history of hypogean fish research has been strongly influenced by neo-Lamarckism (including orthogenesis) and typological thinking. Only in the last few decades has neo-Darwinism made any inroads in the research approach to this subject. The majority of the most distinguished and productive hypogean fish researchers have used their research subjects to confirm their own views on evolution rather than to use those subjects as a spring of knowledge to enrich mainstream biological thought. Of these views, the most pervasive of all is the notion of evolutionary 'progress' that has led many researchers to envision hypogean fishes as prime examples of 'regressive' evolution. It is proposed that the utilization of hypogean fish for the study of convergent evolution should catapult these subjects of research into prime objects of evolutionary studies.

HISTORY: FLOYD COLLINS SYMPOSIUM

THE PRESENCE OF FLOYD COLLINS IN THE MAMMOTH CAVE AREA TODAY

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It has been over 75 years since the tragedy at Sand Cave that eventually claimed the life of Floyd Collins. Present day and recent times seem to have Floyd Collins embellished in the history and culture of the Mammoth Cave area. Probably the area's most "famous son," Collins' presence is still apparent today. Web sites about Collins on the Internet, a recent reenactment video about the ordeal targeted for sale and for cable TV markets, a Floyd Collins museum, and historical signs about Sand Cave marked by the National Park Service are all visible. The Floyd Collins story is often told to tourists throughout the Mammoth Cave region, and historical exhibits are displayed at the American Cave Conservation Association Museum in Horse Cave, Kentucky. Modern books about Floyd Collins by noted cavers such as Brucker and Halliday have added much insight into the story. A play about Collins has made the national rounds. The town of Cave City even sponsors "Floyd Collins Good Ole Day" annually as a community wide event. Some remnants of the Collins saga are slowly disappearing and need to be documented for future use and study.

THE EARLY FLOYD COLLINS BALLADS

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The tragic death of Floyd Collins touched the emotions of many people throughout the country, among them several ballad singers in the South. Shortly after the event, Andrew Jenkins was commissioned to write a ballad about the tragedy. Later he wrote at least one more and probably a third ballad commemorating Collins. Three other ballad writers, George Hunt, Al Eggers, and G.W. Blevens were moved to compose their own tributes.

UNCOVERING THE TRUTH ABOUT FLOYD COLLINS

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Between 1925 and 1979 no comprehensive investigation of the Floyd Collins entrapment story had been undertaken. Newspaper accounts, magazine articles, chapters in books, and reminiscences provided sometimes conflicting and fragmentary information about what really happened. Murray and Brucker investigated, resolved the conflicts, and filled in the details while writing the book *Trapped! The Story of Floyd Collins*. An examination of original source material, Sand Cave itself, was the primary key to resolving ambiguities and assessing the relevance of interviews with participants. Original source material remains the key to discovering additional details of the story.

THE ROLE OF MALCOLM BLACK IN THE FLOYD COLLINS SAGA

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Malcolm H. Black was born less than 8 km from Glasgow, Kentucky. As a boy, he knew many of the participants in the Floyd Collins rescue attempt. In January 1925, while attending high school, he was working nights in the Sports Department of the Louisville Herald-Post. Ultimately he spent 25 years as a journalist, four years in the U.S. Army during which he covered the invasion of Normandy, and 23 years in Kentucky state government, mostly as administrator of a state tuberculosis hospital in Glasgow. At the Herald-Post, he knew and worked briefly alongside Skeets Miller. Because of his local connections, that newspaper sent him to Sand Cave for five days when the story broke. Noted *Chicago Tribune* reporter Tom Killian befriended him and young Black accompanied Killian during the controversial Alma Clark interview and Killian's creation of the hoax about Floyd's dog. Black's reminiscences and his correspondence with Skeets Miller contributed significantly for Halliday's account of the Floyd Collins saga in *Depths of the Earth*.

VERNON DALHART AND "THE DEATH OF FLOYD COLLINS"

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Many who have listened to this record probably regard Vernon Dalhart as a nasal hillbilly singer, but this is far from the truth. Born Marion Try Slaughter II in 1893, he received professional voice lessons at a young age and worked as a singer on Broadway before he ever made any records. Fame came quickly after he started recording and many of his records sold a million or more copies. During his career he was credited with over 3000 records on over 150 labels. His fame diminished in the 1930s and he was largely forgotten until he was posthumously elected to the Country Music Hall of Fame in 1991.

THE EDWARD POST FLOYD COLLINS NEWSREELS

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In January 1964, an article by Clarence Woodbury titled "The Death of Floyd Collins" appeared in the *American Legion Magazine*. Members of the Collins family objected to the article and sued. Louisville attorney Edward Post, who represented the plaintiffs, prepared a 16 mm film containing segments of 1925 newsreels and won a settlement against the magazine.

THE FLOYD COLLINS - SAND CAVE RESCUE POSTCARDS

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Disasters have been a frequent topic seen on postcards during the first few decades of the 20th century. Despite being one of the most sensationalized news stories between the 2 world wars, and covered by dozens of photographers, relatively few postcards of the Floyd Collins tragedy were published. These cards can be divided into three categories: those published by Wade H. Highbaugh, a series of two cards published by the Auburn Post Card Manufacturing Company, and a small group of miscellaneous cards. All of them are difficult to find today and are highly prized by cave postcard collectors.

PALEONTOLOGY

THE EXTINCT MUSKOK *BOOTHERIUM BOMBIFRONS* FROM CAVES IN WEST VIRGINIA AND VIRGINIA

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Teeth of the extinct muskox *Bootherium bombifrons* have been found in three West Virginia caves, one Virginia cave, and provisionally identified from two other Virginia caves. A single upper premolar of *Bootherium bombifrons* was found in surficial deposits in New Trout Cave while a partial upper molar was found in Wormhole Cave, both in Pendleton County, WV. Three teeth, an upper molar, lower deciduous fourth premolar, and an upper third molar of *Bootherium bombifrons* was found while singular incomplete teeth provisionally identified to this species were found in Cedar Hill Cave, Rockingham County, VA and Winding Stair Cave, Scott County.

These finds of *Bootherium bombifrons* are the first for caves in both states and represent minor range extensions for the species. Most of the teeth show rodent gnawing and were likely brought into the caves by *Neotoma magister*. All the sites are believed to be late Pleistocene, mostly based on associated faunas except for the Bush Handline tooth.

THE LATE PLEISTOCENE FAUNA OF MELROSE CAVERNS, VIRGINIA

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A modest excavation in Melrose Caverns, Rockingham County, Virginia, has produced a fauna of >40 species of vertebrates. One species, *Mylohyus fossilis*, is extinct and several others are extirpated from Virginia including *Spermophilus tridecemlineatus*, *Phenacomys intermedius*, *Synaptomys borealis*, *Microtus ochrogaster*, *Geomys* sp., and *Cryptobranchus alleganiensis*. *Geomys* sp. and *Cryptobranchus alleganiensis* represent first records for Virginia.

Geomys now lives as separate species to the south and west. The only other fossil locality for *Geomys* in the Central Appalachians is in the lower levels of New Trout Cave, Pendleton County, WV. The lower levels of New Trout are below a C-14 date of >29 ka and also contain *Cryptobranchus*. The Melrose Fauna lacks the large microtine, *Microtus xanthognathus*, a species characteristic of Late Wisconsinan sites in the area. Thus, it seems likely that the Melrose Caverns Fauna dates to the Early Wisconsinan or, possibly, even the Sangamon Interglacial.

PHOTOGRAPHY

CAVE PHOTOGRAPHY AND ART

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In order to succeed in reaching the non-caver audience through publications, the cave photographer must understand and accept the non-caver perspective. Before creating a cave image, the photographer should decide who his audience will be and what response that audience will have to the image. Four ways to make cave images more artistic are 1) interpret the subject through use of the model(s), lighting and camera angle; 2) visualize an image and then go into a cave and create it; 3) use special effect techniques such as filters, prisms, color gels and "trick" photography; 4) edit the image through cropping, re-shooting and selection.

SURVEY AND CARTOGRAPHY

CURRENT STATUS OF MESHING OF THE WAKULLA SPRING POINT CLOUD

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A point cloud of 10 million wall points (thinned to 3 million) was gathered in 1998-1999 during the Wakulla 2 Expedition. The data was collected in the water-filled cave by a custom-designed sonar Digital Wall Mapper (DWM). Meshing the point cloud into a polygonalized surface remains a chal-

lenge. Problems to be overcome include: 1) the point cloud is unstructured data rather than data collected in grids; 2) branching passages are challenging to write algorithms to interpret; 3) real data contains noise that must be ignored; 4) the multiple data sets required registration. The automated portion of the registration was nearly perfect, but the manual registration was not as good giving a "thickness" to the wall positions. The current process of meshing begins by figuratively placing the point cloud in a box. The outside of the cave point cloud is meshed from points on the box, while the inside of the cave is meshed from the original DWM position within the cave. Parameters such as the length of "legal" polygons are used to refine the meshing. Where the data are thin, such as where the mapper's "viewing" of distant walls or the floor was blocked by obstructions, a longer length must be used to create the proper mesh. However, too short an acceptable length results in erroneous polygons forming at branches in the passage. We envisage that the current technique will solve the meshing problem, but requires extensive experimentation to achieve total success.

HANDHELD LASER RANGEFINDER FOR CAVE SURVEY DISTANCE MEASUREMENTS

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The Leica Disto Classic handheld laser rangefinder sends out a continuous red laser beam when turned on. This is directed to any surface or diffuse (not mirror) reflection target plate and the measurement key is pressed. A pulsed laser signal is sent out and, if enough laser light is reflected back, the distance reading appears on a LCD display in either meters (to 0.001 m), decimal feet (to 0.01 feet) or feet and inches (to 1/16"). Specifications claim an accuracy of ± 3 mm. The Disto Classic mounted on a tripod gave a reading of 98.35 feet as compared with a reading of 98.36 feet from a K&E Whiteface Steel Tape. The steel tape has been heavily used and could be stretched and could be further elongated by the 85° F. temperature during the measurement. Ordinary range is from 0.3 m to over 100 m. The Disto Classic is good enough to do station to station distances with a precisely positioned target plate. It can be used to do up/down/left/right distances at a station or do precise cross sections by pointing at the cave walls with a clinometer at each station. For surface surveying, a long strip of SCOTCHLITE Reflective trim and a target plate ringed with SCOTCHLITE enables one to see the continuous red laser spot for targeting.

CAVE ILLUSTRATOR – AN ADOBE ILLUSTRATOR PLUG-IN FOR CAVE CARTOGRAPHY

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While first learning to create digital maps, the author noticed the complexity in transferring survey data to the art program used to draw the map. It involved entering the data into Compass, or some other cave survey program, then exporting a bitmap or DXF file. This file was then scaled and aligned with the current drawing. Every time a new survey trip returned, a new file would need to be exported from the cave survey program, scaled, and aligned. There had to be an easier way! This led to the idea of a project that allows the direct importation of Compass format data into the popular Adobe Illustrator drawing program. This simplifies the creation of maps, since the plot is updated without exportation and subsequent alignment. Further, it has advanced features and capabilities that are only possible from within the art program. The survey data can be viewed as raw data, in a standard Adobe dialog, while simultaneously being highlighted within the artwork itself. Station labels, line color, etc., can also be manipulated and selected. Further, features such as 'undo', 'select', etc., all work seamlessly between Adobe and the plug-in. The overall result of the effort has been a dramatic increase in the ease and speed at which 'up to the minute' maps can be created.