

SELECTED ABSTRACTS FROM THE 1999 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN FILER, IDAHO

ARCHEOLOGY

SUBTERRANEAN CULTURAL RESOURCE MANIFESTATIONS OF THE ARIZONA STRIP

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Caves on the Arizona Strip, that area of land in Arizona that lies north of the Grand Canyon, have been used by humans for thousands of years. Paleo-Indians, Archaic Indians, Ancestral Puebloans, Southern Paiute, pioneer homesteaders, Civilian Conservation Corpsmen, and modern ranchers have left evidence of their use in caves of this area. The great variety of artifacts found includes rock art, ceramics, and grinding stones (metates). Sites may have been used for shelter, storage, or ceremonies.

BATS AND CAVES

IS ANGLE IRON CORRECT FOR BAT GATES? THE REBUILDING OF TORGAC AND FORT STANTON CAVE GATES

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During the mid-1990s, caver and BLM volunteer Jim Cox built a series of excellent vandal-resistant cave gates that had several unique features, starting with schedule 80 round stock pipe. Round stock was used because Cox tested his designs in a wind tunnel against conventional angle-iron gates and found eddy currents to exist in the case of angle iron. To the author's knowledge, Cox is the only person who ever actually did such a study before designing his gates. Others the author has spoken with have quite subjectively made statements to the effect that angle iron is the most suitable. The round stock versus angle iron distinction may be critical in hibernacula roost site selection for certain bat species, notably Townsend's big-eared bat (*Corynorhinus townsendii*).

MYOTIS SODALIS WINTER POPULATION TRENDS IN INDIANA

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The Indiana bat (*Myotis sodalis*) has witnessed a dramatic population decrease throughout its range over the past fifty years, causing it to be one of the first species to be listed on the US Fish and Wildlife Service Endangered Species list. Current downward trends continue in most states, but known winter populations in Indiana caves have remained relatively stable. While some significant Indiana hibernacula have lost bats, other hibernacula have shown remarkable increases.

THE CURRENT STATUS OF BAT MONITORING STUDIES IN ILLINOIS

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Bat monitoring efforts have been conducted regularly in Illinois since the mid-1980s. Of the 12 bat species that occur in the state, 9 (including 2 federally endangered species and 2 state-endangered species) depend on caves or abandoned mines during at least part of the year. Two Priority II hibernacula for the federally endangered Indiana bat were discovered in Illinois during the 1990s. The Illinois Department of Natural Resources has established a schedule for conducting regular winter censuses at several caves and mines used by bats. There has been an increased focus recently on gating important cave and mine entrances, both on public and private land, and several significant sites also are protected as state nature preserves. In 1985, the Division of Natural Heritage and Illinois Natural History Survey (supported by the Illinois Department of Transportation, Shawnee National Forest, and US Fish and Wildlife Service) began a cooperative program to study the summer distribution of bats throughout the state, with an emphasis on the Indiana bat. Radiotelemetry identified numerous roost trees used by this species, including maternity colonies.

SURVEY WORK AND CONSERVATION EFFORTS FOR BATS IN IDAHO

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Fourteen species of bats have been confirmed in Idaho. Nine of the 14 species are listed as sensitive by the USDI Bureau of Land Management (BLM), USDA Forest Service, or Idaho Department of Fish and Game. An effort to gain a better understanding of bat species distribution, composition and population status was initiated by the Idaho Conservation Effort in 1995. Bats captured by mist nets were identified in a variety of habitats throughout Idaho during the summer months. One hundred and five sites were surveyed and 616 bats representing 14 species have been captured. Little brown myotis and big brown bats were captured commonly and at more than a fourth of all sites surveyed. California myotis, fringed myotis, hoary bat, pallid bat, and spotted bat were caught infrequently. Additionally, California myotis, fringed myotis, pallid bat, spotted bat, and western pipistrelle were caught at 5 or fewer sites. Fringed myotis were captured near older aged forest stands, however, they have also been documented using juniper woodlands in the Owyhee Mountains. Pallid bats and western pipistrelle were only detected at sites located in the southwestern and south-central regions of the state, mostly in steep, rocky canyons. Spotted bats were audibly detected at 9 locations, mostly in steep remote canyons. However, they were also detected at an internationally renowned rock climbing area containing numerous tall granite rock formations.

The species most frequently captured using caves were long-eared bats, Western small-footed bats and Townsend's big-eared bats. Loss of cave habitat due to disturbance and/or deliberate harassment is a threat to bats in southern Idaho. Monitoring of bat populations at several historical hibernacula caves during the winter has shown a significant decline in bat numbers. The BLM is working with local cavers to identify and monitor important bat caves. Signs and gates

are used to inform users and establish seasonal use closures at key roost sites. Educational presentations about bats and cave habitats are provided to local schools and community groups to raise awareness of the predicament of bats and potential human impacts from misinformation and disturbance at roost sites.

BIOLOGY

KARST WATERS INSTITUTE'S SECOND ANNUAL TOP TEN LIST OF ENDANGERED KARST ECOSYSTEMS

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In 1998, the Karst Waters Institute (KWI) published a list of the ten most endangered karst communities, a project that evolved out of the proceedings of a scientific conference held in February 1997 on the conservation and protection of karst biota. Nineteen karst locations were nominated in 1999 as candidates for KWI's "most endangered" list. Karst ecosystems selected exhibited (1) biological significance including rare, endemic or threatened species or communities rich in biodiversity; (2) significant threats to the communities; and (3) individuals or groups interested in protecting the threatened karst. The sites are: caves in central Cambodia; Church and Bitumen Caves, Bermuda; Edwards Aquifer, Texas, USA; Koloa Lava Tube System, Hawaii, USA; Kosciusko Island, Alaska, USA; Movile Cave, Romania; North-Northwest Karst Province, Puerto Rico; Organ Cave, West Virginia, USA; Snail Shell Cave, Tennessee, USA; and Zinzulusa Cave, Italy. The project has a web site that uses a Geographic Information System to publish an interactive map for the list for 1999. This site provides access to information on the site, including the size of the system, number of endangered species and a list of selected species from each site.

AMPHIPODS IN MINNESOTA CAVES

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No amphipods were reported from Minnesota caves in surveys of invertebrate cave faunas by Peck & Christiansen (1990) and Montz (1993). However, the author has observed *Gammarus pseudolimnaeus* Bousfield in abundance in Carvers Cave, the most historic cave in Minnesota, during the past decade, the entire period of his observation. Specimens were graciously identified by John Holsinger.

Carvers Cave is a sandstone cave, ~35 m long, located in the Mississippi River Gorge near downtown St. Paul, Minnesota. It contains a lake 2 m deep, supplied by a spring with a discharge of 100 L/min, for which the recharge area appears to be largely residential. The water temperature is 10°C and the chief source of organic matter appears to be leaf material carried in by the wind. *G. pseudolimnaeus* is not a cave-adapted species, having been documented at numerous surface-water localities in Minnesota by Muck & Newman (1992), who used it as an indicator of water quality.

A November 13, 1913, newspaper article in the St. Paul Pioneer Press entitled, "Blind Crayfish in Carver's Cave," is another reference to crustaceans in this cave.

INFLUENCE OF TEMPERATURE ON *TROGLOPHILUS ANDREINII* (ORTHOPTERA RAPHIDOPHORIDAE)

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We have recorded breeding *Troglophilus andreinii* (cave gryl-

lacrida) circadian locomotor activity at various temperatures (5.6-39.7°C) by a microactograph. In this way, we obtained a pattern of thermal optimum from which to deduce its eutherma grade. The values of temperature at which we have registered the maximum of activity coincide with the medium values of temperature of the apulian caves (18°C).

THE NEUROECOLOGY OF CAVE CRAYFISH: BEHAVIORAL AND ANATOMICAL COMPARISONS OF VISUAL SYSTEMS IN SIGHTED EPIGEAN AND TROGLOBITIC SPECIES

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The activity of visual systems is known to have an effect upon the development of the neural tissue associated with vision. We used three species of crayfish in examining the gross structures of the eye and underlying neural tissue for comparative purposes of the optic system associated with environmental adaptation. The troglobitic crayfish, *Orconectes australis packardii* Rhoades, and the two epigean crayfish *Cambarus tenebrosus* & *Procambarus clarkii* were used in these studies. *C. tenebrosus* raised in the cave are functionally blind although ommatidia do develop, indicating that the primary sensory structures still develop without normal input. Troglobitic crayfish have lost the genomic ability to form a functional visual system and, thus, would be expected not to possess normal ommatidial structures. Electrophysiological records from the sensory neurons of *O. australis packardii* Rhoades showed no response to light. The troglobitic and surface (epigean) crayfish found deep in caves are both behaviorally blind. The neuronal ganglia within the eye stalk of *C. tenebrosus* and *O. australis packardii* Rhoades reveal a disorganization which is likely the reason for the lack of a behavior response in *C. tenebrosus*. Cross sections of the protocerebral tract revealed that the troglobitic crayfish have more neurons of small axon profiles and fewer large axon profiles than the other two crayfish that contain ommatidia. Recent studies show that olfactory projection neurons, that arise from the central brain, send processes to ganglia within the eye stalk. The blind cave crayfish contain more olfactory projection neurons and fewer larger neurons within the protocerebral tract. (Supported by NSF grant IBN-9808631-RLC).

STYGOBITE DISTRIBUTION IN MISSOURI

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Missouri has ~5,700 known caves, of which about 600 have been studied biologically. In compiling the Missouri Biospeleological Database, we have enumerated ~51 species of stygobites (including phreatobites) and 27 terrestrial troglobites. An analysis of the number of stygobites versus the number of caves in each county shows almost no relationship.

ECOLOGICAL ASSESSMENT AND GEOLOGICAL SIGNIFICANCE OF MICROBIAL COMMUNITIES FROM A SULFIDIC CAVE SYSTEM

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Cesspool Cave is a small, non-thermal, sulfidic (average H₂Saq = 7 mg/L) feature formed in travertine deposits along Sweet Springs Creek, Alleghany County, Virginia. Previous research of microbial morphologies suggested the presence of sulfur bacterial communities.

To assess overall ecological potential for this subsurface ecosystem, microbial community activity was measured using radiotracer studies. Autotrophic productivity was determined through [^{14}C] bicarbonate incorporation while [^{14}C] leucine and [^{14}C] acetate assimilations were used to estimate heterotrophic activity. An estimate of total community diversity was determined using molecular cloning techniques employing 16S rRNA gene sequences. To address whether these microorganisms may influence geological processes, specifically sulfuric acid speleogenesis, isolates were obtained of sulfur-oxidizing bacteria using standard laboratory enrichment methods. Preliminary phylogenetic analysis of laboratory strains suggested the closest known relative is *Thiobacillus thermosulfatus*, a known sulfur-oxidizing bacterium that acidifies its surroundings because of sulfuric acid production. Additional physiological characterization of these strains indicated biological acid production may surpass strictly chemical, dissolutional processes for this cave system. This work provides framework for future investigations using a holistic approach to studying these sulfidic environments in an attempt to understand their ecological and geological significance.

MARK-RECAPTURE POPULATION SIZE ESTIMATES OF STYGOBITES IN A VADOSE STREAM AND A PHREATIC LAKE

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I used a mark-recapture method to estimate population sizes of the crangonyctid amphipod *Stygobromus emarginatus* in a headwater stream in Organ Cave, West Virginia, and of the cirolanid isopod *Antrolana lira* in the phreatic lake of Madison Cave-Stegers Fissure, Virginia. A 24-hour interval between marking and recapturing of specimens produced high recapture rates of *S. emarginatus*. Results showed that *S. emarginatus* occurred at a density of 11/m stream length, and yield a total estimated population size of 3300 individuals in the 300 m long stream. A 2-week interval between marking and recapturing was necessary to obtain high recapture rates of *A. lira*. Results showed that specimens found in Madison Cave and in Stegers Fissure are from the same population, and the population size was estimated to be ~6000 individuals.

FAUNA OF THE CHIQUIBUL CAVES, BELIZE

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The Chiquibul Cave System is in the Chiquibul Forest Reserve on the Vaca Plateau of the Cayo District, Belize. Biological collections were made on 5 expeditions since 1984. Eight species of troglobites and about 60 other cavernicoles have been collected. Troglobites include a pseudoscorpion, shrimp and crab that are described species, an isopod that awaits confirmation, and a spider, springtail, entotroph, and ricinuleid that await description. These species represent over half of the troglobite diversity of Belize which has a total of 13 identified species. The energy into these caves is primarily from a large sinking river, which carries surface debris and organisms into the 60-km long system. Much of the habitat sampled is large clay banks that border the main river, but also includes microhabitats formed by upper level inlets, dry historic stream passages, and entrance collapse areas with large energy inputs such as logs and bat guano. Recent

expeditions identified a large passage above flood levels that contains extensive bone remains including those of a spectacled bear, *Tremarctos sp. cf. ornatus*. This is a significant range extension from South America.

ECOLOGICAL POTENTIAL OF SUBSURFACE MICROBIAL PRODUCTIVITY FROM SULFIDIC ENVIRONMENTS

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Although numerous ecosystems utilizing chemoautotrophy as an energy source have been documented, the contribution of subsurface microbial productivity to ecosystem energy budgets is still poorly understood. Therefore, the rates of production of microbial communities from sulfidic karst systems and the potential energy transfer of this productivity to higher trophic levels was investigated. Microbial mat communities from four sites were used for determining productivity: the Frasassi Caves system, Italy; Movile Cave, Romania; Cesspool Cave, Virginia; and Lower Kane Cave, Wyoming. Microbial production was measured in each community using radiotracer studies and standardized using the dry weight of the sample (mg dry weight = mgdw). Autotrophic productivity was measured using [^{14}C]bicarbonate incorporation while heterotrophic productivity was measured using [^{14}C]leucine and [^{14}C]acetate. Autotrophic productivity was highest in the Frasassi Caves system (0.46 nmol ^{14}C bicarbonate/mgdw/day) and lowest in Cesspool Cave (0.003 nmol ^{14}C bicarbonate/mgdw/day). Heterotrophic activity was highest in Movile Cave (0.38 nmol ^{14}C leucine/mgdw/day, 6.69 nmol ^{14}C acetate/mgdw/day) and lowest in the Frasassi Caves (0.14 nmol ^{14}C leucine/mgdw/day, 0.44 nmol ^{14}C acetate/mgdw/day). The ecological impact of the measured productivity was examined in Movile Cave by estimating the ability of the terrestrial isopod *Armadillidium tabacaru* to assimilate the microbial mat. Preliminary results indicate that *A. tabacaru* assimilation efficiencies in Movile Cave fall between 51-90%.

GROUNDWATER CHEMISTRY AND BACTERIAL FAUNA OF FOUR LARGE CAVES IN ILLINOIS' SALEM PLATEAU

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As part of a biological evaluation of the federally endangered Illinois cave amphipod, *Gammarus acherondytes*, (Amphipoda: Gammaridae), we are examining groundwater and sediment chemistry and groundwater bacteria in 4 caves in Illinois' Salem Plateau. Results from the first four months of this study are discussed in light of potential sources of human impact on the amphipod populations (e.g., row crop agriculture, livestock, and urbanization). During high flow periods (February-April), fecal coliform counts were highest in water from Stemler Cave where the amphipod has not been found since 1965, and water from this cave tended to be more turbid than water from the other three caves. To date, agrichemicals have not been detected in water samples or sediments prior to the spring application of agricultural pesticides. High fecal bacterial counts in all four caves, and the abundance of taxa associated with both human and livestock waste, along with heavy sediment loads in Stemler Cave, suggest that several types of human impacts are having a negative impact on groundwater quality.

CONSERVATION & RESTORATION

VOLUNTEER VALUE FORMS

Val Hildreth-Werker, PO Box 1018, Tijeras, NM 87059

Generic forms have been created for documenting volunteer time contributed to any project. Forms can be used for recording our efforts in survey, science, conservation, photography, etc. The volunteer value system is based on government rates. It was created as an adjunct to the volunteer value agreement between the Forest Service and the NSS. However, the system can be applied to caves managed by other agencies, conservancies, or private owners. A web site is being created so we can easily report hours and value.

THE AMERICAN CAVE CONSERVATION ASSOCIATION AND HORSE RIVER CAVE

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The American Cave Conservation Association (ACCA) was founded in 1977 with a mission to protect caves and karstlands. This mission was to be accomplished through public education and professional seminars. In 1986, after a national search, the Association headquarters was relocated in Horse Cave, Kentucky. In 1993 the American Cave Museum opened its doors.

A former show cave (Hidden River Cave) is being redeveloped with environmentally sound methodologies. The ACCA also provides professional seminars, school programs, literature, and management consultation. The Association gated well over 100 caves over the years, mostly on federal land and all by invitation. Recent purchases of property will allow expansion of the museum, offices and the show cave tour in the near future.

EXPLORATION - INTERNATIONAL

CAVING IN THE BORDERLANDS - TABASCO AND CHIAPAS, MEXICO

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Twelve caves were explored and mapped along the border between the Mexican states of Tabasco and Chiapas. The caves ranged from just a hundred meters above sea level to high elevation caves at ~1200-1300 m msl. Many of the caves were highly decorated, notably Cueva de Arroyo Azul. A complex of five caves around Grutas Cuesta Chica was mapped and explored. Locals indicated that perhaps 50 more caves could be found in this same area. A trip into the Sierra Madrigal located a vertical cave that was explored down two drops and the cave continues going down. Local rumors of the Sierra Madrigal tell of another pit that breathes sulfurous odors. Near Arroyo Magestic, Chiapas, an interesting cave formed in sandstone was explored and mapped. Several caves were near Kolem Jaa, including a muddy, crawly cave that has yet to be completed. A trip into a disputed area near Agua Blanca, Tacotalpa, yielded a fine nacimiento which was not entered due to the politically fluid situation along the border in this area.

CAVES OF AUSTRALIA: CAVING IN QUEENSLAND'S CHILLAGOE REEF

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Australia's dry climate restricted karst development mostly to the wet fringes of the continent. One example of such karst is in the northeastern part of Queensland in the Chillagoe-Mungana National Park. In addition to Chillagoe, limestone caves in Queensland are in

the Mitchell-Palmer karst (120 km northeast of Chillagoe) and the Camooweal karst to the southwest. To the south, the Undara lava tubes (volcanic in origin) form a spectacular underground complex. Most of the 500 Chillagoe caves are confined inside limestone towers. Chillagoe tower karst is underlain by a marble plain. Because caves did not form in the marble, they are generally short and can only extend vertically within the towers, whose maximum heights are typically under 100 m. The Chillagoe karst towers formed in limestone that was deposited as a coral reef during the Late Slurian (434-416 Ma). The Chillagoe Formation consists of alternating limestone, sandstone and chert strata. These strata, originally deposited horizontally, were tilted nearly vertical by tectonic forces. Subsequently they eroded, leaving behind parallel, linear-strike ridges composed of less soluble rock. This valley and ridge topography allows relatively easy access to the towers. Because of the extended dry season in this area, bottle trees, relatives of African baobab tree, often grow above subterranean chambers into which they send their roots in search of water. Local caves are also home to children's python, huntsman spiders and several species of bats. Chillagoe caves offer immense opportunity for further study and exploration.

CAVE EXPLORATION IN INDIA: AN INTERNATIONAL EFFORT TOWARDS UNDERSTANDING A NEW KARST REGION.

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Expeditions that began in 1992 have shown that the northeastern Indian state of Meghalaya contains significant cave systems. Known as "Abode of the Clouds", Meghalaya is rich in limestone and receives record precipitation. Warm subtropical climate further enhances speleogenesis of extensive river caves. Expedition members from UK, Germany, India, and US have explored and surveyed 125 km of caves by early 1999. The expeditions have been organized in collaboration with the Meghalaya Adventurers Association. The February 1999 expedition extended survey in Pielkhlieng Pouk, the third longest cave in India, to 9.7 km in length. The main passage of this cave features huge gour dams up to 8 m high. The dams define a series of lakes and canals necessitating over three kilometers of swimming on the through trip. Synrang Pamiang was extended to just over 14 kms, making it India's second longest cave. Trips to 21 km-long Kotsati-Umlawan System, currently the longest cave in India, completed photographic and biological surveys of the cave. These efforts resulted in a discovery of two potentially unknown species of blind cave fish in Synrang Pamiang and Pielkhlieng Pouk. In the Cherrapunjee area, several new caves were explored adding 2.5 km of new cave passage and the promise of more to come. The expedition also conducted reconnaissance trips to other areas in preparation for return trips that are planned for 2000. The success of these explorations would not be possible without the hospitality of the Meghalayan people.

EXPLORATION - UNITED STATES

MALHEUR CAVE

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In March 1999, Tom Miller and Larry Hill traveled to Malheur Cave, located in the desert southeast of Burns, Oregon. Malheur Cave is a lava tube with an opening large enough to drive a vehicle into (~2 m high by 6 m across). The cavern opens into a lava tube ~6 m high and 12 m across. The cave is currently owned and used by the Masons for meetings. The cave has historical uses dating back more

than 300 years, when Indians used the cave for shelter.

The cave system consists of ~250-300 m of dry cave, 600 m of partially submerged cave, and 670 m of totally submerged cave. There are numerous springs located along the walls of the submerged portion of the cave. The most recent mapping of the cave was in 1973 by the Oregon Grotto. The 1973 mapping effort ended where the lava tube becomes totally submerged.

RECENT CAVE EXPLORATION IN THE SAN JUAN MOUNTAINS, SW COLORADO

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Colorado's San Juan mountain contains over 930,000 hectares, most of which consist of volcanic and other igneous rock. Mississippian and Pennsylvanian limestones are in the western San Juans. Recent cave discovery and exploration activities have resulted in identification of 40 previously unreported caves and pits. About half of these discoveries have been surveyed, and several limestone outcrops have yet to be investigated. Most of the San Juan caves are in Pennsylvanian limestones of the Hermosa Group (middle Honaker Trail Fm.) that are usually no more than 9 m in thickness. These beds contain a variety of small, cold, wet caves at elevations of 3000-3400 m. The largest of these, Surprise Cave, has over 1100 m of surveyed passage, another (Twin Pit/Sunset Slide) has 370 m surveyed, and several other caves also have the potential for having over 300 m of passage.

DISCOVERY AND EXPLORATION OF COYOTE CAVE, SOUTH DAKOTA

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Discovered by Tom Miller in 1974, Coyote Cave is the second longest cave known within Wind Cave National Park, South Dakota. The cave is formed within a thin limestone bed in the Minnelusa Formation, which overlies the cavernous Madison Limestone. Even though the cave has strong airflow that hints at the cave's potential, exploration has been sporadic and currently only 370 m of survey have been completed. The cave's small passages and tight squeezes have not made exploration easy or appealing. In late 1997, Joel Despain, Merrilee Proffitt, and Greg Stock squeezed through the cave's most intimidating squeeze to discover going cave beyond.

DEFINING THE TROUT LAKE SYSTEM

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The Trout Lake caves are probably the largest, unrecognized lava tube system in the United States. In 1853, Captain George McCellan, later General of the Army of the Potomac during the Civil War, explored the lava fields while searching for a railroad route. Later, cavers explored the area and found numerous caves. The 1972 NSS Convention at White Salmon, Washington, focused interest on the caves. Until recently, cavers thought the caves, featured in the 1972 and 1991 NSS Convention guidebooks, were randomly located. We can now establish the connectivity of the caves with 32 km of mapped passages and the aid of geologic studies. While the picture is but half complete, the study is driving the exploration for new caves and passages. Northwest cavers discovered new passages in Dynamited, Dead Horse, and Poachers caves. We have placed Chubby Bunny, Technonine, Down Draft, Three Sinks, and Skamanic caves in their correct locations relative to other caves in the system. By filling in the gaps in the system, it is hoped that new caves will be discovered.

GEOLOGY & GEOGRAPHY

COMPARISON OF KARSTIFICATION AND SOLUBILITY OF THE LOYALHANNA LIMESTONE, CHESTNUT RIDGE AND LAUREL HILL, WESTERN PENNSYLVANIA

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The Mississippian Loyalhanna Limestone is the primary cave-forming unit in the geologically similar Chestnut Ridge and Laurel Hill anticlines. Exploration and mapping show Chestnut Ridge has more and larger caves than Laurel Hill. The Loyalhanna Limestone is a massive, cross-bedded rock unit that varies in composition from a calcareous sandstone to a sandy limestone. Even though Laurel Hill has more Loyalhanna Limestone exposed and appears to receive more precipitation, Chestnut Ridge contains 178 solutional caves compared to Laurel Hill's eight. The discrepancy could reflect exploration bias. However, the caves that have been discovered on Laurel Hill are significantly smaller and less extensive than those on Chestnut Ridge. This study examined the amount of outcrop, precipitation, and solubility of the limestone in order to explain this difference. The amount of outcrop was determined from published maps by Berg and Dodge (1981). Qualitative analysis of satellite imagery was used to estimate relative amounts of precipitation. The rates of dissolution of 15 rock samples from Chestnut Ridge and 14 samples from Laurel Hill were measured in 5-7% acetic acid (vinegar) over 91 hours. This experiment showed a higher rate of dissolution in the limestone of Chestnut Ridge than in the limestone of Laurel Hill. Solubility of the limestone, probably caused by facies change, thus appears to be the controlling factor that favors karst development on Chestnut Ridge over Laurel Hill. Other factors may include the number and density of joints and fractures, differences in grain size, and variations in stratigraphy and lithology.

ALPINE KARST DEVELOPMENT AND SPELEOGENESIS IN THE LIME CREEK HYDROLOGIC SYSTEM, EAGLE COUNTY, COLORADO

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This study determined the controls on and the nature of alpine karst development in Lime Creek, Eagle County, Colorado. The major controlling factors on karst development in the Lime Creek/Tellurium Park area are lithology and structure. Paleokarst and mineralization affect individual passages, but have little control on overall cave morphology. In general, water is captured in sinkholes and follows fractures, bedding planes, and open conduits until encountering major faults. Flow continues along these faults to the karst conduit that feeds into Clark Spring in Lime Creek Canyon.

Detailed mapping of cave sediment distribution and composition was used to assemble a depositional history for caves in the study area. Cave development probably began about 130-95 ka and continues to the present. Sediment deposition was strongly controlled by glacial advances and retreats in the Lime Creek Valley.

During glacial periods, caves overrun by glacial ice were characterized by calcite deposition and roof breakdown. Periglacial caves were marked by active stream erosion and deposition, and calcite deposition in abandoned cave passages. Meltwater from glaciers increased stream energy and completely filled some passages with glacial materials. During interglacial periods, speleogenesis in most of the caves was probably characterized by roof collapse, calcite precipitation, and sediment deposition.

LUMINESCENCE BANDING IN YOUNG FLOWSTONE: COMPARISON WITH CONTEMPORARY CLIMATIC RECORDS

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Most calcite speleothems display a blue-white to green-white luminescence under excitation by ultraviolet light. The brightness of the luminescence varies along the growth direction of the speleothem producing alternating light and dark bands with a thickness on the order of 20-60 μm . These have been associated with annual wet and dry cycles so that the luminescence banding, if it can be properly interpreted, forms a paleoclimatic record that can extend through the Holocene and into interglacial periods. To read the climatic record, it would be useful to compare luminescence banding with known climatic data. Woodward Cave, Pennsylvania, contains thin layers of flowstone over bare limestone walls that are known to have grown since mud and silt were cleaned out of the passage during commercialization in 1924. Likewise, there is recent flowstone forming in limestone mines of western Pennsylvania. Luminescent banding was measured on slabbed and polished samples of Woodward Cave and limestone mine flowstone using laser excitation focused through a microscope to a 1-2 μm spot. Luminescence radiation emitted from the spot was transmitted back through the microscope, through a monochromator, to a photomultiplier for quantitative intensity measurement. The specimen was mounted on a precision stage that could be advanced in micrometer intervals for high spatial resolution. By this means, luminescence banding records have been obtained which can be compared with actual climate records for central and western Pennsylvania.

STATISTICAL ANALYSIS OF CAVE TEMPERATURE VARIATIONS IN SALTPETRE CAVE, CARTER COUNTY, KENTUCKY: A POTENTIAL REFERENCE FOR ASSESSING THE APPLICABILITY OF THE THREE-ZONE CAVE TEMPERATURE MODEL

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Past workers have discussed three-zone models for temporal and spatial variations of temperature within caves. With the recent introduction of inexpensive data loggers capable of recording temperature changes with high resolution and precision, the opportunity to quantitatively reassess the three-zone model exists. Recent investigations indicate the three-zone model insufficiently explains temperature variations in caves situated in tropical climates and/or containing active streams, multiple entrances, etc. As a point of comparison, high resolution data on the temperature structure of a cave adhering to the three-zone model would be useful. However, such an analysis is unavailable. To provide such a reference, a statistical examination of temperature variations in Saltpetre Cave, Carter County, Kentucky is presented.

Temperatures at 14 locations along a 200 m horizontal transect into the cave were recorded every five minutes for 7 days in January 1998 using HoboTM® data loggers. Additionally, temperature was recorded outside the cave providing a reference for external meteorological patterns. Statistical analysis of these data show decreasing variance (7.2-0.0 $^{\circ}\text{C}$), range (10.9-0.0 $^{\circ}\text{C}$), standard deviation (3.3-0.0 $^{\circ}\text{C}$), and standard error (0.07-0.0 $^{\circ}\text{C}$) away from the cave entrance. These patterns suggest that external influences on cave temperature decrease with increasing distance from the entrance. As expected during the winter season, the mean temperature increased with increasing distance from the entrance. In agreement with the model, three cave zones were determined to exist in Saltpetre Cave: twilight cave (0-~18 m), middle cave (~18-~60 m), and deep cave (>60 m).

However, truly static temperature conditions are not found until 183 m.

GEOMICROBIOLOGY OF SULFURIC ACID SPELEOGENESIS

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Oxidation of reduced sulfur compounds (e.g. H_2S , S^0) to sulfate, and ultimately sulfuric acid, controls development of sulfidic karst. Traditionally, sulfidic cave systems were believed to originate by primarily chemical karstification mechanisms. More recently, a host of complex microbial biofilms, which have the potential to oxidize reduced sulfur to sulfate, have been identified in some systems. Previous work has speculated that these bacteria may be directly involved with sulfuric acid speleogenesis, but this work is the first to test those hypotheses.

Geomicrobiological interactions occurring during sulfuric acid speleogenesis were investigated from active sulfidic caves, including Movile Cave (Romania), the Frasassi Cave (Italy), Cesspool Cave (Virginia), and Lower Kane Cave (Wyoming). Strains of sulfur-oxidizers were isolated using standard laboratory enrichment techniques and their acid production potential was screened for using two unique plating methods. The first method detected acid production through introduction of a pH indicator, bromocresol green, into the growth medium. The bromocresol green plates indicated that strains lowered the pH of the media to values below 3.8. The second method introduced CaCO_3 within the growth medium. As the bacterial colonies grew and produced acid, the CaCO_3 was cleared from the plates in the vicinity of the colonies. Although preliminary, gypsum precipitation was also linked to microbial sulfur oxidation in the laboratory strains. Attempts to identify the cultures indicated that they are new species, with their closest known relatives being acid-producing, sulfur-oxidizing bacteria, such as *Thiobacillus*.

CHARACTERIZATION OF KARST GROUNDWATER BASINS USING NORMALIZED BASE FLOW ANALYSIS, FORT KNOX, KENTUCKY

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Fort Knox occupies an upland sinkhole plain bounded on three sides by base level streams. The karst aquifer is developed within a 60-m thick sequence of St. Louis Limestone and is constrained by an underlying aquitard, the Salem Limestone. To evaluate groundwater quality concerns from hazardous materials facilities located throughout Fort Knox, karst groundwater basins were characterized and delineated using a combination of dye tracing (visual, qualitative, and quantitative), spring flow characterization (discharge, temperature, pH, and conductivity), and structural and topographic controls.

Normalized base-flow (NBF) was calculated for both the entire study area and for 28 individual basins. Projected basin areas were measured by planimeter from topographic maps. Discharge measurements collected in October 1997, representing 5-10% of peak discharge, were used for base-flow conditions. NBF calculations yielded a site-wide value of 1.53 (0.33 L/s/km² or Lsk), with individual basins ranging from 1.86 to 1.09 Lsk, and were comparable to published results from similar terrains. Comparison of NBF values between individual basins and the site-wide result proved an effective indicator for groundwater flow characterization. Basins with higher than average NBF have less-developed conduit systems and greater storage potential. Alternatively, further investigation in several basins with unusually high NBF found artificial contributions to groundwater flow from leaking water and sewer lines. Basins with lower NBF have well-developed conduit systems that efficiently transport

groundwater through the basin, limiting storage. Additionally, NBF results were used to refine the basin limits and to establish boundary zones in areas of uncertainty or potentially overlapping basins

ESTIMATES OF SEEPAGE RATES OF REDUCED, SALINE GROUNDWATER INTO THE DRAGONS LAIR TUNNEL OF THE CRYSTAL BEACH SPRING CAVE SYSTEM

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Crystal Beach Spring is a freshwater, submarine spring in the intracoastal waterway of the Gulf of Mexico to the east of Honeymoon Island and ~300 m offshore (west) from Crystal Beach in Pinellas County, Florida. A unique ecosystem exists within the Crystal Beach Spring cave system at a penetration of 700-820 m and a depth of 37 m salt water in a tunnel known as the Dragons Lair. This area of the cave is characterized by a pycnocline, a distinct thermocline/halocline in the water column separating freshwater flowing toward the entrance from warmer, stagnant saltwater. Just above the pycnocline, a "cloud" of sulfur oxidizing bacteria is present. These bacteria use hydrogen sulfide from the saltwater as an energy source (electron donor) and oxygen as the electron acceptor. This allows primary production to be performed without photosynthesis. The saltwater in the Dragons Lair is seeping up through the carbonate sediments covering the floor of the cave in the Dragons Lair. The vertical hydraulic gradient of the saltwater was measured using a piezometer and submersible manometer. The manometer data showed an upward hydraulic gradient, and water quality data demonstrated that the Dragons Lair saltwater was significantly different from the Gulf saltwater. A specific discharge of 2.92×10^{-5} m/s for the saltwater was obtained using a saltwater/freshwater mixing model. This model was based on the change in total dissolved solids of the freshwater as it flows across the saltwater in the Dragon's Lair.

COMPARATIVE OBSERVATIONS FROM TWO ACTIVE SULFUR-RICH SPRING CAVES: LOWER KANE CAVE AND CUEVA DE VILLA LUZ

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Lower Kane Cave (LK), Wyoming, USA, provided much of the evidence Egemeier (1973) cited in his "replacement-solution" model of hypogenic speleogenesis. Recent work in Cueva de Villa Luz (VL), Tabasco, Mexico, has expanded our knowledge about erosive processes in sulfur-rich spring caves, prompting several new observations in Lower Kane Cave.

The two caves display similar features, including: 1) Springs rising from the floor form sulfur-rich streams; 2) Spring waters have pH values between 6-7 and pHs of the streams are 7-7.5; 3) White bacterial stringers undulate in the streams; 4) Bright red microbial mats line the bedrock and stream bottoms adjacent to and for ~20 m downstream of some springs in each cave; 5) Actinomycetes are common; 6) "Biovermiculations" are abundant in stream passages of Villa Luz and near the entrance of Lower Kane; 7) Small snails (LK <5 mm and VL <2 mm across) are abundant in the stream sediments; 8) Spiders are plentiful in Villa Luz and present in Lower Kane; 9) Gypsum crystals ranging from microcrystalline pastes to macrocrystalline blades coat most of the walls and ceilings. Gypsum pastes consistently display pH values of 1-3.

Atmospheric H₂S levels are markedly higher in Villa Luz (maximum recorded value of 158 ppm versus 3 ppm in Lower Kane). Carbon monoxide has also been recorded (V.L. = 58 ppm; L.K. = 24 ppm). Unidentified gas bubbles, thought to be CO₂, rise from some

springs in both caves. Apparent "corrosion residue" near one spring in Kane resembles deposits from Lechuguilla Cave.

TOWARD A SUITABLE CONCEPTUAL MODEL OF THE NORTHERN GUAM LENS AQUIFER

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The Northern Guam Lens Aquifer is a carbonate island aquifer in an uplifted limestone sequence consisting of a Miocene-Pliocene detrital facies grading upward into a Pliocene-Pleistocene coral-algal reef-lagoon facies. The limestone sequence rests atop a Eocene-Oligocene submarine volcanoclastic basement. Basement topography is complex, varying from a maximum elevation of ~200 m, where it crops out to form the highest point above the limestone plateau, to a minimum of more than 150 m below sea level. The island has been generally emergent over Pleistocene time; the entire Pleistocene section is currently above sea level, the highest elevation of the plateau being about 180 m. Relative sea-level still-stands are recorded in several notches and marine terraces incised in cliff faces surrounding the plateau. The entire sequence has undergone fresh-water diagenesis as it was uplifted through the fresh water lens. How karst processes have modified the subsequent porosity is of fundamental concern to those attempting to interpret or predict aquifer behavior. Three especially compelling questions include: (1) What is the relative importance of cavernous, fracture, and diffuse porous flow in the current vadose and phreatic zones, and what controls the occurrence of each type of porosity? (2) How strongly has horizontal conductivity been modified by water table dissolution at previous still-stand levels? (3) What is the relative importance of concentrated versus diffuse infiltration? Answers to such questions are crucial for assessing the reliability of models for evaluating pump test results and predicting groundwater flow directions, fresh water lens geometry, and response to withdrawal.

HYDROLOGIC INSIGHTS FROM A FINITE ELEMENT MODEL OF THE YIGO-TUMON SUB-BASIN, NORTHERN GUAM LENS AQUIFER

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The Northern Guam Lens Aquifer (NGLA) is a Pleistocene karst aquifer in an uplifted Cenozoic limestone sequence forming a plateau about 60-180 m high. The climate is tropical wet-dry, with average rainfall about 2.5 m/a, 80% of which falls between July and January. Monthly recharge estimates for 1982 through 1995 based on positive-definite daily differences of rainfall minus pan evaporation suggest a relationship between monthly precipitation and recharge of $N = \max(0, -1.7 + 0.87P)$, where N and P are estimated minimum monthly recharge and precipitation, respectively, in inches. We used a two-phase fresh water/saltwater flow model to simulate transient regional-scale responses of the fresh water lens to monthly variations in natural recharge in the Yigo-Tumon sub-basin of the NGLA. Boundary conditions included monthly-averaged mean sea-level changes. Recharge rates were based on the assumption that 100% of monthly recharge infiltrated to the fresh water lens within each one-month time step. Comparison of observed well water elevations with elevations simulated for various values of hydraulic conductivity, K, sug-

gest a regional K of about 6100 m/day, consistent with previous studies. Variations of 20% around this value produced calculated water levels consistent with observed water levels. The most significant result from the modeling study, however, is that even for best-fit simulations, simulated water levels are consistently higher than observed levels for wet season months and lower than observed levels during the dry season months. The simplest explanation is that vadose storage is sufficient to dampen monthly-scale variations in recharge.

THE HISTORICAL IMPORTANCE OF THE BAUMANNSHÖHLE/HARZ ILLUSTRATED BY THE REPORT OF ZÜCKERT (1763)

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The Baumannshöhle, in Rübeland, Harz, Germany, is one of the most important caves in early scientific literature. First mentioned in 1546, it was the first natural cavern from which a picture of its interior (1654) and a map (1665) was made. It also was the first cave to be protected by decree and for which a guide was appointed (1668). In the 18th and 19th century, it was the focus of investigations by numerous scientists, and appeared in many publications and in most of the natural science overviews. Here I report about a description published in 1763 by Johann Friedrich Zückert (1731-78), a physician and author, so far unknown to speleological literature. Zückert appears to have been a critical observer. He not only described the individual flowstone figures, taking account of previous reports, but he also discussed the question of their formation, showing a thorough knowledge of the chemistry of his time. Furthermore, he deals with the bone deposits in the cave, however, without identifying them as bear bones, even though Horst (1656) and Brückmann (1734) had already stated that the bones from the Einhornhöhle were bear. Walch (1769) was the first to acknowledge Baumannshöhlen bones as bear bones. In 1774, Esper suggested that they belonged to the ice bear, and, in 1794, Rosenmüller finally realized that they represent an extinct species: *Ursus spelaeus*, the cave bear. Using the most recent survey of the Baumannshöhle (Fricke 1998), we were able to identify many of the historical flowstone figures discussed by Zückert.

MIXING CORROSION AT MANITOU SPRINGS, COLORADO

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Precision measurements of the anion and cation content of myriad springs of Manitou and a surface stream along with their flow rates were used to calculate the mass balance of the conservative and non-conservative anions and cations entering and leaving the mixing zone beneath the city of Manitou Springs. The conservative cations and anions are nitrate, sodium, potassium, lithium, sulfate, bromide, fluoride, and chloride. The non-conservative cations are calcium, magnesium, iron and manganese. The calcium and magnesium content of the water increases from the mixing of two different groups of waters. When one group, which has elevated total dissolved solid and very high CO₂ content mixes with another group, which has low total dissolved solid and low CO₂ content, a solution is created that has the ability to dissolve ~71 tonnes/a of the dolomitic limestone that hosts the mixing zone.

The iron and manganese content of the water decreases in the mixing zone from the mixing of the same two groups. In this case the first group of waters is rich in dissolved iron and manganese and the second group is rich in oxygen. When these two waters mix, the manganese and iron precipitate out in the mixing zone. The nearby Cave of the Winds along with the manganese- and iron-rich sediments in

the cave are excellent proof that the mixing corrosion taking place at present had been actively dissolving limestone for millions of years.

DOES CRYSTAL SPLITTING PLAY A PART IN THE CURVATURE OF HELICTITES?

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At straight segments of calcite helictites, the crystal axis of fastest growth maintains a constant orientation, whereas at curved segments it follows the curvature. Three mechanisms for rotated crystals are (1) the long axes of the crystals in conical stalactites always point toward their curved outer surface, because they crowd out slower growing seed crystals of other orientations; (2) Russian investigators explain radiating crystals by crystal splitting, the insertion of molecular wedges to divide an initial crystal; and (3) microorganisms cause a non-typical diagonal orientation of calcite moonmilk grains. Helictites are nourished by a capillary at the tip. The growth increments consist of nested cones, but thin sections show that the crystal units are wedges that diagonally cross the whole helictite. The youngest wedge points toward the intersection between two faces of the helictite's 3-sided pyramidal tip. The wedges grow toward that intersection (the trace of a scalenohedral tip) and by crystal overgrowth at the edges of older wedges. Deposition follows the crystal lattice of the wedges but is greatest near the capillary, leading to an increased angle. When water flow stops periodically, subsequent growth is controlled by crystal crowding. It is perpendicular to the outside of the curve next to the capillary, and its crystal orientation differs slightly from that of the previous wedge. I cannot, with certainty, distinguish crystal crowding from crystal splitting near the orifice of the capillary, but crystal splitting ought to cause a fanning from the orifice, whereas the wedges are planar across the entire helictite.

THE ROLE OF MAPPED AND UNMAPPED IMPERMEABLE UNITS IN CONTROLLING CAVE DEVELOPMENT AND CONTAMINANT TRANSPORT IN CENTRAL TENNESSEE: THE "PERCHED WATER TABLE THEORY" REVISITED

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Studies by the authors have shown that thin, impermeable shaly and sandy units occur in central Tennessee that prevent the downward migration of groundwater and contaminants. In the Highland Rim, four impermeable units exist. The Chattanooga Shale is mapped and is obvious, but the Warsaw Limestone contains an upper and lower clay- and sand-rich limestone member that perches contaminated groundwater. Dye trace studies substantiate this hypothesis. These two members have not been depicted on geology maps. Large, horizontal caves occur above the two impermeable Warsaw members. Higher in the stratigraphic section, there is an unmapped non-continuous green shale that occurs in the Monteagle Limestone. Where present, this shale perches water causing many deep pits to terminate at this unit.

In the Central Basin, the mapped Hermitage Formation and Pierce Limestone are shaly, and major horizontal caves are developed above them. Groundwater tracing from two state-listed Superfund sites demonstrates the importance of the Pierce in perching potential contaminants above it. Less conspicuous is the unmapped Lower Ridley Confining Unit which has been mistakenly identified and mapped as the Pierce throughout many areas of the Central Basin. Mis-identification of the Pierce and Lower Ridley Confining Unit has caused cross-contamination of aquifers by monitoring wells.

IDENTIFICATION AND DEPOSITION OF METATYUYAMUNITE AND RELATED MINERALS IN CAVERNS OF SONORA, TEXAS, USA

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A new mineral association composed of metatyuyamunite, celestite, opal, and several minor additional mineral phases has been identified from Caverns of Sonora, Sutton County, Texas. Metatyuyamunite, $\text{Ca}(\text{UO}_2)_2(\text{VO}_4)_{2-3}\text{H}_2\text{O}$ occurs as patches of bright lemon yellow crystalline crusts on a limestone substrate that has the appearance of dried and cracked lime mud. The yellow crystals luminesce the characteristic bright green from the uranyl ion. Blue 200-300 μm prismatic crystals of celestite, SrSO_4 , occur in association with the metatyuyamunite and nearby gypsum crusts. Metatyuyamunite takes the form of platy crystals about 50 μm in diameter. In some places, a thin layer of botryoidal opal covers the metatyuyamunite. Associated with the opal are stringy masses of silica that appear to be the residue of bacteria. Mineral identification was by X-ray diffraction with crystal habit determined by scanning electron microscopy. Several other minor mineral phases were observed in the SEM images but were too sparse for X-ray identification. The ultimate source of uranium and vanadium may be from deep seated hydrogen-sulfide rich waters supported by other evidence that the primary excavation of Caverns of Sonora was by the sulfuric acid mechanism now generally accepted for the caves of the Guadalupe Mountains. If this is so, the deposition of metatyuyamunite and associated minerals is much older than the deposition of the calcite speleothems that decorate Caverns of Sonora.

INTERPRETING PREGLACIAL KARST WITH THE AID OF GRAVITY SURVEYS
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Late Pleistocene glaciation in New York State buried most of its karst landscapes beneath as much as 100 m of till, outwash, and lake deposits. Nearly all the karst is preglacial, so this process had a profound effect on groundwater flow and the relation of caves to the surface. Gravity surveys reveal preglacial karst topography by making use of the density contrast between bedrock and overlying glacial sediment. Calibration with well logs suggests densities of 1.7, 2.0, and 2.5-2.65 g/cm^3 for unsaturated sediment, saturated sediment, and bedrock. Because of the broad extent of the gravity traverses, terrain and latitude corrections are essential. Theodolite surveys provide the necessary precision for elevation corrections. Approximate bedrock depths can be estimated with the Bouguer equation, but they must be refined by finite-difference calculations, which reveal far greater local relief than do the initial approximations. We have devised interactive computer software for this purpose. Results show that much of the present karst drainage was adjusted to topographic conditions quite different from those of today. Glacial deposits filled major valleys to roughly half their depth, and topographic relief was reduced by about a third. Many small valleys were completely filled and now show little or no topographic expression. The gravity surveys help to reveal the origin and distribution of artesian springs, filled-valley barriers between neighboring cave systems, blocked inputs, and deranged upland recharge.

FOSSILIZED BACTERIA IN THE RUSTICLE STALACTITES OF LECHUGUILLA CAVE

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We investigated iron oxide filaments in two sections of unusual iron-oxide stalactites from Lechuguilla Cave, New Mexico. The filaments were reported by Davis *et al.* (1990) as fossilized bacteria. We investigated further to characterize their material and biological aspects. Outer layers of these stalactites consist of calcite with thin bands of iron oxide, while their inner cores consist predominantly of iron oxide. The filaments are reddish to yellowish brown and mostly encased in calcite, dolomite, or quartz within the central canal of the stalactite where they are restricted. The filaments vary in diameter from 1-6 μm , and in length from 10 to >100 μm . They have a curved, sinuous to helical morphology, and optical examination shows that they have a central tube. Electron microscopy images clearly show that the filaments are constructed of radial laths of crystalline iron oxide around a "pre-existing" central tube. X-ray diffraction of the stalactite core indicates that the crystalline phase of the iron oxide is goethite. Crystallinity of these laths is confirmed by electron diffraction. Central tube diameters were measured up to 0.5 μm at which size the tube is most distinct. Smaller diameter central tubes in these filaments are probably the result of goethite laths growing into the tubes. The 0.5 μm diameter of central tubes in these filaments is consistent with the diameter of most iron-depositing filamentous bacteria. The filaments may be fossils of *Leptospirillum ferrooxidans*, which grew in an acidic environment, somewhat similar to acid mine drainage settings.

KARST HYDROLOGY OF THE LOGAN CANYON AREA, BEAR RIVER RANGE, NORTHERN UTAH

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Recharge areas and residence time were determined for water from four springs in Logan Canyon, in the Bear River Range of northern Utah. Dewitt, Wood Camp Hollow, Ricks, and Logan Cave Springs discharge from Paleozoic carbonate rocks into the Logan River, east of Logan, Utah. The Logan River is base level for groundwater that discharges from this alpine region.

Dewitt Spring discharges from 0.28-0.99 m^3 and has a recharge area that largely coincides with a regional syncline. Wood Camp Hollow Springs discharge less than 0.1 m^3 to at least 1.4 m^3 from two outlets. Ricks Springs discharge along a normal fault and range in flow from about 0.28-2.1 m^3 . Recharge areas for these springs are at least 26 km^2 and as much as 980 m higher than the springs.

Recharge to the springs occurs primarily during snowmelt, resulting in peak discharge from late spring to early summer and base flow during the winter months. Qualitative dye tracing indicates maximum groundwater travel times of 2-4 weeks from more than 11 km.

Specific conductance of water from all springs during peak discharge ranges from 250-290 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) and temperature ranges from 5.5°-6.0°C. Conversely, specific conductance of water during base flow ranges from 340-420 $\mu\text{S}/\text{cm}$ and temperature ranges from 6.5°-7.75°C. Differences between these values result from mixing of snowmelt with groundwater with a longer residence time.

DEVELOPING A CAVE & KARST INFORMATION SYSTEM USING ARCVIEW® GIS

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A Cave and Karst Information System (CKIS) is a specialized type of geographic information system (GIS). Common tasks and issues are found in developing a CKIS when compared with other types of GISs, but developing a CKIS also presents a unique set of problems, issues, and considerations. ArcView® GIS is a popular desktop GIS software product that includes tools, extensions, and customization capabilities that provide a robust framework for data management and visualization of cave survey data and inventories, as well as a substrate for both analytic and interpretive applications. Several prototypes have been implemented that have demonstrated the usefulness of cave and karst information systems and ArcView® GIS. Preliminary work has yielded specialized code and techniques for visualization and data management. This work has also identified issues and shortcomings that future work will need to address.

KARST INVENTORY OF THE NORTHERN GUAM LENS AQUIFER

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The population of Guam is rapidly growing. Over 70% of its water supply is drawn from the carbonate Northern Guam Lens Aquifer. This project is the first attempt to comprehensively inventory, map, and interpret the aquifer's karst features. Guam exhibits characteristic island karst features, but karst evolution and hydrologic behavior have been influenced in important ways by rapid uplift (up to 180 m in Pleistocene time). Moreover, in spite of the aquifer's relatively small size and young age, it also exhibits, on some terrain, some well-developed classic karst features more typical of continental settings (e.g., blind valleys and disappearing streams). Features on which this investigation is focused include epikarst, closed depressions, caves, and coastal springs. Epikarst on Guam appears identical to epikarst of other carbonate islands. Dissolutional closed depressions include large sinkholes mimicking cockpit karst, small collapsed sinkholes, and blind valleys. The largest closed depressions are probably constructional. Exposed caves on Guam include pit caves, stream caves, and flank margin caves. Numerous pit caves vary widely in size and reach depths of 50 m. Stream caves are associated with allogenic rainwater catchment by volcanic rocks. Flank margin caves are exposed on the cliffs in Northern Guam and indicate previous sea-level still stands. Additional types of caves include voids created on the top, bottom, and within the freshwater lens. These voids, not exposed at the surface, are often intercepted during well drilling. Coastal springs include discharging caves, fractures, and underwater vents along cliff lines, and springs and seep fields along beaches.

KARST GEOARCHAEOLOGY OF PIEDRAS NEGRAS, PETEN, GUATEMALA
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Piedras Negras is the modern name for an ancient Mayan city in the karst lowlands of Guatemala's Peten region. The city's location was determined by a geologically favorable location along the Usumacinta River, on a low-relief platform above seasonally flooded valleys, and part of an arch across a regional syncline. Black chert exposed along the river provided the community a rich deposit of tool making material, and along with rocks stained black from manganese

dioxide, was the source of the town's modern name. The site is within a cone-karst setting; cockpits are not associated with the cones, and there is little apparent internal drainage. Caves are small, less than 10 m in length and mostly collapse-formed shelters. However, one pit is possibly the largest in Guatemala at 100 m in diameter by 66-120 m deep. These contrasts result from the late Cretaceous and Paleocene units underlying the site. The uppermost unit is a cliff-forming dolomite to dolomitic limestone that supports little solutional enlargement for caves. It is underlain by an easily eroded carbonate chalk that forms no caves. Karst cones are partly formed by solution of the dolomitic limestone and partly from weathering of the chalk, undercutting and collapsing the dolomitic limestone. The pit formed by the collapse of both units into a deeper limestone where large phreatic conduits are apparently present. The Maya, known for attributing religious significance to caves, used them for rituals and important burials, but not as intensively as in other locations where caves are larger.

STRONTIUM ISOTOPES OF REDMOND CREEK CAVE, WAYNE COUNTY, KENTUCKY

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Redmond Creek Cave is near Monticello, in Wayne County of south-central Kentucky. The cave cuts through the Kidder and Ste. Genevieve limestones and is overlain by the Hartselle, Bangor Limestone, Pennington, Breachitt, and Lee formations.

Strontium isotopes have been used to evaluate the sources of Sr in groundwater and to see if they changed over time. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and Sr concentrations have been analyzed in bedrock and water samples taken from the surface, the cave, and its main resurgence and resurgence. Water from both the dry and wet seasons were analyzed. Also, different growth layers of a stalactite were analyzed to evaluate long-term variations.

Significant variations are observed with $^{87}\text{Sr}/^{86}\text{Sr}$ ranging from 0.7082 to 0.7078 for limestone bedrock and from 0.71307 to 0.70837 for water. Sandstone of the Hartselle and Lee Formations have the highest $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, up to 0.7337. In contrast, limestone of the Kidder and Ste. Genevieve limestones have the lowest $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, near 0.7080; the limestone values are consistent with the seawater $^{87}\text{Sr}/^{86}\text{Sr}$ during the Mississippian Period when these rocks formed. All water samples are intermediate, indicating that they have mixed sources of Sr. Some changes in these over time are apparent. Waters from dripping speleothems have ratios closer to the limestone. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in a stalactite show only minor variations. Overall, the values of $^{87}\text{Sr}/^{86}\text{Sr}$ in water and the stalactite appear to reflect the paths of water flow and the degree to which the water interacted with bedrock of various types.

AIRFLOW AT THE DOYAL VALLEY ENTRANCE OF THE MAMMOTH CAVE SYSTEM, KENTUCKY: IMPLICATIONS ON CAVE CLIMATOLOGY

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Around-the-clock studies of airflow at the Doyal Valley entrance to Mammoth Cave, Kentucky, indicate that the temperature of outside air at ground level correlates most closely with movement of cave air at this site. Barometric pressure changes of multiple origin also affect

airflow. Change in humidity plays a minor role. Other factors are not significant here. Each main factor has been analyzed to show its contribution to airflow and its relation to the other factors. We suggest that this information can be used to advantage in controlling the climate of the cave.

Installation of sensors and a remote controlled airgate would allow for control from a central point. Such control could be automated to help achieve the desired changes in cave climate. A network of such controls operated over time would have a beneficial effect on the cave climate. These include modification of cave temperature, increased cave humidity, and increased ventilation of tourist routes, if desired, to reduce radon levels. If indicated for the protection of visitors, who may number a million a year, fans and in-cave baffles could be discreetly installed to augment natural flow.

HISTORY

BEYOND THE SUMP: THE BURNLEY MAP OF CARVERS CAVE

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Carvers Cave is a sandstone cave, ~35 meters long, at the foot of Daytons Bluff near downtown St. Paul, Minnesota. Containing a spring-fed lake, it became the "baptismal font" of Minnesota caving when explorer Jonathan Carver visited it in 1766-67 and subsequently published his account, one of the first descriptions of a cave in the Upper Mississippi Valley. Since then, the cave has gone through the cycle of being shut by talus and then dug open again several times per century.

Carvers Cave was most recently reopened with a front-end loader in 1977 by city officials and was thereafter secured with a steel door. Since then, a 2 m thick deposit has accumulated below the bluff, burying the door and deepening the lake. Although still accessible today through a small opening, the cave will again be lost to view early in the next millennium.

The 1913 reopening of Carvers Cave by Colwell, however, generated the most publicity. At that time, a journalist named Burnley drafted a conjectural map showing large rooms beyond the sump at the rear of the cave. Probing the sump with poles today, there is good reason to believe that Burnley's rooms exist. After failed scuba and pumping efforts to crack the sump in the 1990s, local cavers resorted to trenching the talus in the hope of draining the lake that fills the cave and exposing the rooms.

THE REDISCOVERY OF HEISKELL CAVE: A CONFEDERATE NITRE BUREAU WORKS

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Heiskell Cave is the Civil War name of a cave near Rose Hill area of Lee County, Virginia, within the boundaries of Confederate Nitre District No. 1. Payroll records for a saltpeter mining operation in this cave are known from October 1862 through August 1863. The exact location and modern name of this cave remained a mystery to speleohistorians until November 1994, when the names of three Civil War miners were matched between payrolls and cave graffiti. The inscriptions "John R. Fitts 1863," "A.P. Waterman Mar 7 1863," "A.P. Waterman March 10 1863," and "1863 Andrew J. Milbourn CSA March 24 1863" were found on the walls of Jones Saltpeter Cave and correlate with the Heiskell Cave payroll names of John R. Fitts (laborer) January-August 1863, Alfred P. Waterman (laborer) February-August 1863, and Andrew J. Milbourn (laborer) January-April 1863.

Other mining evidence observed includes piles of rocks culled from sediment, old sediment levels on walls, mattock marks, torch perch sooting, taley marks, and old leach vat cast piles.

Jones Saltpeter Cave is once again closed to visitation by cavers and researchers alike.

SURVEY & CARTOGRAPHY

SPELEOMORPH COMPUTER-ASSISTED CARTOGRAPHY

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As computer-assisted drafting becomes more popular with cave cartographers, the problem of entering and manipulating sketches becomes problematic. The optimum solution would be to have a computer program that would scale, rotate, and move the sketch on the computer to match the entered data. SpeleoMorph is the first program to fully automate this process. This talk discusses the Kolstad Algorithm, which is the key for achieving the non-linear transformations required, and presents the results from the SpeleoMorph program on a one-mile (1.6 km) long cave system.

CREATING A SUCCESSFUL COMPUTER GENERATED CAVE MAP WITH FREEHAND®

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As home computer hardware and software becomes cheaper and easier to use, graphics software is replacing the manual cartography methods used by cavers in the past. The use of FreeHand® software is one such package available to cave cartographers. Understanding how to set-up and execute using a variety of FreeHand® tools is essential in creating a successful computer generated map.

FreeHand® is an object oriented drawing application that is robust and boasts many more features than the original version that first appeared 12 years ago. Cross platform and menu driven, the latest version, FreeHand 8®, enables one to draw high quality cave maps and graphics. Creative tools like freeform tool and reshaping tool allow you to edit paths interactively without using Bezier control points. Transparency effects, blends, shadow tools, and graphics hose are just a few of the new features that can give your cave maps a professional look.

Computer generated maps have the advantage of easily adding color to a cave map. Proper use of color can add visual impact to your map. The use of color is added quickly and easily with graphics software. As more cavers start using FreeHand® and other illustration programs, computer generated maps will be the preferred choice and method to draw and display cave maps.

THE DEVELOPMENT OF A "GRID-STYLE FORM": A NEW WAY TO COMBINE CAVE INVENTORY WITH CAVE SURVEY

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Despite the diversity in objectives, forms, procedures and data reduction techniques, there are four basic types of cave inventory methods:

1) "whole cave, open-ended" methods, 2) "whole cave, checklist" methods, 3) "location-based, open ended" methods, and 4) "location-based checklist" methods. Each of these methods has its advantages and limitations. In the process of developing a cave inventory system for Sequoia and Kings Canyon National Parks, we have designed a new style of cave inventory form that has multiple advantages over many of the methods currently in use. Our "location-based, grid-

style" form is simpler and easier to use than standard "checklist style" forms. The grid-style form also facilitates the detection and recording of resource information in the cave and the data transfer and manipulation afterwards. Using this form, it is easy to combine cave inventorying with cave surveying or to return and inventory the cave after the mapping is complete.

PALEONTOLOGY

FOSSILS AND BONES FROM THORN MOUNTAIN CAVE, PENDLETON COUNTY, WEST VIRGINIA

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Thorn Mountain Cave is developed in the very fossiliferous, upper Devonian Helderberg Limestone. A collection of invertebrate fossils free from the limestone matrix was made in the 1950s and has been examined and identified. The fauna consists of brachiopods, crinoids, corals, and gastropods. Additionally, a few bags of floor matrix (primarily aragonite crystals) was also collected in the 1950s and has now been partially screened for bones. Preliminary identification of the fauna includes bats, shrews, and voles.

THE PLEISTOCENE PECCARY *PLATYGONUS VETUS* FROM POORFARM CAVE, POCAHONTAS COUNTY, WV

Fredrick Grady, Arlington, VA, Ray Garton, WV Geological Survey, Morgantown, WV & Marshall G Homes, Snow Shoe, WV USA

A virtually complete, articulated skeleton of the extinct peccary *Platygonus vetus* has been recovered from an obscure passage in Poorfarm Cave, Pocahontas County, West Virginia. *Platygonus vetus* dates from the early to middle Pleistocene at about 0.4 to 1.5 Ma. Based on other associated fauna, the Poorfarm specimen probably dates at the younger part of this time span. *Platygonus vetus* is much less frequently found than its younger and smaller relative, *Platygonus compressus*. The Poorfarm skeleton is only the second relatively complete skeleton of *Platygonus vetus* ever found in the United States. *Platygonus vetus* has also been found in other West Virginia caves such as Rennick Quarry Cave, Greenbrier County, Hamilton and Elias Davis Caves in Pendleton County, and, possibly, Bowden Cave in Randolph County.

VULCANOSPEOLELOGY

ESTIMATING DEPTHS AND VOLUMES OF LAVA TUBE PLUNGE POOLS – AN ONGOING STUDY

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Modeling thermal erosion in paraffin produces similar features to those commonly found in lava tubes. Of particular interest are extremely deep plunge pools melted into the paraffin "substrate". These paraboloid-shaped pits are only formed where plunge pools are stationary and the otherwise aggressive headward backcutting cannot occur. If we assume mature (not backcutting while active) lava plunge pools are dimensionally proportional to the paraffin models, the original depths of the pools are approximately twice their maximum pool width.

Ten mature plunge pools were studied in Kazumura Cave, Hawaii. Their sunken surfaces were measured to calculate the volume of contraction that had occurred during the slow cooling of the lava tube. Contraction volumes are figured using an equation for spherical segments. We can then calculate for the depth and volume of the pool, and test the feasibility of the depth estimate based on

twice the pool width. For some mature pools, depths calculated from contraction volumes are 9-25% deeper than depth estimated from pool width alone. Several reasons are given for discrepancy using the expected 9% contraction volume. Those fully mature plunge pools with shallower than expected contraction appear to have been partially filled by falling breakdown during their cooling, which would lessen their contraction volumes.

SOME UNUSUAL CAVES IN HAVO (HAWAIIAN VOLCANOES NATIONAL PARK)

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Recent exploration in HAVO turned up two unusual caves for which I had the good fortune to do photo-documentation. The first cave, Lae' apuki, is only 2.5 years old and formed from the Pu'u O'o flows from Kilauea. Portions of the cave were measured at 42°C. The cave has extensive mineral deposition, including white depositional stalactites up to a foot long. Longer stalactites seen in December had vanished by April, suggesting some of these minerals are short-lived. The second, unnamed cave was found in a 400-year-old flow. It contains massive amounts of red-tinted Pele's Hair encrusting stalactites and "stretched" stalactites. Above a 6m lava falls, a fist-sized clump hangs free from a stalactite, flapping in the cave wind. Additionally, portions of the cave are splattered with various colors of intrusive lava. Some of the "spattermites" also grade into thin strands of Pele's Hair.

STUDIES IN YOUNG LAVA TUBES OF HAWAII VOLCANOES NATIONAL PARK

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Recent work in Hawaii Volcanoes National Park has included exploration and analyses of features in recently formed lava tubes. During the last 13 years, numerous lava tube systems have developed between various vents and the sea, a straight-line distance of 11 km, in the active flow field on the southeast flank of Kilauea. Tubes on the coastal flats form by inflation of surface flows rather than by roofing over of lava channels. While some tubes were buried soon after their formation, a few others have remained accessible and have cooled sufficiently to allow exploration. Two caves near the coast have been a focus of our attention. The first, formed in 1995, provided us with samples of soda straws as well as secondary minerals. The second, active in 1996, contained spectacular stalactites, stalagmites, and other features composed of secondary minerals. Materials collected were analyzed with the cooperation of scientists at the USGS Hawaiian Volcano Observatory.

Mineral crystals such as ilmenite, magnetite, plagioclase, copper titanium oxide, and iron titanium oxide were identified by petrographic and scanning electron microscopic studies of soda straws. These studies demonstrate that straws form while tubes are active as well as during the initial cooling process. Minerals such as bloedite, thenardite, mirabilite, gypsum and others are often spectacularly developed on walls, floors, and roofs of young, hot caves. These relatively low-temperature-phase minerals are unstable and are observed to grow and dissolve as a result of changing environmental factors.

GEOPHYSICAL DETECTION OF ENTRANCELESS LAVA TUBES

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Entranceless lava tubes possess two characteristics that enable them to be detected by geophysical methods from the surface.

1. Volcanic rocks are weakly magnetic because they contain the mineral magnetite. A cavity in volcanic rocks, therefore, causes a distortion of the earth's magnetic field that can be measured with a sensitive magnetometer. However, the distance between the magnetometer sensor and the center of the void cannot be much larger than the void's diameter or detection may not be possible. Non-uniform fields from various causes, and magnetization caused by lightning strikes also limit the depth of detection.

2. Lava tube roofs generally lie a near-constant depth from the surface for long distances. This characteristic allows detection by gradient-array resistivity surveys. A circular tube may be reliably detected under favorable conditions provided the depth from surface to the ceiling is not more than the diameter. A major limiting factor is geologic noise mainly due to other small cavities in the area that are nearer to the surface. Natural-potential survey, another geophysical electrical-method, was tried in a few areas using the same survey grid as the resistivity surveys but was found to have limited application over lava tubes.

CONDUIT FLOW OF WATER IN VOLCANIC PSEUDOKARSTS

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Conduit flow of lava in some volcanic pseudokarsts is so commonly observed as to be taken for granted. Yet conduit flow of water in the same or similar pseudokarsts is omitted from conceptual diagrams and models of their hydrology. Due to a variety of factors, conduit flow of lava and of water are of different orders of magnitude here. Yet, much of the water supply of a town in Terceira (Azores, Portugal) is obtained from conduit flow through a lava tube cave, with municipal water works constructed in the cave. The extent of similar occurrences in Hawaii is unknown. However, Kaumana Cave demonstrates varying levels of conduit flow in response to different quanta of rainfall. It has striking parallels to karstic water flow, from a wetland or bog recharge area to floodwater filling of major sections of the cave. Due to increasing urbanization of some sparsely inhabited, "substandard" subdivisions on Hawaiian pseudokarsts, an increasing threat of groundwater contamination and pollution exists from such conduit flow. Groundwater dye tracing is increasingly needed in certain critical areas.

THE ROOTS OF VULCANOSPELEOLOGY KEYNOTE ADDRESS

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The American root of vulcanospeleology is in the Pacific Northwest, but an Italian root is more than 2000 years old. Only on Mt. Etna did lava tube caves exist in the geographic mainstream of Western civilization and culture. The first recorded visit to a volcanic cave in Japan was in 1203, but as late as 1959, studies of such caves were barely begun in Japan.

Participants in early European voyages encountered lava tube caves in Iceland, then other oceanic islands. Finally, they reached those of Hawaii in 1823. A map of Iceland's Surtshellir was published by 1757. In Hawaii, James Dana was the first American scientist to discuss such caves, but he was preceded by both British and American missionary-savants.

In the 1940s, Bischoff and Rhodenbaugh independently focused attention on lava tube caves of the Pacific Northwest. My 1963 *Caves of Washington* has been given credit for beginning descriptions of lava tube caves "in general" and for introducing much of today's terminology. However, it was only one part of a world-wide flowering of vulcanospeleology in the latter half of the century. Reflecting the dual roots of this new subsience, the 1st and 3rd International Symposia of Vulcanospeleology were in the Pacific Northwest; the 2nd, 4th, and forthcoming 9th in Italy at the foot of Mount Etna. They constitute the "cutting edge" of the field.

LAVA SURFACES AND FORMATION OF LAVA TUBES

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Recognition of types of lava surfaces is useful in understanding how lava tubes form. Pahoehoe, aa, and fracture (broken) surfaces are common. Sheared or grooved lava indicates that relative movement took place between two pieces of lava, at least one of which was still plastic during the movement. Separation of a crust from molten lava below it leaves spiky projections on the underside of the crust. Some stretched stalactites likely are spiky projections. Gas pockets may be lined with similar spiky projections. Presence of remelt glaze indicates that the surface was exposed to intense heat. Lenticular chips of earlier rock and stringy bits of spatter are commonly embedded in cast surfaces. A cast surface indicates cooling while in contact with some earlier formed solid. The thickness of a lava layer, defined by surfaces, relates directly to the amount of time required for the layer to have solidified. Black color of a lava surface indicates a lack of available oxygen at the time of cooling; red lava indicates that cooling occurred in the presence of steam. Identification of lava surfaces helps to reduce larger problems into simpler elements. Individual lava layers, and their surfaces, remain from the processes that emplaced the layers. Those processes are, in part, recorded on the lava surfaces. Observation of specific lava surfaces in walls around caves can clarify the overall formation mechanism. Surfaces of lava layers in a cave roof can tell certain details of the roof formation.

CHANNEL AND CAVE SYSTEMS OF THE PUHIA PELE FLOW, HUALALAI, HAWAII, AND ITS RELATION TO THE 1801 (HUEHUE) FLOW
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Hualalai, the only active volcano in its terminal alkali basalt phase on Hawaii, erupted last in 1801. The precise size of this flow was, however, unclear. With the exploration of the 10.8 km long Huehue Tube and the analysis of its geologic structure, a long-standing riddle was solved. The flow field formerly attributed to the 1801 eruption is a composite of three individual flows: the contemporary Huehue and Mystery Flows, and the underlying and older Puhia Pele Flow. The Huehue 1801 flow reached the ocean and formed a large lava delta, partly occupied by the Kona airport. The upper part of the flow is, however, covered by the Mystery flow, which originated about 50 m north of the inconspicuous Huehue vent from a low shield. Two caves are attributed to the Mystery Flow, Zoes Puka, 428 m long, and Puka-4-Cave, 292 m long. Both flows interacted. The Mystery Flow consists of shallow flows, grading from fast flowing pahoehoe to sluggish aa within a few hundred meters below the vent, transgressing much of the upper Huehue Tube and partly draining into it. The underlying Puhia Pele Flow was gas richer and, therefore, spatter cones and spatter ramparts formed along the vent fissure at 490 m msl. Below the vents, a large tube and trench system formed, which we now mapped

by DGPS. Several blockages occurred, causing the trench to overflow, forming two side channels. Below 80 m msl, a tube developed feeding a large delta about 10-15 m thick. The tube is only partly accessible because of ponding and collapse.

WAIPOULI AND KAMAKALEPO, TWO SECTIONS OF A LARGE AND OLD MAUNA LOA TUBE ON HAWAII

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Exploration and survey of a large tube near South Point, Hawaii, yielded several interesting results. Two large collapse holes, Lua Nunu O Kamakalepo (Pigeon Hole of the Common People) and Waipouli (Dark Waters), 560 m apart, give access to four individual caves (upslope to downslope): Kamakalepo (305 m long), Kamakalepo Makai (155 m), Waipouli Mauka (125.5 m) and Waipouli (260 m). The tube is up to 13 m high and 23 m wide. The lava is picritic tholeiitic basalt, with abundant large olivine phenocrysts. The tube is one of the oldest accessible in Mauna Loa lavas. In Waipouli, sea level is reached 34 m below ground. The tube is filled by a 200 m long lake, before the ceiling drops below the water level. After 127 m a large block, 12 m wide, 6 m high, and 8 m long, originally floating on the lava river, is jammed into the ceiling. The water is 10 m deep and a halocline is found at its bottom. We found an individual whale backbone in the water. Next year we will conduct a diving expedition to explore the 600 m long section remaining to the seashore. The Kamakalepo sections feature splendid archeological remains (Bonk 1967), among them two large defense walls and over 100 sleeping platforms. Mauka, a very narrow crawl, leads into a 111.5 m long continuation. Charcoal shows that it was already visited by ancient Hawaiians, a remarkable deed. It is geologically unclear why this large tube simply pinches out upslope and between the entrances.

ROCK RING/LAVA TUBE RELATIONSHIPS ON HUALALAI VOLCANO, HAWAII

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Two rock rings are found in a prehistoric flow (2140 years BP) on the northwest rift zone of Hualalai volcano at elevations of 290-270 m msl. These rings have been called collapsed tumuli by Kauahikaua, who hypothesized that they formed over widened parts of a tube. Following collapse, vertical flexure of this material in response to variations in lava flowing within the tube resulted in deposition of a shattered rock ring at the perimeter of the collapse. The Hualalai rock rings do not match these observations. Surveys of the tubes beneath the rings show that the tube traverses the eastern perimeter of the lower ring rather than passing beneath it and a bifurcated tube passes beneath the upper ring with both arms of the branched tube terminating beneath trenches in the floor of the ring. Tube widths beneath the upper ring are up to 9 m while the diameter of the ring is about 100 m. Evidence of a pre-existing, widened tube that led to development of the ring has not been seen in the existing tubes.

KA'ELEKU CAVERNS AND OTHER RECENT SURVEY ACTIVITIES IN LAVA TUBES ON MAUI

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For the past two years, members of the Hawaii Speleological Survey have started surveying caves on the lower slopes of Haleakala on the island of Maui. Along its East Rift Zone is where the last major stage of volcanics on the island ended some 10 ka. It is here that Ka'elegu Caverns was formed in a flow that has been radiocarbon dated at 30 ka.

In January-February 1998 and April 1999, there were several survey trips into Ka'elegu Caverns. This is Maui's largest lava tube and it is currently a cave-for-pay operation run by Maui Cave Adventures near Hana. About 3 km have been explored and mapped to a depth of 220 m. Exceptionally "daggerlike" lavacicle ceilings and "botryoid" formations are in the upper portions of the cave.

This April, exploration and mapping has started on the dry southern slopes of Haleakala. An 8 m deep skylight entrance near the coast gives access to a large lava tube. A couple hundred meters downslope leads to a sump that probably connects to the ocean. Mapping has started upslope in this lava tube, which is quite large and has passages up to 10 m in diameter. We are just beginning to study and understand these older lava tubes on the "Valley Isle" of Maui.