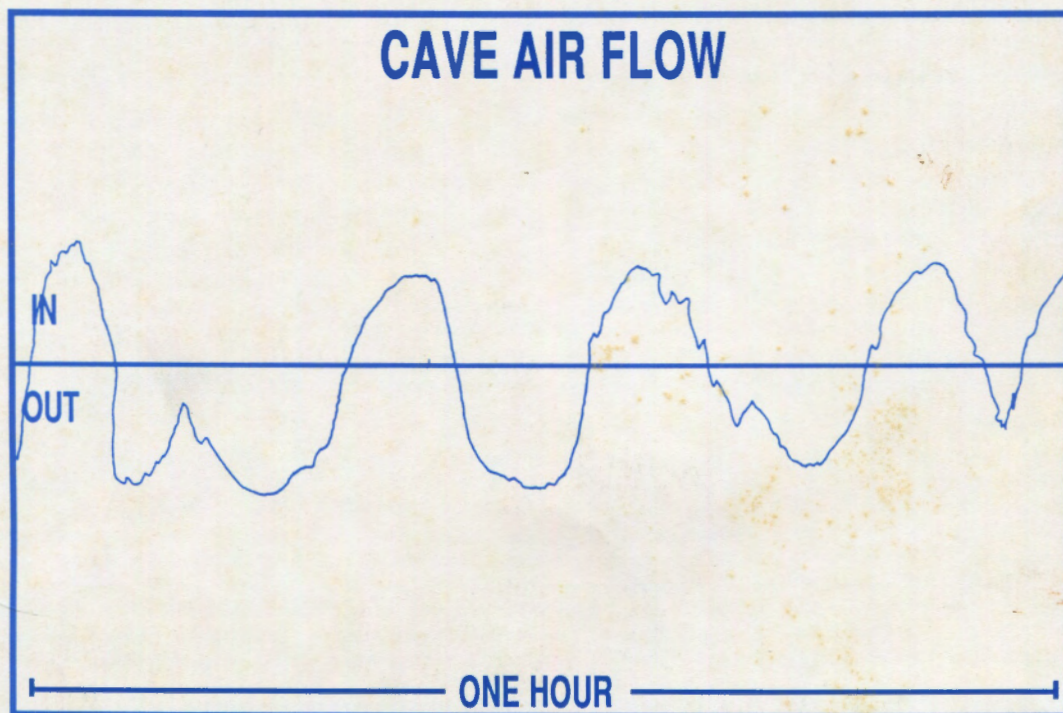


THE NSS BULLETIN

Journal of Caves and Karst Studies



Volume 53 June, 1991 Number 1

Published by

The National Speleological Society

ISSN 0146-9517

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The NSS Bulletin (ISSN 0146-9517) is published semiannually by the National Speleological Society, Inc., Cave Avenue, Huntsville, Alabama 35810. The annual subscription fee, worldwide, by surface mail, is \$18 U.S. Airmail delivery outside the United States of both *The NSS NEWS* and *The NSS Bulletin* is available for an additional fee of \$40 (total: \$55); *The NSS Bulletin* is not available alone by airmail. POSTMASTER: send address changes to *The NSS Bulletin*, Cave Avenue, Huntsville, Alabama 35810.

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ATMOSPHERIC PRESSURE CHANGES AND CAVE AIRFLOW: A REVIEW

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Atmospheric pressure changes play an important role in the movement of air in and out of caves of large volume. These barometric movements are independent of convective airflow or "chimney effect," which is due to change of external temperature. On a tracing of barometric pressure, variations may appear as random movements or may follow a rhythmic pattern. The period of patterned oscillations, if present, may range from a duration of several weeks to less than one second. They may be characterized as weather cycles, diurnal tides, acoustic-gravity waves or infrasound vibrations. Several varieties will often be superimposed on one another on the tracing from a sensitive barograph. Airflow in the entrance passage of many caves is similar in period to external atmospheric waves. It appears that many phenomena reported as cave breathing and cave resonance may be related to variations in atmospheric pressure.

INTRODUCTION

Barometric pressure at the entrance to a cave is constantly undergoing change. The atmosphere itself is a tossing sea of air, with layers shifting and streaming across the earth's surface, altering the pressure. Penetrating and engulfing this atmosphere are a variety of wave-like structures that keep it locally in motion. The cave is buffeted by disturbances in air of different wavelengths and amplitudes, coming from different directions on the horizon, striking at various vertical angles. These vibrations often travel long distances from a variety of sources. Many of these changes in air pressure will have an effect on cave airflow.

The association of caves with air movement resembling respiration has been observed for centuries. In both Latin and Greek the very words are related. Root words for "cave" and "breathing," *speos* and *spiro*, for example, are etymologically related through *speis* and *speus*, hypothetical Indo-European roots (Donald Martin, pers. comm.). Such associations are found also in classic literature. "It is as if the tenebrous caverns were the mighty lungs of mother earth." And, "Aeolus, the god of storms, confined all the winds in his vast throne room" (cited by Hovey from the Classics, 1882).

It is not surprising that the pressure changes show great variation since over 20 kinds of atmospheric waves are known (Beer, 1974). Many, but not all, of these waves will affect barometric pressure at ground level (Cook & Young, 1962). The cave can be thought of as an oversized container with rigid walls and narrow mouth. Air flows in and out of the mouth in response to change of pressure. When inside and outside pressures are nearly equal, the flow may stop and reverse direction with each pressure change. These reversals, caused by pressure disturbance of any wavelength, may occur rarely or with great frequency. Airflow in cave

entrance passages is often measured from one reversal to the next.

Variations in barometric pressure that occur in repeated patterns are of special interest. A number of these types are illustrated in this article. Long periodic changes are referred to as cycles while short periods appear as oscillations or vibrations. The wave spectrum is continuous across the scales except for a point between Acoustic and Gravity waves, at which no waves travel. At the break point, which is close to 5 or 10 minutes, the character of the wave changes. This gap is the Väisälä-Brunt discontinuity. These Gravity Waves are also called Buoyancy Waves to distinguish them from Gravitational Waves predicted by the theory of relativity (Gossard, 1960) (Fig. 1).

MACROSCALE

*The synoptic cycles (weather patterns) and daily tides
Period 6 hours to several weeks (limits not fixed)*

The large swings commonly observed on the standard barometer or barographic tracings are due to the weather cycles. These cycles are associated with the successive passage of high and low pressure zones and their associated frontal systems moving generally from west to east as shown on the weather map. In the Temperate Zones, cyclonic (low pressure) and anti-cyclonic (high pressure) air flow patterns dominate the weather scene. These cycles usually follow one another every three to seven days in an orderly progression, but occasionally one system may dominate the local weather picture for several weeks. They are the major cause of barometric flow of air into and out of caves. This was noted quite early in Eisrieswelt of Tennegebirge in Salzburg (Gressel, 1958), and in other European caves (Geze, 1965; Trombe, 1967). In general, these variable weather systems are weaker and become less important in the Tropical Zone.

Pioneering studies of weather cycles at caves in America

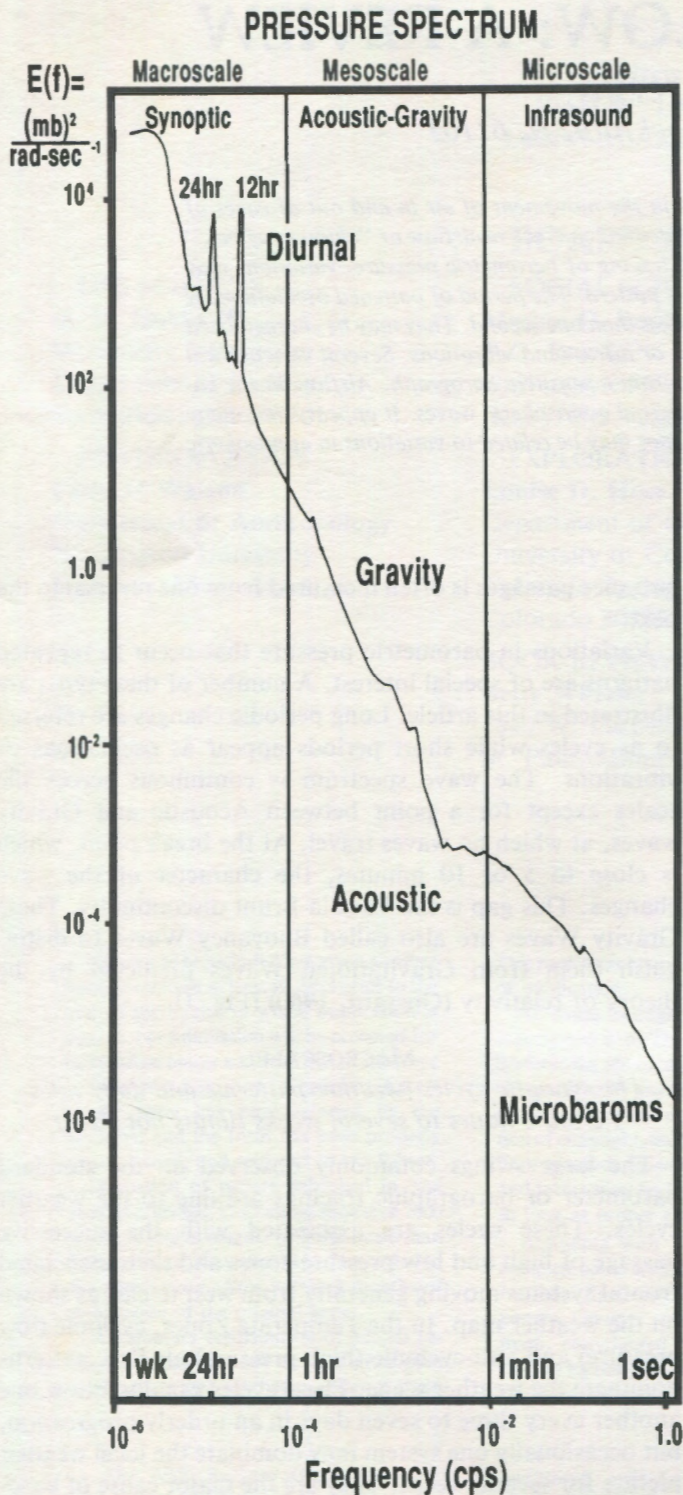


Figure 1. Spectrum of Pressure Waves in the Atmosphere.
 (Courtesy of Earl E. Gossard, William H. Hooke, and Elsevier Scientific Publishing Company, Amsterdam.) These representative values were recorded at San Diego, California. The range of audible sound is off the graph, down and to the right.

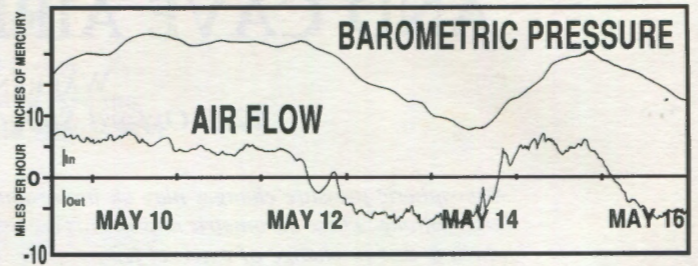


Figure 2. Cave Airflow due to Weather Cycles and Diurnal Tides.

Jewel Cave, South Dakota (courtesy of Herb and Jan Conn). Cave airflow reflects the changes in barometric pressure associated with the weather cycles during a quiet week in May. On most days, there is also a rise and fall in flow between 6:00 P.M. and midnight. This daily variation is a response to diurnal tides. The continued flow of air after several days of stable high pressure shows that the cave is slow to come into equilibrium. This suggests a large cave with relatively small openings.

were made at Wind and Jewel caves in South Dakota (Conn, 1966) (Fig. 2). With the aid of a homemade anemograph, a pendulum-type anemometer, the investigators were able to show a good correlation between cave wind and external pressure change. From their measurements of changing airflow, they postulated a cave volume of 56 million m^3 (2 billion ft^3) for Wind Cave and up to 112 million m^3 (4 billion ft^3) for Jewel Cave. They considered the effects of friction on cave air flow, both at the entrance and inside the cave. Also studied was the flow at a noisy constriction, deep in Jewel Cave, called Hurricane Corner, at which high air speeds were registered. Air movement was utilized repeatedly by these explorers to aid in the discovery of new cave passages (Conn & Conn, 1977).

At times, air flow tracings vary significantly from those of the recording barometer (Gerlier, 1905). This is particularly so in large caves with small openings (Geze, 1965; Trombe, 1952). Wind reversals often lag behind external pressure changes. Some caves will respond quickly to impending weather change since they are more sensitive than a standard barometer which is damped to some degree. Other caves are more susceptible than the barometer to surface winds which, if severe, will foul the airflow tracing. The tracing made at a cave with large volume and small opening most closely resembles that of a microbarometer.

Not only the air in caves but also that in some wells and mines responds to synoptic pressure change. In the Canton of Geneva, Switzerland, barometric flow was observed at water wells which blew air in and out (Gerlier, 1905). A prehistoric flint mine in chalk in England had a large flow. In Pays de Caux, Seine Maritime, France, well-like shafts sunk to mine underlying beds of chalk, were found to ex-

change large volumes of air (Idrac & Cauille, 1931). With ingenious instruments of their own design, this team of scientist and engineer recorded the volume of airflow, direction, time and temperature (Cauille, 1936). There was a local folk saying about these pits.

Puits soufflant—Pluie venant.

Puits aspirant—sec arrivant.

(Pits blowing—rain coming;

Pits aspiring—dryness arriving.)

Both local observers and scientists were able to check on the use of these pits to predict the weather. It was confirmed that these artificial pits, which tapped underground spaces in boulders, were more sensitive to changes in the weather than the hand-crafted barometers (Idrac & Cauille, 1931). Underground air volume of 2 million m³ (70 million ft³) were estimated by these researchers from the changing air flow. Further information on air movement in wells and pits was collected and analyzed in subsequent studies (Crestani, 1937).

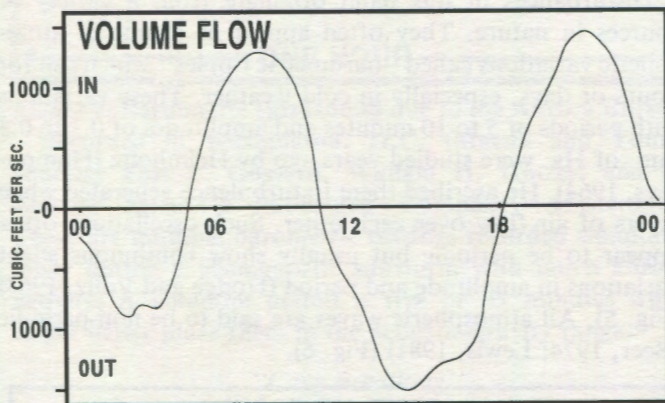


Figure 3. Cave Diurnal Airflow Volume.

Mullamullang Cave, Nullarbor Plain, Australia (after Wigley). The volume of flow of air is shown for 24 hours. Airflow in this cave is dominated by the diurnal tides. The air flows in each direction for two periods of each 24-hour day. Airflow into the cave is noted during the late morning and the evening hours. Outflow occurs at night and during the afternoon.

Atmospheric Tides Due to Solar Radiation

Atmospheric tides cause daily variations in pressure and are usually of much lower amplitude than the weather cycles. In some ways they resemble the ocean tides of lunar origin from which they are named. These diurnal fluctuations are caused by broad, standing and westward moving waves with periods of 6, 8, 12, and 24 hours. They are caused by the heating action of the sun directly on the atmosphere and heat reflected from the earth's surface. Atmo-

spheric tides are prominent in the Tropical Zone and parts of the Temperate Zone closest to the tropics. This type of flow was found in caves in Venezuela and Australia (Jahn, 1968; Michie, 1984) (Fig. 3).

Daily pressure variations due in solar radiation do not follow the same pattern as daily variations in temperature (Hines, 1972). A typical tidal curve has two maxima and two minima in 24 hours whereas the temperature curve has only one which is close to midday. In a common type of diurnal curve, the pressures are greatest at 10 A.M. and 10 P.M. and least at 4 A.M. and 4 P.M. (Bowen, 1982). In other words, at the point at which the temperature curve soars upward in midday, a large down-dip occurs in the pressure curve. This puzzling mid-day inversion is now known to be due largely

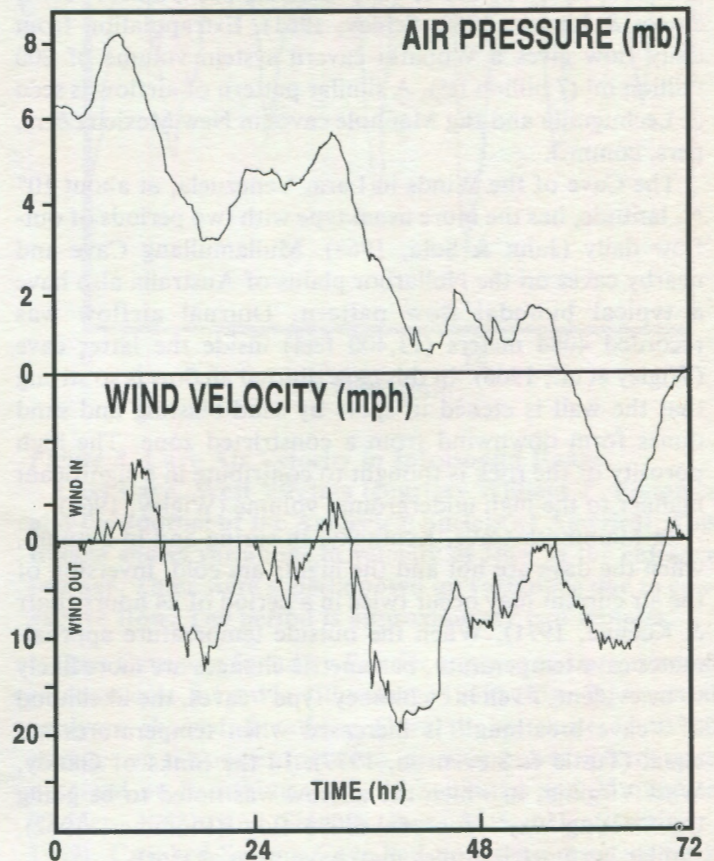


Figure 4. Cave Flow due to Multiple Causes

Blowhole No. 3e. Wupatki, Arizona (after Sartor and Lamar, courtesy The Rand Corporation, Santa Monica, CA). The barometric pressure is gradually dropping over a three-day period from a passing weather system. The blowhole is blowing out more air than it is taking in. The 24-hour, peak-and-valley, diurnal waves are to be seen in both tracings. Airflow tracing shows some short regular disturbances several times per hour as well as irregular variations probably due to surface winds.

to absorption of the sun's energy by ozone, the so-called "ozone shield," and by water vapor in the atmosphere. Some additional loss of energy results from reflection and radiation due to the brightness (albedo), of the earth's surface. Mid-day solar heating causes strong vertical acceleration of the air layers and pressure drops at ground level. Atmospheric tides are more prominent in winter than in summer (Fig. 4).

In the mountainous regions of the western United States, the diurnal wave has only two prominent cusps, a maximum at 8 to 10 A.M. and a minimum at 5 to 7 P.M. (Deland & Kessler, 1982). Variations are found with the higher elevation of the sites and the configuration of the mountains. At Wupatki Earth Cracks, Arizona, this type of diurnal flow is prominent (Bridgemon et al., 1976). The daily extreme pressures differ by about 4 mb (Lamar, 1964; Sartor, 1964; Sartor & Lamar, 1962; Schley, 1961). Extrapolation from daily flow gives a Wupatki cavern system volume of 200 million m³ (7 billion ft³). A similar pattern of airflow is seen at Lechuguilla and Big Manhole caves in New Mexico (Zerr, pers. comm.).

The Cave of the Winds in Lara, Venezuela, at about 10° N. latitude, has the more usual type with two periods of out-flow daily (Jahn & Sola, 1968). Mullamullang Cave and nearby caves on the Nullarbor plains of Australia also have a typical bimodal flow pattern. Diurnal airflow was recorded 4084 meters (13,400 feet) inside the latter cave (Wigley et al., 1966). In this cave diurnal airflow is so strong that the wall is etched in spots by sand-blasting and sand dunes form downwind from a constricted zone. The high porosity of the rock is thought to contribute in a significant manner to the high underground volume (Wigley, 1967).

In Mammoth Cave, Kentucky, in spring and in autumn, when the days are hot and the nights are cold, inversion of the air current may occur twice in a period of 24 hours (Barr & Kuehne, 1971). When the outside temperature approximates cave temperature, barometric changes are more likely to be evident. Even in "chimney-type" caves, the likelihood of "cave breathing" is increased when temperatures are equal (Tuttle & Stevenson, 1977). In the Sinks of Gandy, West Virginia, in which the airflow was noted to be going the "wrong way" for convective flow (Plummer, 1962), similar barometric forces may have been at work.

Airflow at Jewel Cave, South Dakota, showed a rise and fall each evening over a seven-day period (Conn, tracing, May, 1966). Wind and Jewel caves lie between 43° and 44° North latitude. The diurnal pattern, which is strong near the Equator, is likely to be weak because of the northerly location of these caves. At Lechuguilla Cave, Carlsbad, New Mexico, the barometric curve on August 2, 1987 registered a strong upward swing followed by a single downward cusp. From this, an initial estimate of cave volume of 20 million m³ (700 million ft³) was made (Zerr, pers. comm.).

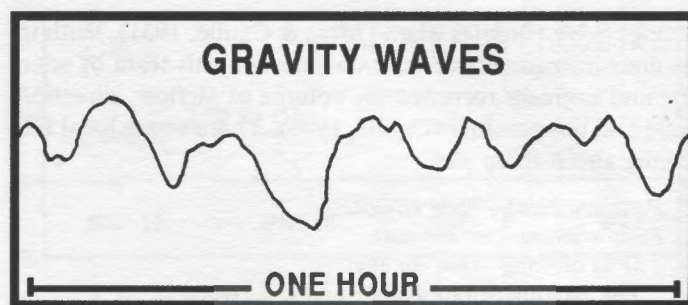


Figure 5. Barometric Gravity Waves

Weather Bureau, Washington, D.C. (after Hodge and Volz). This barometric tracing shows a variety of gravity waves in winter. These originate not only with oscillations of the jet stream but also with storm fronts and possibly in association with areas of clear air turbulence.

MESOSCALE

Acoustic-Gravity Waves

Variations from 3 minutes to 3 hours approximately

Disturbances in this band originate from a variety of sources in nature. They often appear as chains of atmospheric variations called "barometric ripples" which run for hours or days, especially in cold weather. These variations with periods of 5 to 10 minutes and amplitudes of 0.1 to 0.3 mm. of Hg. were studied years ago by Helmholtz (Humphreys, 1964). He ascribed them to turbulence generated when layers of air flow over each other. Such oscillations often appear to be periodic but usually show continuous slight variations in amplitude and period (Hodge and Voltz, 1964) (Fig. 5). All atmospheric waves are said to be non-periodic (Beer, 1974; Lewis, 1981) (Fig. 6).

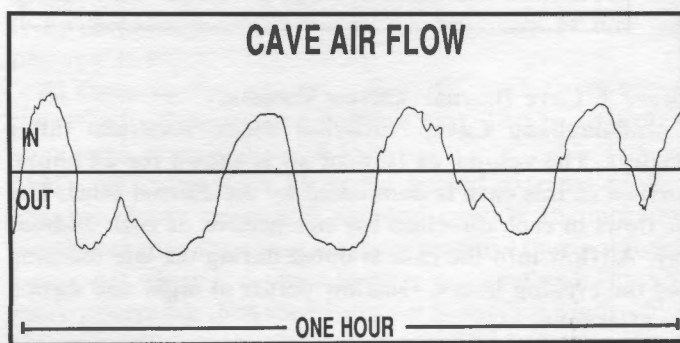


Figure 6. Cave Airflow resembling Gravity Waves.

Coldwater Cave, Iowa (Lewis; Tom Backer and Jim Klager, engineers; Barber-Colman Co. recorder; Pete DeVries, Coldwater Project Director; Kenneth and Wanda Flatland and sons, cave owners). This tracing shows a train of airflow waves which are similar to gravity waves in the atmosphere from the jet stream. This was recorded with a hot wire anemometer in winter.

Other atmospheric disturbances are generated by air streaming across north-south trending mountain ranges, such as the Rocky Mountains and the Andes, sometimes called lee waves. There may be loci of violent activity in rotor clouds in the lee of such mountain ridges. Some variations in mid-continent and along the eastern seaboard are associated with the oscillations of the jet stream. Acoustic-gravity disturbances are also generated along active storm fronts, in tornados, and may be found near clear air turbulence. Short bursts of acoustic-gravity waves generated by nuclear explosions may travel thousands of miles, even around the earth (Yamamoto, 1956). Waves from the Aurora Borealis may also travel long distances (Maeda and Young, 1966) (Fig. 7).

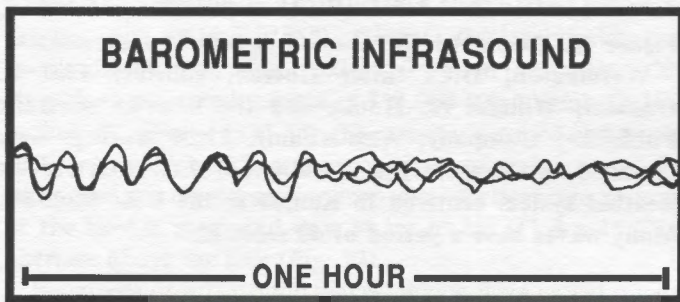


Figure 7. Barometric Infrasound due to the Aurora Borealis Recorded in Washington, D.C. (Maeda and Young, courtesy Earl E. Gossard, William H. Hooke; and the Elsevier Scientific Publishing Company, Amsterdam). These are multiple barometric tracings recorded simultaneously during a geomagnetic substorm with much auroral activity. A common period is five or six minutes which might better place them in the acoustic-gravity range.

“Cave Breathing”

There was an early report of an Italian cave near Monrupino that was puffing or panting (Pipan, 1955-56). Such air movements have at times been overlooked in the observations (Cigna, 1965). In America, reversals of airflow in a few seconds or a few minutes are referred to as *cave breathing* (Faust, 1947). In European literature, cave breathing refers to flow that may last for hours before reversal is noted (Wigley, 1967).

Breathing Cave

In the United States, the study of cave breathing originated near Burnsville, Virginia at Salt Petre Cave. The cave has been renamed Breathing Cave. In a crawlway near the entrance the air was observed to flow in for a minute, pause a minute, and then reverse. A complete cycle took four minutes. On five subsequent occasions the cycle ranged from 8 to 20 minutes in duration (Faust, 1947). On May 7, 1955, the cycles were approximately one minute in duration (Moore, 1964). Other variations in period were noted (Cour-

noyer, 1954). In 1955 the oscillations of North Passage and Breathing Passage were similar in amplitude but out of phase with each other (Cournoyer in Moore, 1964). These passages go to the left and right off the entry passage (Moore, 1978). The apparent anomaly of flow in opposite directions in the two branches can be explained by waves which originate outside the cave.

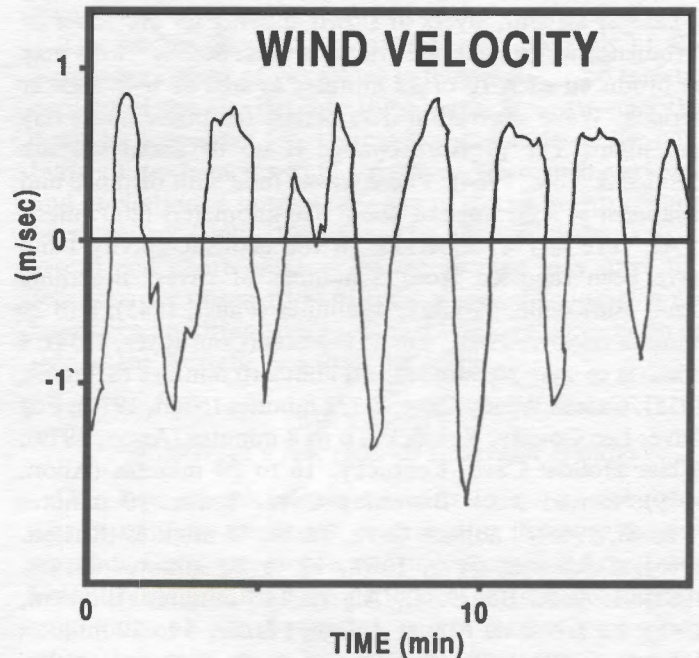


Figure 8. Cave Air Velocity in Infrasound Range.

Cass Cave, West Virginia (courtesy William T. Plummer and the Journal of the Acoustical Society of America). This tracing shows variations in velocity of flow in the entrance passage. These were superimposed on variations due to convective flow. The period is approximately two minutes.

Cass Cave was found by Fourier analysis to show marked resonance at 8.1 mHz (Plummer, 1969) (Fig. 8). Spectral analyses showed Breathing Cave to be clustered at 20 minutes on the power spectrum. Further power spectra were obtained on Breathing Cave, 16.2 minutes and 25 minutes (Eckler, 1963), and Sinnett Cave, 86.5 mHz (Plummer, 1969). Crooked Swamp Cave had no strong resonant peak in the period studied (Eckler, 1963).

At Cassell Windy Cave, West Virginia, the atmospheric fluctuations at times are made visible by fog. “The observer will behold to his greatest consternation a tongue-shaped cloud of fog emerge from the entrance and float across the ground for about one and three-quarters of a minute. Suddenly further progress stops and the air currents change for no apparent reason, causing the fog to retrace its path into the opening. Time of inhale [sic] was measured to be similar to the time of exhale” (Nigh, 1970).

At a talus cave near Baker Lake, Skagit County, Washington, a definite layer of cold air was noted in low lying cracks with snow in them in January. Several times a distinct layer of fog was noted to form in a low spot and then dissipate (Senger, 1981).

One major source of waves in the 6 to 20 minute range is the jet stream which oscillates in flowing waves about 20 km from crest to crest. The areas of contact of this fast-moving stream of air with layers of slowly moving air are zones of turbulence which generate gravity waves. Strong waves may be produced each 10 or 12 minutes as well as with shorter periods. Wave generation may persist for many hours day and night. The pressure change is up to about 0.1 mb (Hodge & Volz, 1964). These waves fade with distance and disappear at a distance of about 320 kilometers (200 miles).

Air reversals with periods in the acoustic-gravity band have been reported from a number of caves: Breathing Cave, Burnsville, Virginia, 4 minutes (Faust, 1945); 8 to 20 minutes (Eckler, 1963); 4 to 25 minutes (Cournoyer, 1954); 4 minutes to over 30 minutes and about 10 minutes (Schmidt, 1958); Cassell Windy Cave, 3-1/2 minutes (Nigh, 1970); Fog Cave, Lee County, Kentucky, 6 to 8 minutes (Anon, 1979); White Hollow Cave, Kentucky, 16 to 20 minutes (Anon, 1979); Round Rock Breathing Cave, Texas, 90 minutes (Russell, 1965); Laubach Cave, Texas, 45 minutes (Russell, 1965); Coldwater Cave, Iowa, 12 to 20 minutes (Lewis, 1981). L'Anou Boussouil, Algeria, 40 minutes (Birebent, 1948); La grotte de Niaux, Ariège, France, 6 to 30 minutes (Andrieux, 1981) (Fig. 9).

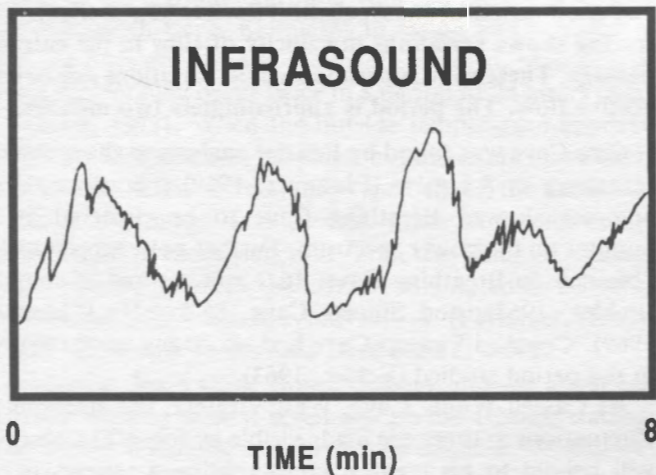


Figure 9. Barometric Infrasond of Two Types.

Switzerland (after Saxer). This strip shows several infrasond waves with a duration of over one minute with numerous small microbaroms superimposed on the longer waves.

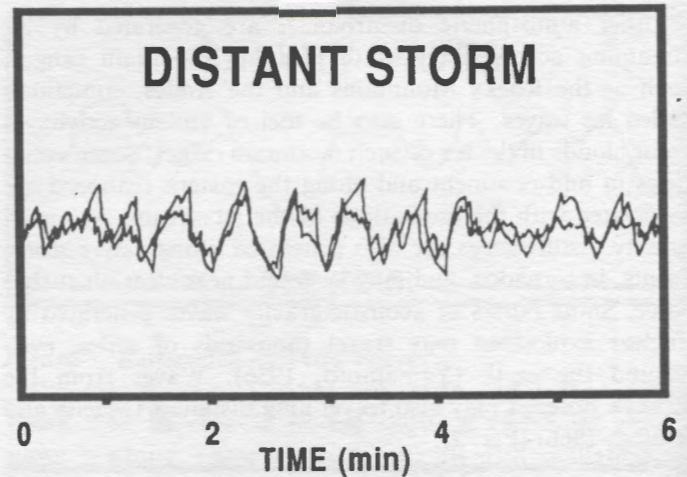


Figure 10. Barometric Infrasond-distant Thunderstorms. Washington, D.C. (after Goerke, courtesy Earl E. Gossard, William H. Hooke and the Elsevier Scientific Publishing Company, Amsterdam). These tracings were recorded simultaneously in Washington, D.C. from a severe weather system centered in Kansas in the U.S. Midwest. Many waves have a period of 40 seconds.

MICROSCALE (INFRASOUND)

Variations from 3 seconds to 3 minutes approximately

Infrasond is the name given to disturbances in the atmosphere of short period. This includes those arising from winter storms at sea called microbaroms. Infrasond waves can travel long distances with little loss of energy and are currently monitored by a world-wide network of stations for evidence of atomic explosions (Donn, 1963). Infrasond can originate from many natural and artificial processes: volcanic and man-made explosions, earthquakes, big guns at sea and even traffic noises (Fig. 10).

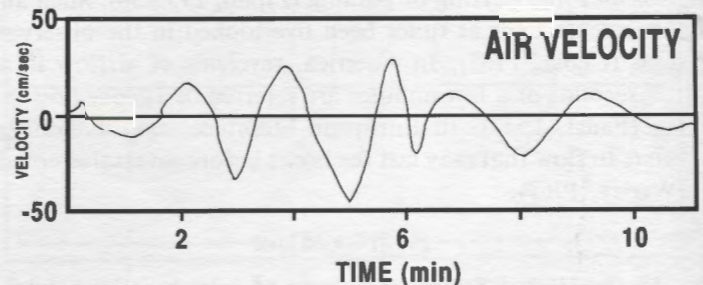


Figure 11. Cave Air Oscillations in Infrasond Range.

Grotta Gigante, Italy (after Polli), August 26, 1951, at 19 minutes past 5:00 P.M. The barometer was dropping slightly and the sky was overcast. Six gentle reversals were recorded in 11 minutes in the entry passage. The usual period is slightly less than 2 minutes. Hundreds of such vibrations of variable duration were recorded during several seasons of observation.

Some waves originate high overhead in the displays of northern lights. Infrasound waves from such supersonic auroral discharges 100 km high may have a period of 20 to 80 seconds (Chrzanowski et al., 1961) and may take 7 minutes to reach the ground (Wilson, 1967). Earthquakes and tornados may generate similar waves (Cook, 1962) (Fig. 11).

Gigante Grotto

Gigante Grotto is the primary site for observation of infrasound. It lies about six kilometers north of Trieste in the Italian karst. The grotto has been a show cave for many years. According to a 1908 poster, visitors were charged for a candle or acetylene lamp, whichever they wished to use, to see the cave (Morris, 1958). Gigante Grotto consists primarily of one large room, 160 x 110 x 60 m (525 x 360 x 200 ft) with an estimated volume of 350,000-500,000 m³ (12-17.6 million ft³) (Polli, 1955-56). This room is connected to the surface by two short passages, only one of which is used for entry, and it is closed with an iron gate. Airflow into and out of the cave is measured in a 30 by 40 cm (11.8 x 15.7 in) aperture above the gate (Fig. 12).

Hundreds of infrasound waves, which were called microbaroms, were recorded over many hours with a period which varied from 20 to 100 seconds. Within that band they seemed to be clustered in three groups. Through three seasons of observation, these variations were found to be present on 11 out of 12 weekend visits (Polli, 1955-56).

Infrasound waves had been recorded and studied by the regional meteorologist for years along with other

parameters of local weather and climate. Among other accomplishments, he had constructed an improved recording microbarometer and published tracings (Polli, 1949). The weather station in Villa Opicina, 3 km southeast of Gigante Grotto, was used for microbarometric correlation. He was able to state unequivocally that the variations observed in the entryway of the cave were the same as the microbarometric waves recorded at the weather stations.

The studies showed that airflow and reversals of flow were independent of variations in temperature and moisture content of the air. Because some waves were stronger than could be accounted for, there was speculation on the possibility of resonance within the cave. Were such variations and oscillations a normal function of the air in entry tunnels of all caves? (Polli, 1955-56). The ellipsoidal shape of the grotto and short passages to the surface may have been felicitous for observation of these waves. The location may have been important since some air tides are stronger on one side of the Adriatic Sea than the other.

MICROSCALE

Period from a few seconds to several minutes

One type of microscale waves is called microbaroms. Chains of these waves are generated in the surging ocean waves during winter storms and may persist for days (Saxer, 1945). They usually have periods of 5 to 6 seconds and amplitudes of 1 to 5 microns, except during great storms when they may reach 100 microns. Such waves travel at approximately the speed of sound in air (Cook, 1962). They are the equivalent in air to microseisms which are seismic

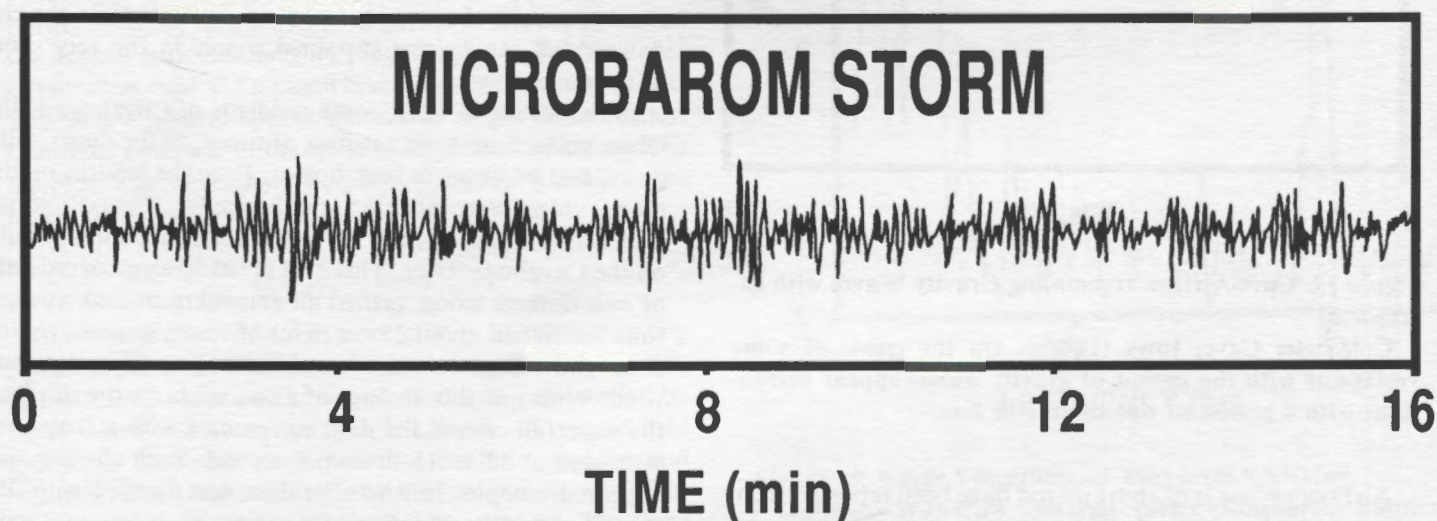


Figure 12. Barometric Infrasound-Microbaroms

Boulder, Colorado, November 29, 1968 (courtesy Earl E. Gossard, William H. Hooke and the Elsevier Scientific Publishing Company, Amsterdam). This type of wave is associated with stormy conditions at sea, especially in winter. They occupy a narrow band with a period of five or six seconds. These waves travel long distances through the atmosphere with little loss of energy. A similar set of vibrations is found in the earth known as microseisms.

vibrations in rock and are of the same origin. The two vibrations have the same period (Saxer, 1945). These waves may travel long distances sandwiched between layers of the upper atmosphere by a process called ducting. Waves from a storm in the North Sea were recorded in Switzerland, a distance of 1400 km (Saxer, 1945) and have been recorded in Colorado (Fig. 13).

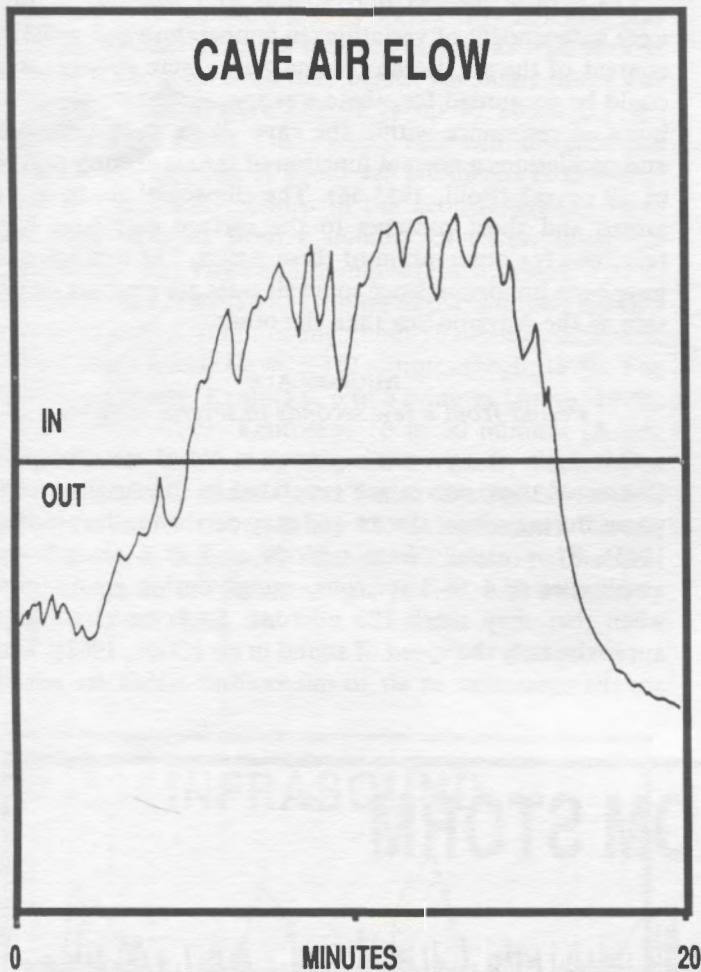


Figure 13. Cave Airflow resembling Gravity Waves with Infrasond.

Coldwater Cave, Iowa (Lewis). On the crests of some variations with the period of gravity waves appear oscillations with a period of one minute or less.

Airflow reversals of short period have been reported from many caves: La Grotte de Niaux, Ariège, France, spring and fall 18 to 20 seconds, winter 5 to 15 seconds (Andreieux, 1981); La glacière de Monthézy, 52 seconds (Browne, 1865); Breathing Cave, Virginia, 30 to 60 seconds (Moore, 1964); Gypsum Caves of Podolie, Ukraine, several tens of seconds

(Dubljanski, 1979); Dobrina Ice Cave, Slovakia, 90 to 100 seconds (Podzimek, 1958); La Gruta del Palmeto, N.L. Mexico, 60 to 200 seconds (Russell, 1965); Wupatki Blowhole, Arizona, 2 seconds (Schley, 1961); Coppermine Cave, Australia, 30 to 120 seconds (Michie, 1984); Crooked Swamp Cave, New Jersey, 78 to 80 seconds (Chapman, 1954); Cass Cave, 2 minutes (Plummer, 1962); Cass Cave, 2 to 2-1/2 minutes (Plummer, 1969); Coldwater Cave, Iowa, 55 seconds (Lewis, 1981).

Pressure variations in this range can be generated by lightning flashes and in the turbulent zones of storm systems. Reversals in Casparis Cave of 8 seconds duration were associated with a passing storm front (Dunn, 1956). At Papoose Cave, Idaho, at the lower entrance, there was an outrush of air followed by a big inrush while a front with a dry thunderstorm passed high overhead. Temperature and pressure were restored in an hour (Huppert, 1981). At Wupatki Earth Cracks, Arizona, a passing "dust devil" made a blip in the tracing indicating a high degree of sensitivity to air moving in a vortex (Sartor, 1962).

Very Short Infrasond

Regular Oscillations of 1 second or less Waterfalls and Cave Resonance

Periodic vibrations of a quite different sort can occur in this sub-acoustic range. At this wavelength, the regular waves have many characteristics of sound waves but are too low to have a definite pitch. They may be heard as rumbling, shaking or humming sounds such as those during earthquakes or felt as puffs of air on the face in crawlways near waterfalls. Strictly speaking, these vibrations are not due to a natural atmospheric pressure change. They require another source of energy to produce wave action in the air. A waterfall can be one sustained source in the very short infrasond range.

In the winter of 1841, some residents of Cuyahoga Falls, Ohio, noticed constant rattling, at times, of the doors, windows, and crockery in their homes. Even the tendrils on the grape vines were shaking rhythmically. The vibrations generally were ascribed to a 4 m (12-1/2 ft) dam newly-built on the Cuyahoga River. This 27.4 m (90 ft) long curved dam of oak timbers stood against an embankment that was unfinished. When about 15 cm (6 in) of water flowed over the dam, the village houses started rattling as if in a strong wind. With just this amount of flow, neither more nor less, the waterfall caused the dam to resonate with a frequency estimated at 12 to 15 times per second. Such shaking disappeared completely when the dam was damped with 250 tons of rock. The vibrations did not return under any conditions of flow (Loomis, 1843).

The vibration of natural waterfalls in Iceland, Canada, and the continental United States has been studied. These include Yosemite, Niagara (Canadian and American falls),

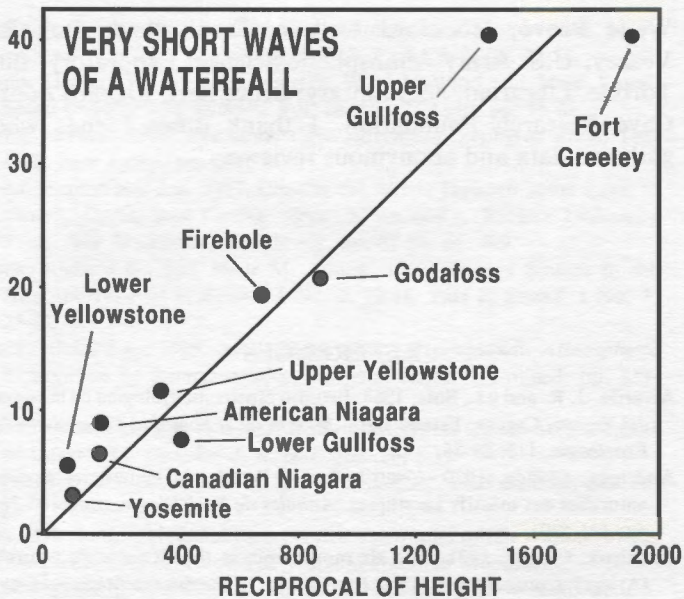


Figure 14. Seismic Vibrations of Waterfalls and Height.

Waterfalls of Iceland, Canada and the United States of America (after Rinehart). The inverse of the height in meters is plotted against the frequency in mHz. The tallest waterfalls vibrate at the lowest frequencies. The slope of the line is about 250 m/sec. The waterfall is vibrating in a quarter-wavelength mode.

Upper and Lower Yellowstone, Firehole, Godafoss, Upper and Lower Gullfoss, and Fort Greeley. A seismometer, HS-10 Geophone, placed on the rock near the falls, recorded the vibrations (Fig. 14).

When there were two separate falls, then two frequencies would appear on the tracings (Fig. 15). The period was proportional to the height (Rinehart, 1969). The reciprocal of the various waterfall heights plotted against the frequency of vibration yielded a straight line with a slope of 250 m/sec. This gave a general approximation of height to frequency. One fixed node was at the lip of the falls and an antinode at the foot. The wavelength was approximately four times the height of the waterfall.

HÖLLOCH CAVE

In Hölloch Cave in Switzerland on May 23, 1904, a strong rhythmic pulsation was observed in the air of a large room. In this room was a violent waterfall in a stream swollen by flood waters. Close to the falls, the needle of a hand-held altimetric barometer was seen to oscillate rapidly and regularly. The total amplitude of the oscillations was 18 to 20 mm and the complete period was one second. The same phenomenon was noted in all accessible parts of the cave. The rhythmic pulsation diminished in intensity in the passage leading toward the entrance and disappeared completely outside the cave (Rahir, 1905).

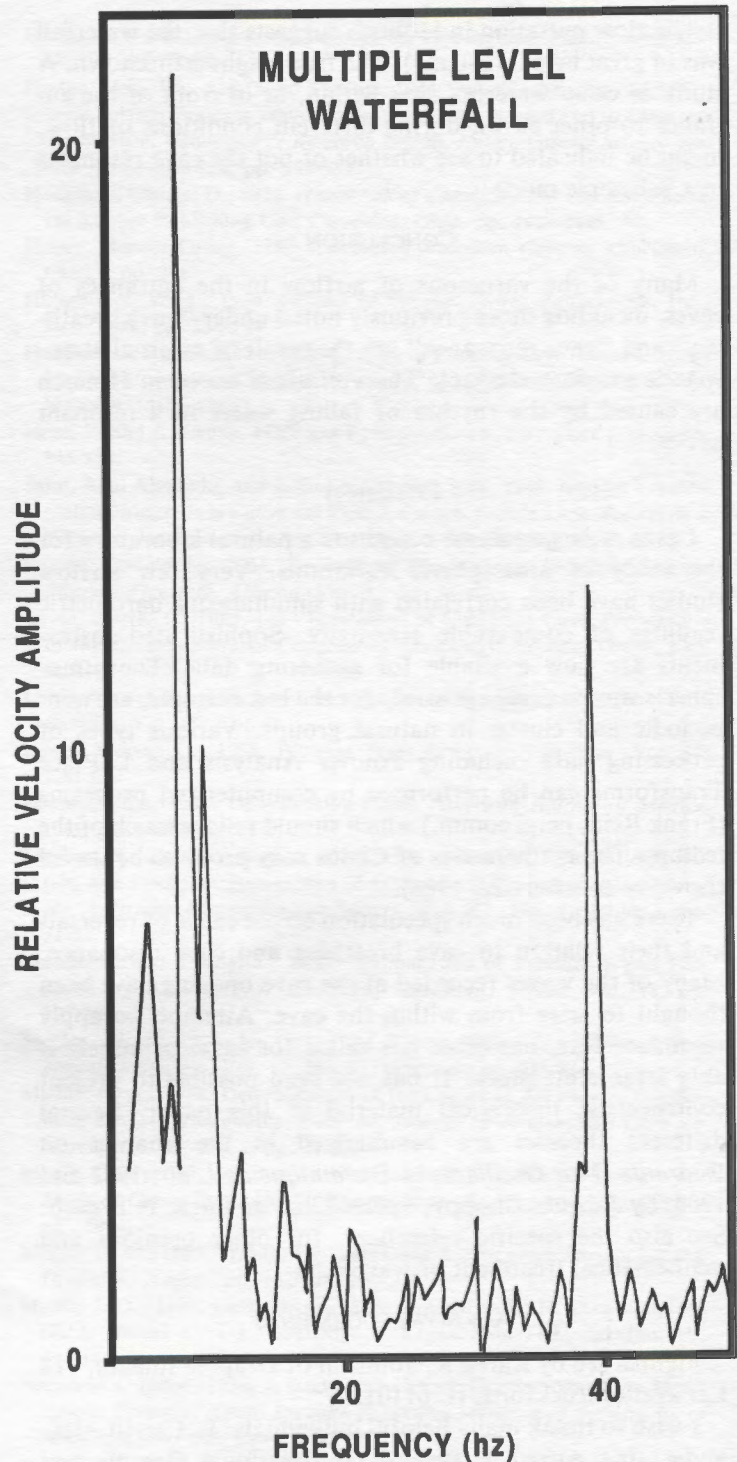


Figure 15. Earth Vibrations of Two-level Waterfall.

Gullfoss Waterfall, Iceland (after Rinehart). Fourier analysis of earth vibrations of this two-level waterfall yields two peaks, one at 6 and the other at 40 Hz. These correspond to the 27 m drop of the lower falls and the 7.5 m drop of the upper falls.

The slow pulsation in Hölloch suggests that the waterfall was of great height (250 m?). The true height is unknown. A study of other waterfall sites within, or in front of the entrance to other caves, during different conditions of flow, might be indicated to see whether or not the cave resonates in a sub-sonic mode.

CONCLUSION

Many of the variations of airflow in the entrances of caves, including those previously noted under "cave breathing" and "cave resonance" are the result of external atmospheric pressure changes. The vibrations noted in Hölloch are caused by the rhythm of falling water in a resonant cavity.

COMMENT

Caves of large volume constitute a natural laboratory for the study of atmospheric variations. Very few airflow studies have been correlated with simultaneous barometric readings of comparable sensitivity. Sophisticated instruments are now available for gathering data. The atmospheric waves, except possibly for the last example, are non-periodic and cluster in natural groups. Various types of processing data including Fourier Analysis and LaPlace Transforms can be performed by computerized programs (Frank Reid, pers. comm.) which should relieve much of the tedium. The mathematics of Chaos may prove to be useful (Lovejoy & Schertzer, 1986).

There has been much speculation on the cause of reversals and their relation to cave breathing and cave resonance. Many of the waves recorded at the cave opening have been thought to arise from within the cave. Attempts to apply resonance formulas often has called for caves of unbelievably large dimensions. It has not been possible to present controversial theoretical material in this paper. Several different theories are summarized in the chapter on *Courants D'air Oscillants* in *Dynamique de L'air*, 1982 and 1986, by Jacques Choppy, Spéléo-Club de Paris, in French. See also the specific references, for other opinions and mathematical treatment of wave data.

ACKNOWLEDGEMENTS

Figures are by Karen K. Johnson of Graphic Images, 718 LaFayette, Rockford, IL 61107.

I wish to thank many helpful individuals: E. Calvin Alexander, Jr.; Alfred J. Bedard, Jr., National Oceanic and Atmospheric Administration; American Meteorological Society; Richard J. Blenz, Rondel R. Bridgemon, Cave Research Foundation; Richard K. Cook, National Bureau of Standards; Nancy Dale, Librarian, St. Anthony Hospital Library; Reuben Honahnie, National Park Service; Dorothy A. House, Librarian; Leslie Lewis, Sr., Medical Writers' Association; Phil Mantin; Anne Oldham; Tony Oldham;

Wade Provo, Rockford College; Frank Reid; Don R. Veazey, U.S. Army Atmospheric Sciences Laboratory; Bill Torode, Librarian, NSS Library; Bruce Zerr, Richard Zopf, Cave Research Foundation. I thank other friends who gathered data and anonymous reviewers.

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- "Le 23 Mai 1904, dans le Höll-Loch (Suisse), Rahir constatait qu'à proximité d'une violente cascade grossie par une crue, l'aiguille de son "baromètre altimétrique oscillait rapidement, régulièrement et d'une façon continue, à droite et à gauche de la normale, et que l'amplitude totale de ces oscillations (duree de double oscillation = 1 seconde) était de 18 à 20 millimètres de hauteur barométrique."
- "Dans toutes les parties alors accessibles de la caverne, ce même phénomène était toujours sensible, "mais il diminuait d'intensité vers la sortie pour cesser complètement à l'extérieur. . . ."
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DISCUSSION—HISTOPLASMOSIS: A HAZARD TO NEW TROPICAL CAVERS— A REPLY

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I thank Dr. Stephen A. Craven for classifying, by country and province, southern African caves and caving areas involved in histoplasmosis. He modestly refrained from adding De Iloop Guano cave in southern Cape Province, as well as Koggelbeengrot in northern Cape Province, of which he has reported outbreaks. These caves were omitted by error. He also mentioned histoplasmosis as being endemic in Indo-China and Indonesia, so cavers might be warned.

I also thank him for corrections of the references. In particular, I appreciate his tracking down the *Young* reference. I had the article from a symposium, but lacked identifying data and date. I urge that anyone interested in cave outbreaks of histoplasmosis, or who plans to cave in South Africa or Zimbabwe, study Dr. Craven's articles.

**ABSTRACTS OF THE
NATIONAL SPELEOLOGICAL SOCIETY
ANNUAL MEETING, June 27 - July 1, 1988
Hot Springs, South Dakota
Norma Peacock, Editor**

BIOLOGY

*BAT REMAINS FROM CARNIVORE SCATS IN TWO
WEST VIRGINIA CAVES*

Fred Grady

Carnivore scats probably attributable to raccoons, *Procyon lotor* have been recovered from Hamilton Cave and Hellhole Cave, both in Pendleton County, West Virginia. The Hamilton scats contain jaw parts of two different bats *Eptesicus fuscus* and *Myotis* sp. along with arthropod and fish parts. The Hellhole scats, based on a partial examination, contain only bones, skin, and hair of medium sized *Myotis* sp. Both of these finds were considerable distances from the respective cave entrances.

OBSERVATIONS ON PACK RAT NEST CONTENTS

Christopher A. Holler

Many years of caving in pack rat territory have provided some interesting observations on the collecting habits of these fascinating rodents. Their attraction to unusual objects have provided numerous entertaining moments underground.

*SCANNING ELECTRON MICROSCOPY
AND ENERGY DISPERSIVE X-RAY ANALYSIS
OF ARTIFICIAL AND NATURAL SUBSTRATES
FROM THE PHANTOM FLOWSTONE OF
SULPHUR RIVER IN PARKER CAVE, KENTUCKY*

Rick Olson and D. Bruce Thompson

In order to sample the bacterial population, two mylar artificial substrates were placed in the Phantom Waterfall of Sulphur River in Parker Cave, Kentucky. When the substrates were retrieved for study after 112 days, both were encrusted with a layer of flowstone approximately 1 mm thick. Scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX) revealed that the flowstone consists of mineral precipitate and a bacterial consortium. Based upon the lack of significant cation peaks in the spectra, the sulfur present in this flowstone appears to be native rather than complexed as sulfates or sulfides. The geological and hydrological conditions associated with native sulfur deposits are found in this portion of the Central Kentucky Karst. Although sulfur bacteria have not yet been isolated from a cave sulfur deposit, the Phantom flowstone may prove a good candidate for such confirmation. In order to compare the artificial with natural substrates, two unattached gypsum needles (among many growing in the sec-

ondary spray of the waterfall) were also collected. SEM and EDX showed that bacteria, sulfur crystals and calcium phosphate were present on the surface of the needles.

*THE EFFECTS OF BAT GUANO ON THE WATER
QUALITY OF THE CUEVA EL CONVENTO STREAM
IN GAUAYANILLA, PUERTO RICO*

Carlos Conde-Costas

Water quality variation resulting from the introduction of large quantities of bat guano were investigated at the Cueva El Convento System on Guayanilla, Puerto Rico. Many large colonies of bats (*Brachyphylla coverarum*, *Monophyllus redmani*, and *Mormoops blainvilli*) roost throughout the cave. Guano contribution is estimated at 6.4kg/m²/yr. Sampling stations were located inside the cave at springs which feed the perennial stream and along the stream to the resurgence. Water samples were collected during low flow conditions, about 15 L/s. Nitrogen species, phosphates, and other nutrients increased significantly downstream, demonstrating that bat guano contributes to the eutrophication process of the cave stream. Fecal bacteria increase dramatically inside the cave but decreases before the water leaves the cave. The pools and small waterfalls in the cave diminish some of the effects of bat guano on the stream.

*WATER QUALITY AND BENTHIC
COMMUNITY STRUCTURE OF CAVES RECEIVING
URBAN RUNOFF*

Thomas E. Pride, Michael J. Harvey, Albert E. Ogden, and Winston Paul Smith

To determine the influence of urban runoff on cave stream benthic diversity, biological samples from riffle areas and water quality data were collected from three caves in Cookeville, Tennessee. An analysis of variance of Shannon diversity indicates (Capshaw Cave = 0.3174, Ament Cave = 0.2491, and City Springs Cave = 0.4912) resulted in rejection ($P < 0.001$) of the null hypothesis: $H'_1 = H'_2 = H'_3$. A Tukey test revealed a difference ($p < 0.05$) among all three benthic communities. Capshaw and Ament Caves were dominated by an oligochate/dripteran assemblage (94.1% and 98.8%, respectively) while City Springs Cave supported primarily isopods (69.9%). Capshaw and Ament Caves exhibited larger coefficients of variation for most water quality parameters than City Spring Cave, especially temperature, dissolved oxygen, turbidity, chloride, and fecal coliform. Capshaw and Ament Caves historically received sewage contaminated runoff and are hydrologically connected. A relationship between degrading water quality and reduced biotic diversity is suggested.

ADAPTIVE RADIATION AMONG SURFACE AND
CAVE DWELLING NEMOBIINE CRICKETS IN HAWAII

Fred D. Stone and Frances G. Howarth

Lava tubes on the young island of Hawaii (<0.7my) are a natural laboratory for study of evolutionary processes. Two sympatric species of cave-adapted crickets (*Caconemobius varius* and an undescribed species) have apparently evolved from either a marine strand species (undescribed) or a surface cricket of recent lava flows (*C. fori*). The cave species are widespread in the mesocavernous tree root zone of deep lava cracks and 'a'a cinders, where their range overlaps that of both surface species. The cave species differ morphologically and behaviorally; *C. varius*, larger and darker than *C.n.sp.*, actively avoids light but readily falls into pitfall traps; *C.n.sp.* doesn't react to light and avoids pitfall traps. It is hypothesized that the two species evolved from their surface relatives by adaptive shifts to take advantage of energy resources in two (overlapping) subsurface zones: shallower cracks or closer to lava tube entrances (*C. varius*) and deeper cracks and lava tubes (*C.n.sp.*).

BIOLOGY OF CAVE CRICKETS, *HADENOECUS*
SUBTERRANEUS, AND CAMEL CRICKETS,
CEUTHOPHILUS STYGIUS (INSECTA: ORTHOPTERA) -
METABOLISM AND WATER ECONOMIES RELATED TO
SIZE AND TEMPERATURE

E.H. Studier and K.H. Lavoie, Biology Department, University of Michigan-Flint, Flint, MI 48502-2186

Metabolic rate (MR in cal/hr) increases with increasing mass in both species. MR of female cave crickets increases more rapidly with mass than in males. There are no sex-related differences in MR of camel crickets. Size related MR of camel crickets is lower than in cave crickets and both are lower than expected in insects of similar size. Water budget parameters (crop, metabolic, and total water gain as well as mixed waste and evaporative water losses) parallel metabolic patterns. Water turnover, in water saturated air, is greater in female cave crickets than in males. There are no gender differences in camel crickets and their water turnover is less than that of cave crickets. On a mass corrected basis, there are no gender differences in thermal sensitivities in cave and camel crickets but metabolic rates of cave crickets increase much more rapidly than camel crickets when exposed to elevated ambient temperatures. Water turnover in cave crickets also increases much more rapidly than in camel crickets with increasing ambient temperature.

CHARACTERISTICS OF MICROBES AND ENZYMES FROM
THE DIGESTIVE TRACT OF CAVE CRICKETS,
HADENOECUS SUBTERRANEUS

K.H. Lavoie, S. Phillpotts, C.R. White, and E.H. Studier, Biology Department, University of Michigan-Flint, Flint, MI 48502-2186

Adult cave crickets (*Hadenoecus subterraneus*) were dissected and pure cultures of microbes isolated from the crop. Crop and hindgut contents were also analyzed for enzyme activity. The effects of temperature on growth of

microbes and enzyme activity were determined. Determination of specific growth rates for microbes showed temperature optima around 28°C for two isolates and 23°C for another 4 isolates. Enzymes assayed for degraded glycogen, amylose, chitin, cellulose, xylan, and azocoll (a proteinaceous substrate). Enzyme activity was highest at 23°C. Activity levels were low compared to other insects and were not significantly different between the crop or the hindgut. Cave crickets are restricted in their foraging by temperature which may reflect a need to maintain control over the production of enzymes by microbes in their digestive tracts.

CONSERVATION & MANAGEMENT

INTRODUCTION

Rane L. Curl

Privately owned undeveloped caves are managed today by methods ranging from intentional neglect to intensive control of visitors. Managers range from individual land owners to land trusts owning or leasing one of more preserves. All must face questions that may include purchase of lease of caves, preservation of the cave and surface resources, visitor control, community and public relations, fund raising, finding and using volunteers, incorporation, insurance and taxes, and developing educational, scientific, and interpretive programs.

This symposium will describe the variety of approaches to managing such caves, the problems encountered, and how problems were solved. It is believed that by sharing information cave managers may learn how to solve their own problems and persons and groups interested in managing caves can learn how to get started.

THE DYNAMICS OF CAVE VANDALISM
DETERRENCE: THE RESULTS OF THE CAVE
VANDALISM DETERRENCE REWARD

John M. Wilson

The history, purpose, and philosophy of the Cave Vandalism Deterrence Reward are reviewed. The demographic characteristics of the perpetrators and reward recipients are stated, and the circumstances surrounding the arrest and conviction of cave vandals are provided. How to use the Rewards to discourage cave vandalism is explained and its use as an educational tool and its degree of effectiveness on a larger population are discussed. The method available to control the cost and extent of the reward to the sponsoring organizations are evaluated.

The review of the research on learning and behavioral change indicates that traditional punitive methods are less effective in educating and otherwise obtaining responsible behavior than progressive judicial decisions such as requiring restitution. Almost all perpetrators have received sentences requiring restitution in lieu of jail or prison time. This finding supports the conclusion that the nature of the sentences imposed as a result of violation of cave protection acts are favorable to the NSS goals of deterring cave vanda

ism. These conclusions apply primarily to the perpetrators and the community where the acts were committed. Other theoretical constructs such as modeling and the control of contingents making vandalism behavior incompatible with mandates restitution are examined. The effectiveness of authoritative versus authoritarian methods are compared. Based on the results of this program it is reasonable to conclude that the reward program is a cost effective method of deterring cave vandalism.

MANAGEMENT OF MCFAIL'S CAVE, NY

Thomas D. Engel

McFail's Cave is owned by the NSS. With 6.4 miles of known passage it is the longest cave in northeast United States. Because of its length and large passage size, the cave is very popular with cavers from the northeast US and eastern Canada. However, due to the vertical entrances and large amounts of cold water (48F) the cave is physically demanding. Rules have been set by the McFail's Cave committee to ensure the safety of the cave and the caver. Access is controlled with gates at the entrances and regular property inspections are made to check for unauthorized visitation and to determine maintenance needs. Maintenance consists of everything from keeping the parking area and trails clear to replacing damaged or missing posted signs to repairing gates.

BIOLOGICAL CONSIDERATIONS IN THE MANAGEMENT OF SHELTA CAVE, HUNTSVILLE, ALABAMA

H. H. Hobbs III and Fred M. Bagley

Currently no "management plan" exists for the National Speleological Society-owned Shelta Cave in Huntsville, Alabama. This cave is the habitat for at least 31 species of aquatic cavernicoles, eleven of which are troglobionts. These include the Southern Blind Cave Fish, three species of sympatric and syntopic crayfishes, and the atyid shrimp, *palaemonias alabamiae* Smalley. This shrimp is known only from two localities and is a candidate for inclusion on the Federal Endangered Species List. This species may have been extirpated from Shelta Cave; no shrimp has been seen in this cave since November 1973.

With so diverse a biotic community, it is imperative that a management plan be adopted and currently one is being drafted by the Shelta Cave Biology Committee. It will treat the preservation of surface resources, visitation, hydrological concerns, the preservation of the complex and sensitive biota, and other resources of this unique cave.

ACQUISITION, PROTECTION AND MAINTENANCE OF KINGSTON SALT PETER CAVE, GEORGIA

Joel M. Sneed

Studies conducted at Kingston Saltpeter Cave, Bartow County, Georgia since 1980 have proved the historical and scientific value of this cave. The cave was acquired in 1983 by the Felburn Foundation of North Carolina, and

given to the NSS on a long-term lease arrangement for protection and maintenance. Funds for the gates and fencing were provided by the Foundation, as are annual maintenance funds. During the four years since closure of the cave, essentially all trash and non-historical graffiti has been removed from the walls; the forty acres of property have been restored; and the study of the cave has been completed. Three species of bats are now using the cave. Entry to the cave has been limited to work and study trips, but now the focus will be on conducting groups to the cave for the purpose of education.

BARTON HILL KARST PRESERVE

Janet Thorne

In December, 1987, a property in Schoharie County, NY, containing the entrances to Gage Caverns and Greens and Keyhole Caves, was donated to the National Speleological Foundation. Over-all responsibility for the management of real estate has been delegated to the Foundation's Vice President. The property was named the Barton Hill Karst Preserve, and negotiations are in process with the NSS for the Society to assume direct responsibility for management of the Preserve. A contract to that effect and a management plan are being developed and are expected to be finalized at the 1988 NSS Convention. The caves are closed until these documents are accepted by both organizations. Key points of the management plan will be that a manager living near the property will be selected, that liability release forms must be signed by visitors, and that information on safe caving and conservation will be made available.

LEASE AGREEMENTS AS A MANAGEMENT TOOL FOR PRIVATELY-OWNED CAVES

Kathy D. Hornaday

The Indiana Karst Conservancy (IKC) has executed lease agreements with three landowners, covering five caves. This arrangement provides the landowner with liability protection and the IKC with access to and control of the caves. Each cave has a Patron, and a Management Plan. Problems we have encountered include resistance from local cavers, secondary leases with conflicting interests, vandalism of signs and gates, and lack of clear authority to prosecute trespassers.

Improved communication with local cavers, and a growing base support, have resolved some of these problems. Clarification of rights and responsibilities has also occurred as we gain experience and recognize pitfalls. Some of the problems, such as vandalism, will never be completely resolved, but increased credibility as an organization with a clear stand on conservation issues has had an impact on the caving community that has carried over to some of the occasional "speleoboppers."

*KNOX CAVE, NEW YORK: IMPROVING A RESOURCE
THROUGH ACTIVE MANAGEMENT*

Thomas D. Engel and Emily Davis Mobley

Knox Cave is perhaps the best known cave in New York. Over the years, visitors have ranged from the serious caver to the avid partygoer. Management of this cave, owned by the Northeast Cave Conservancy, was so lax that even the local sheriff regarded the property as being unowned.

In Spring 1987 we took over management of the cave and instituted procedures to tighten access. The property was posted and signs replaced when damaged. This permitted arrests for trespassing. Surveillance of the property allowed us to stop parties and tell unauthorized visitors to leave. Finally, several tons of rock riprap were placed on the access road to prevent access to the cave by car.

Since starting this program, the number of visitors without permission has gone way down. The number of parties went from probably one a week to only two during all the summer and fall.

*ATTEMPTED RESOLUTION OF THE DILEMMA
OF USE VERSUS CONSERVATION AND
PROTECTION: THE FIRST TEN YEARS
OF THE PERKINS CAVE CONSERVATION
AND MANAGEMENT SOCIETY*

John M. Wilson

The management philosophy of PerCCAMS has been steadfast in maintaining its primary value of preserving the unique quality of Perkins Cave in Virginia. Secondary goals such as restoring a potential Gray Bat maternity colony site, using the cave as an educational tool, mapping and documenting the cave photographically, and encouraging scientific study were undertaken. These secondary goals were in varying degrees of compatibility with the primary objective. This dilemma sets the ideal primary value against everyday, practical reality of implementing the goals in an imperfect world.

There should be less conflict between primary and secondary goals and values now that a recently opened second entrance is usable. The structure, rules, procedures, and goals have had varying degrees of success in the protection of Perkins Cave.

*FUND RAISING IN A SMALL CONSERVANCY,
A CASE STUDY: FIBORN KARST PRESERVE, MI*

Aubrey Golden and David Luckins

Fund raising to support acquisition projects is a formidable task. Raising funds to support an initial acquisition is likely to occur early in the development of a conservancy when management skills have not fully matured, membership small, and fund raising skills are undeveloped. The Michigan Karst Conservancy (MKC), while in the process of developing management skills and broadening its membership, began the acquisition of its first preserve — the Fiborn Karst Preserve (FKP) — a 480 acre site in

Michigan's upper peninsula. FKP contains 5 caves, numerous sinkholes, and a complete hydrologic system.

To acquire FKP, MKC employed techniques that included analysis of revenue sources, assessment of alternative schemes, consultations with conservancies, and reliance on the commitment of its membership.

Fund raising provided a two-fold success. Monies to support the project were raised and the conservancy's management skills and membership were strengthened. The techniques have application potential for similar organizations.

*RAT'S NEST CAVE: PROBLEMS OF CAVE
MANAGEMENT IN ALBERTA, CANADA*

Charles Yonge and David Thomson

Rat's Nest Cave, 2 km in length, is situated in the Rocky Mountains 25 km east of Banff National Park near the town of Canmore. It lies under Crown Land and is currently within industrial leaseholds. Limestone quarrying is actively being pursued over 1 km from the cave entrance.

A lease for the cave and land in its vicinity was sought in an attempt to develop the cave as an interpretive site and underground laboratory. After 5 years of negotiation the cave was declared a "Provincial Historical Site" by Alberta Culture thus protecting it from quarrying and vandalism. Nevertheless, the site is still considered to be the responsibility of the quarry companies. With the "Historic Site" designation, a management strategy is being developed with the current leaseholders, Alberta Culture, and Alberta Speleological Society. In addition, a grant to study and make a inventory of the cave has been obtained.

GEOLOGY/GEOGRAPHY

*SOLUTION CAVE DEVELOPMENT, SOUTH ANDROS
ISLAND, BAHAMAS*

John W. Mylroie and James L. Carew

South Andros Island is located on the Great Bahama Bank, 300 km SE of Miami, Florida, a low-lying island made up of Late Pleistocene limestones of marine and eolian origin. The island has numerous deep blue holes located along prominent fracture zones, which lead into extensive underwater caves. Short subaerial caves also exist on the island. These subaerial caves developed during a past, higher sea level event, and are commonly single rooms or chambers, from which a number of short dead-end passages radiate. They have a limited vertical extent, are within three to four meters of current sea level, and open on the margin of low hills. The subaerial caves originated through solution by the mixing of fresh water from the island interior with encroaching marine waters, called the "flank margin" model. Other subaerial caves exist that are stable mechanical arches produced by the stoping upward from a large solutional void below current sea level. These collapse structures are very similar in morphology to caves in Bermuda, where a similar stoping model has been proposed.

ORIGIN OF CAVES IN RESPONSE TO DRAINAGE
EVOLUTION IN THE NEW RIVER BASIN,
SOUTHWESTERN VIRGINIA

Ernst H. Kastning

The karst of the New River drainage basin of Virginia lies within the Valley and Ridge physiographic province. It may be subdivided into two speleogenetic regions, based upon prevailing geologic and hydrologic settings, distribution and morphology of karstic land forms, and progressive sequence of cave and karst development in response to the geomorphic evolution of the drainage basin. The origin of the surficial landscape and the emergence of groundwater flow patterns are dominantly controlled by the lithologic character of the Paleozoic strata and geologic structure of the Appalachian foldbelt.

The southeastern most region (farthest upstream within the drainage basin) encompasses the karst of the Great Valley, lying between the Blue Ridge Mountains and the folded Appalachians (Allegheny Mountains). This includes the southern extension of the Shenandoah Valley in Montgomery and Pulaski Counties in Virginia. Here the karst is characterized by broad valleys underlain by carbonate rocks that have been only moderately deformed. Typically, karst is expressed as clusters of sinkholes and shallow cave systems of short to moderate length that are mildly dendritic. Sinkholes and caves exhibit excellent structural control along fractures. Cave development is typical of that under a sinkhole plain of relatively low relief where drainage through enlarging conduits follows prevailing hydraulic gradients toward a moderately incised stream, in this case the New River.

The region to the northwest (downstream) lies within the intensely folded Alleghany Mountains of Bland, Giles, and Graig Counties of Virginia. Karst is confined to relatively narrow exposures of carbonate rocks, generally along valley floors or low on flanks of adjacent mountains. Sinkholes are less prevalent than in the Great Valley, but tend to be well aligned along bedrock strike and, in places, along fracture swarms associated with major thrust faults. Progressively downcutting streams govern points of groundwater discharge (springs), and parallel-dendritic flow networks and caves evolve accordingly. Surficial stream capture during the evolution of the New River drainage system and subsurficial stream piracy have significantly affected the morphology and orientation of caves. In places, meanders and abrupt changes in gradients of surficial streams have influenced discharge points of emerging cave systems.

CAVE PASSAGE DEVELOPMENT IN BELIZE

Tom Miller

The Maya Mountains channel acidic streams with clastic loads onto Cretaceous limestone karst: these have bored *without integration* at 60-200 m depth to emerge individually into the coastal plains. These enormous "trunk conduits" mix with flow from "zuhuyhas": 2-4 meter-diameter passages with few clastics that often precipitate calcite as they enter the trunks. Some display dendritic networks,

but sumps or restrictions terminate explorations. Not all zuhuyhas enter trunk conduits: many emerge independently from the karst. Cockpits and other closed depressions funnel much surface runoff into short, vertical, "swallet" caves. These are the likely sources for the zuhuyhas.

"High-level-phreatic" passages contain no clastic sediment, and are often large and extensive. Some show indication of phreatic conduit flows, but most are isolated. Their genetic relation to the trunk conduits and zuhuyhas is uncertain.

Modification has occurred by surface of internal collapse, clastic infilling events (possibly a major climate change), and tremendous amounts of calcite precipitation. Multi-level caves are common to each karst, and likely represent episodic uplift associated with a nearby tectonic plate margin. Currently, paleomagnetic analysis suggests the huge trunk conduits developed within the present polarity epoch.

HYDROLOGY OF THE SISTEMA HUAUTLA KARST
DRAINAGE BASIN, OAXACA, MEXICO

James Smith.

The Sistema Huautla Karst Drainage Basin is a dendritic vertical drainage system with input from many surface and subsurface streams. This research proved that the discharge occurs from one perennial spring in the north wall of the Rio Santo Domingo Canyon.

Geologic mapping and fracture lineament analysis indicated two possible locations for springs. Over 140 kilometers of surface reconnaissance revealed one suitable area for the Sistema Huautla resurgence. Charcoal dye receptors were placed at Cueva Pena Colorado, in surface streams, and at five springs. A spring with 1.25 cumec discharge, 1730 meters below the highest input, tested positive to Fluorescein dye (Acid Yellow 73).

The simultaneous use of multiple dyes qualitatively traced hydrologic flow routes from major surface and subsurface streams to confluences of cave streams within Sistema Huautla. Rio Iglesia, a major surface stream, enters the hydrologic route between Sistema Huautla and its resurgence. Nita He and Nita Nashi, 600 meter deep caves, tested positive as independent 1000 meter deep water routes into Sistema Huautla.

Qualitative dye tracing has redefined the hydrologic schematic, and extended the known limits of the drainage basin.

SOIL AND ROCK ANALYSIS FROM COCKPITS:
IMPLIED FLUVIAL DEVELOPMENT

Tom Miller.

The karst surface of Belize has been dominantly affected by fluvial modification, as shown by both modern streams, and abandoned and/or restructured channel courses. In the Chiquibul karst of Belize, 50 analyses of cockpit soils and neighboring Cretaceous limestone bedrock were compared to topographically-higher non-carbonate rocks and to their derived sediments that inundate the bordering fringe of the karst. The cockpit soils were found

to be very similar to the non-carbonate material, and distinctly different in all respects from the limestones and their possible solutional residuum.

The same results were obtained when collection was extended to other karst on Cretaceous limestones in Belize and to younger Yucatan limestones

Nearly all of the sampled carbonate rock was limestone, rarely with more than 5% insolubles. The silica fraction of the sediments from the non-carbonates declined with distance from their source while aluminum and iron oxides increased proportionately. This trend continued into the cockpit soils with their greater distance from the non-carbonates.

GROUNDWATER PIRACY IN THE DEVELOPMENT OF HONEY CREEK CAVE, TEXAS

George Veni

Seven stages of development occurred in the hydrologic evolution of Honey Creek Cave, Comal-Kendall Counties, Texas. During these stages, groundwater piracy was the dominant factor which resulted in the cave's extensive length (26.22 km Feb 1988) and in the development of five conduit groundwater divides. Determination of the number and order of these stages is based on the observed hydrology and on morphologic features in the cave. Piracy occurred in three fashions: 1) subsurface meander cut-off for the Guadalupe River; 2) capturing flow from the adjacent Cibolo watershed; and 3) adjustment of stream gradients within the cave resulting in flow diversions between passages. When conduit flow diversions occur, flow in the original passages is reversed in what was originally its "downstream" direction. Eventually the reversed flow segment of the passage lengthens until it reaches an infeeding tributary. At that junction a conduit groundwater divide forms; water entering the main passage flows down along its original path and also down what was previously the upgradient direction.

THE GEOLOGY OF LECHUGUILLA CAVE, NEW MEXICO

David H. Jagnow

Lechuguilla Cave is located 6 kilometers WNW of Carlsbad Cavern in the heart of the Permian-aged Capitan Reef complex. To date, the cave has been surveyed to a length of more than 25 kilometers, and a depth of 432 meters — making it the second deepest cave in the U.S.

The entrance shaft and upper reaches of the cave are formed in the more soluble Seven Rivers Formation, immediately below the Yates contact. Detailed mapping of surface geology reveals a small inlier of Seven Rivers in the upper reaches of Lechuguilla Canyon as well as numerous small flexures. The North rift and Sugarlands area of Lechuguilla extend downward into the underlying Queen Formation.

The vast majority of Lechuguilla Cave has developed in the highly soluble reef equivalents of the previously mentioned backreef formations. The Western Borehole has developed along a breccia tube that parallels the reef

front in the Goat Seep Dolomite (Queen equivalents), while the Southern Borehole appears to be in the lowest Capitan Limestone (Seven Rivers equivalents). Lechuguilla provides a unique view of this portion of the reef. The closest outcrops of the Goat Seep Dolomite are 34 kilometers to the southwest.

INFLUENCE OF FORMER EVAPORITES ON S.D. CAVES

Margaret V. Palmer

Caves of South Dakota are concentrated along former evaporite zones in the Pahasapa (Madison) Limestone. Fracturing and replacement within these zones are responsible for many of the features that make these caves unique, such as boxwork and brecciated wall rock. These features are rarely seen in surface outcrops, except adjacent to truncated cave fragments. The lower dolomitic beds of the Pahasapa contain zones of former evaporites (gypsum and anhydrite) replaced by calcite and silica. Replacement is indicated by doubly terminated quartz crystals and euhedral calcite crystals that mimic the shape of the original evaporite crystals. The quartz crystals have a sandy texture and red color due to hematite released by the replacement of iron-rich dolomite bedrock. Large breccia bodies cut across the bedrock and show evidence for multiple faulting. Fracturing continues in all directions into the bedrock around these discordant bodies. Fractures are lined with large dolomite crystals tipped with iron oxide containing abundant bacterial filaments. The remaining space in the fractures is filled with calcite spar colored orange-brown by iron oxide. The replacement probably took place in stagnant groundwater just prior to the late Antler uplift (Mississippian). Few calcite veins continue upward beyond a 3-m zone of chert beds two-thirds of the way from the base of the Pahasapa. The overlying limestone contains bodies of limestone breccia with a matrix of internally derived sediment, as well as ovoid bodies of quartz and dolomite; but the orange spar is missing. The present caves follow these altered zones almost exclusively. The striking evidence of the former evaporites is the extensive boxwork in Wind Cave and the massive breccia bodies in Jewel Cave.

GEOLOGY AND SPELEOLOGY OF SALINIA CAVES OF THE SALINIA BLOCK, WEST CENTRAL CALIFORNIA

Bruce Rogers

The 485 km long, 50 km wide Salinia block is a suspect terrane derived from the western coast of either southern Mexico or Honduras and transported north along the San Andreas fault to its present location at the western edge of Central California. Its lithologic units include Paleozoic/Mesozoic metasedimentary and granitic rocks covered with a mantle of Cenozoic sedimentary rocks. Caves developed in salinia include meters-long rock art shelters in Eocene sandstone, 100m long sea caves in Miocene shale, 640 m talus caves in a rifted Miocene volcano, and 1.6 km long solution caves in Paleozoic (?) banded marble. Speleothems of calcite, gypsum, jarosite, hydroxylapatite, taranakite, goethite, birnessite, christobalite, quartz, and asphalt have been identified. Several caves have large

Quaternary bone deposits. Surface karst is of limited exposure, largely mantled by soil, and short sinkholes. At least 4 large (20,000 cu, m/day) karst springs are known.

*GEOLOGY AND SPELEOGENESIS OF COLOSSAL CAVE,
PIMA COUNTY, AZ*

Lanford F. Brod, Jr.

Colossal Cave is a limestone cavern on the southern margin of the Rincon Mountains in Pima County, Arizona. Examinations of the cave and mapping of the surface geology revealed numerous faults. The limestone containing the cave was closely flanked by four tectonically emplaced formations of contrasting lithologies. The pervasive fracturing was produced by gravity glide faulting of an allochthonous sheet of carapace rocks from the Rincon Mountain metamorphic core complex, which probably occurred in late Oligocene time. The configuration of the cave indicated a hydrologically diffuse source of ground water. The presence of red clay in a nearby cave implied the possibility of a former alluvial fill overlying the cave horizon. Colossal Cave was probably formed during a period of Pleistocene climatic stability when ground water from the alluvial fill flowed laterally through the narrow limestone ridge to a lower elevation.

*REMOVAL OF URBAN STORM WATER RUNOFF,
BOWLING GREEN, KENTUCKY*

Philip P. Reeder and Nicholas C. Crawford

Formerly, storm water runoff sank naturally into the Lost River Karst Aquifer at thousands of locations throughout Bowling Green. But due to recent land use changes, runoff has greatly increased necessitating the drilling of nearly 600 drainage wells to direct storm water into the subsurface. At the Center for Cave and Karst Studies we have investigated the contamination of the aquifer by urban storm water runoff and have made recommendations to the city based on our results.

As urban growth continues, more drainage wells are drilled to transmit runoff into the subsurface. Research is also underway to (1) differentiate areas of the city as optimal for removal of storm water runoff, (2) correlate lithologic features between wells, and (3) determine optimal depths to which new drainage wells should be drilled. This is being accomplished using maximum capacity test, correlation of lithologic features between nearby wells and comparing void density to depth below the land surface. Thus far, one section of the city has been determined as possessing a good interconnected void system. Research continues to differentiate area of the city as good locations for future drainage wells and also to develop depth criteria for the new wells.

*WATER QUALITY OF RURAL WELLS IN AN
AGRICULTURAL BASIN IN MINNESOTA*

Betty J. Wheeler, E. Calvin Alexander Jr., and Russell S. Adams, Jr.

More than two years of water-quality monitoring of karst springs at a Fish Hatchery near Lanesboro, Minnesota has shown that: (1) during high intensity storm events, a run-in component delivers a slug of relatively insoluble substances, such as sediment and some pesticides, which can create acute water quality problems; but (2) most of the soluble and mobile substances such as nitrates are present at nearly constant rates all year, apparently derived primarily by infiltration. Changes in amounts of nitrates and pesticides appear to respond to different drive-in forces: therefore water analysis for nitrates is not a good predictor of pesticide levels.

A total of 68 wells, tapping a range of aquifers, in the Duschee Creek watershed near the Fish Hatchery, have been sampled once. These wells show that (1) approximately 94% have elevated levels of nitrates (> 1ppm); (2) more than 22% have nitrate levels above the drinking water standard of 10ppm; and (3) at least 42% have detectable levels of pesticides. Nitrates and pesticides persist year-round in groundwater in this karst region of southeastern Minnesota.

*PRELIMINARY RESULTS OF AN INVESTIGATION
OF RADON LEVELS IN THE HOMES AND
CAVES OF BOWLING GREEN, WARREN
COUNTY, KENTUCKY*

James W. Webster and Nicholas C. Crawford

Bowling Green, a city of approximately 50,000, is built completely upon the classic karst landscape of southcentral Kentucky. The city is underlain by an extensive, shallow cave system. Radon and radon daughters are known to accumulate in high levels within caves. Testing reveals that, at times, some Bowling Green caves have developed concentrations of radon daughters in excess of 5 working levels (1000 pci/1 of radon gas assuming 50% equilibrium). Past problems with toxic fumes from contaminated caves entering homes has raised the question as to whether high levels of radon gas may be coming into homes as well.

One hundred homes have been tested as of November 1987 using a significant source of indoor pollution for many Bowling Green residents. Residential radon levels averaged 10.4 pci/1 and ranged from less than 1 pci/1 to greater than 130 pci/1. The average radon level for 12 buildings with a history of fume problems tested thus far is 44 pci/1. The average residential radon level for the 879 homes tested throughout Kentucky as part of a federally sponsored radon survey was 2.8 pci/1. The United States Environmental Protection Agency has adopted 4 pci/1 as the indoor radon concentration at which further testing and mitigation is suggested. Fifty-seven percent of the Bowling Green homes included in the general survey and eighty percent of fume homes tested at or above 4 pci/1.

RADIOACTIVITY RESULTING FROM THE
DEPOSITION IN CAVES OF RADON
DAUGHTER PRODUCTS

R. S. Lively and E. P. Ney

Studies of the radiation environment in a cave usually involve measurement of the gaseous isotope ^{222}Rn in the cave atmosphere. In some caves the short-lived daughter products in the air may also be measured. However, the short-lived isotopes that follow radon decay are not gasses and will eventually reach and attach to the cave walls. A radioactive of the ^{210}Pb is thus formed on all surfaces within the cave. In a cave with little ventilation the radioactivity of the ^{210}Pb is proportional to the concentration of the radon in the cave air.

Radon samples collected from a cave in southeastern Minnesota were compared with ^{210}Pb measurements on surfaces within the cave and on a sample of rock removed from the cave. Radon concentration ranged from 80 to 350 picoCuries per liter. All of the surface radioactivity resulted from the deposition and decay of airborne radon daughter products and was not produced by the decay of uranium in the rock. The amount of ^{210}Pb deposited on a rock is influenced by the surface orientation; the ^{210}Pb activity on horizontal surfaces is higher than that on vertical surfaces. Because of the relatively long (22 years) half-life of ^{210}Pb , measurement of its activity on surfaces may provide a means of assessing average radon levels in a cave over the past 100 years.

REESERS LANDFILL: A SUPERFUND SITE INVESTIGATION IN THICKLY MANTLED KARST

Raymond A. Scheinfeld

Reesers Landfill, a former municipal waste disposal site, located 8 miles west of Allentown, PA, was an investigation for the US EPA as a CERCLA (Superfund) site during 1987-88.

The land fill is situated in a thickly mantled karst terrain. The lower to middle Ordovician age formations mapped in the area include the Epler and Jacksonburg Limestones and the Martinburg Shale, all of which are completely folded and faulted. These formations, part of the Shantz Spring Basin, supply a large quantity of water to the homes and businesses in the rapidly growing western suburbs of Allentown, PA.

The landfill is located 600 feet from the nearest residential water supply well, and 1950 feet from an 0.75 mgd public water supply well. The landfill is thought to be the source of heavy metal contaminants detected in a nearby stream and a residential well.

The investigation focused on characterizing the contaminants presents in the landfill and their potential for migration to the groundwater found in the area. The effect of an additional Superfund site located 2000 feet west of the Reesers Landfill was also considered.

The Reesers Landfill investigation included a fracture trace analysis; seismic refraction and magnetometry geophysical surveys; test pits; a suite of soil and water samples from nearby streams, ponds and springs; the installation of four overburden and five bedrock monitor wells, borehole

geophysics and downhole TV camera techniques; water supply and monitor well sampling; a high capacity pump test and a computer generated flow model.

The bottom of the landfill is separated from the bedrock by 50 feet of very low permeability soils. Preliminary results suggest that at present Reesers Landfills has little or no effects on the groundwater of the area.

A CHEMICAL AND ISOTOPIC SURVEY OF THE AGE OF GROUND WATERS IN THE PALEOZOIC KARST AQUIFERS OF SOUTHEASTERN MINNESOTA

E. Calvin Alexander, Jr., and Scott C. Alexander

We have determined the ^{14}C , ^{13}C , ^3H isotopic contents and the chemical composition of water from 21 wells in Olmsted County in southeastern Minnesota karst region. Five wells contain no detectable ^3H (<0.8 T.U.) or nitrate-nitrogen (<0.1ppm). These wells are producing water that entered the ground before the advent of atmosphere nuclear weapon testing in the 1950s. Seven wells contain > 10 T.U. and elevated levels of nitrates and/or chlorides and sulfates. These wells are producing water dominated by recent and contaminated recharge.

Nine wells contain little or no nitrate and tritium concentrations between 1 and 10 T.U. These are interpreted as mixing of recent and older waters. Eight of these wells are in the regionally important Jordan Sandstone Aquifer. In two cases, the overlying Prairie du Chien carbonate aquifer contains water with lower tritium concentrations.

CALCITE, DOLOMITE AND GYPSUM SATURATION CONDITIONS IN THE EDWARDS AQUIFER

Paul D. Collar, Albert E. Ogden, Kristie G. Hamilton, and Melissa C. Rogers

Time series hydrogeochemical data from three of the largest springs in Texas were utilized to determine seasonal effects on calcite, dolomite, and gypsum saturation. Saturation indices were also calculated from data for ninety wells sampled within a 50 square mile area around San Marcos, Texas. High calcium hardness values within some fault blocks were thought to be related to gypsum dissolution with respect to gypsum. No increasing trends were observed in saturation with respect to gypsum, calcite, or dolomite between the Recharge Zone and the Bad Water Line as anticipated. Despite long transport distances (greater than twenty miles) and deep circulation, Comal, San Marcos, and Hueco springs remained undersaturated except during a six month period associated with a severe drought and a large decrease in spring flow. Rock cores near the San Marcos Springs contain calcite-filled vugs. Therefore, undersaturation may be related to calcite deposition before reaching the springs or mixing effects of undersaturated local recharge waters.

*THE CARBONATE CHEMISTRY OF THE RIO
CAMUY DRAINAGE BASIN, PUERTO RICO:
A HUMID TROPICAL KARST*

Joseph W. Troester and William B. White

Water samples were taken along the Rio Camuy every month for one year. When the Rio Camuy enters the karst it is undersaturated with calcite (average $SI_c = -0.06$), low in hardness (average hardness = 71 mg/L as $CaCO_3$), and has a partial pressure of carbon dioxide only slightly above atmospheric (average $PCO_2 = 0.11$ volume percent). Hardness increases downstream, with the largest increase occurring as the river enters the karst due to the addition of calcium- and bicarbonate-rich, autogenic water from groundwater tributaries, which have higher PCO_2 's (maximum of 0.95%). Because the river flows in an open cave, excess carbon dioxide, added by tributaries, degases and causes the calcite saturation index to become positive. As the river flows through a flooded passage, carbon dioxide cannot degas, and PCO_2 reaches its maximum (average $PCO_2 = 0.39\%$), and SI_c approaches equilibrium. Total hardness and SI_c show some seasonal variation, being somewhat lower during months of higher rainfall. No seasonal variation was observed in PCO_2 .

*THE EFFECTS OF BAT GUANO ON CARBONATE
CHEMISTRY IN CUEVA EL CONVENTO,
GUAYANILLA, PUERTO RICO*

Carlos Conde-Costas and Joseph W. Troester

Carbonate chemistry variations resulting from the introduction of large quantities of bat guano into a cave stream were investigated at the Cueva El Convento System in Guayanilla, Puerto Rico. Many large colonies of bats roost throughout the cave. The guano production in the cave is estimated to be 6.4 kg/m²/yr. Samples were collected during low flow (about 15 L/s) at the two springs which feed the perennial stream, two additional points along the stream, and the resurgence. When the ground water enters the cave, it is at saturation with respect to calcite and high in CO_2 (average $PCO_2 = 2.1$ volume percent). As the water flows through the cave PCO_2 decreases steadily and the calcite saturation index (SI_c) increases. The production of CO_2 from the bat guano did not appear to be a significant factor in determining the PCO_2 or the SI_c . At the resurgence PCO_2 is closer to atmospheric ($PCO_2 = 0.28$) and the SI_c is +0.9. Despite this amount of supersaturation, calcium and magnesium concentrations remain constant throughout the cave, indicating no calcite precipitation. It is possible that the large amount of guano inhibits calcite crystal growth.

*ACCUMULATION OF CALCITE RAFT DEBRIS NEAR
LAKE OF THE CLOUDS, CARLSBAD CAVERN, NM:
A U-SERIES STUDY*

D. C. Ford and C. A. Hill

Calcite raft detritus has accumulated to a depth of ~2 meters on a prominent ledge ~80 m above Lake of the Clouds, the lowest point in Carlsbad Caverns. A sampling

access hole has been drilled by acidic drip water from the ceiling, two meters above the surface of the detritus. Nine samples were extracted for isotopic analysis, yielding five satisfactory results.

U series age ($^{230}Th:^{234}U$ method) range from ~250,000 y BP at the base of the deposit to 50,000 y BP at the top. The pool surface that was the source of the raft detritus must have been stable within +0.5 to +2.0 meters at the site for much of that period. It is now some 80 m lower. The mean rate of raft accumulation on the pool floor was 1.05 cm per 1000 y.

*URANIUM SERIES SPELEOTHEM DATES FROM
TWO CAVES IN THE DRIFTLESS AREA OF
SOUTHWESTERN WISCONSIN*

R. S. Lively

The majority of speleothem ages in Upper Midwest cave postdate 160,000 years. Ages between 160,000 and 350,000 years are few and generally unconnected to younger material. To begin to broaden both the geographic and chronological range of speleothem dates, two caves in the unglaciated area of southwestern Wisconsin were resampled in the summer 1987. One was Cave of the Mounds in Blue Mounds State Park, south of the Wisconsin River, and the other was Eagle Cave just north of the Wisconsin River near the Town of Blue River.

Dates from Cave of the Mounds show that speleothems were growing between 225,000 years ago and the present. The number of samples are not yet sufficient to show if growth was continuous or occurred mostly during interglacial cycles as it did in caves nearer the ice margin. There appears to have been a major interval of speleothem development between 225,000 and 160,000 years which is not seen in caves in Minnesota. Dates from Eagle Cave extend from the present back to 300,000 years. The calcite sampled was mostly flowstone and shows lone intervals between deposition of successive layers. Initial studies indicate that some of the sediment beneath the basal flowstone resembles pre-Illinois lake sediments that formed along the glacier edge farther to the north. This suggests that pre-Illinois meltwater may have flooded Eagle Cave at the same time.

*POLLEN DEPOSITION IN CAVES: RESULTS FROM THE
CANADIAN ROCKIES*

Jany Mulewich

Fossil pollen analysis has become an important technique in studying the history of climatic change. Cave deposits provide a record which extends over multiple glaciations.

Speleothems provide the best record because there is no possibility of postdepositional movement of pollen and also because samples less than 350,000 years old can be dated. (Fluvial cave deposits are almost impossible to date and are often reworked). But the amount of pollen found in speleothems from the Crownest Pass area in the Canadian Rockies is very low. Samples closer to entrances or from caves with high winds yield better results.

In order to better interpret the fossil pollen record, the process of modern pollen deposition in a cave was investigated. To measure the distribution of airborne pollen, traps were placed for a year in four caves in the Canadian Rockies selected to represent different aerodynamic regimes. The results show a strong correlation between pollen deposition and wind speed.

No pollen was found in cave drip waters, although a full year's worth of drip water was not analyzed.

Near entrances, pollen deposition by animals or humans may be locally important. For example, pollen and rodent bones were found in organic material dated at 8,000 BP at the end of Castleguard Cave, presently underlying 250 m of ice (the Columbia Icefield). This suggests that the icefield was much smaller at the time and the passage was an open entrance, and possible that the treeline was higher.

PALEOMAGNETISM OF SPELEOTHEMS IN GARDNER CAVE, WASHINGTON

Kyle Martin

Gardner Cave is the biggest limestone cave in Washington state with as wide variety of speleothems. Cores extracted from the Dry Stream stalagmite and Holocene flowstone were analyzed for remanent magnetism. Ages provided by $^{234}\text{U}/^{239}\text{Th}$ dating of calcite layers span from 20 to 5.4 ka.

Both speleothems reveal stable remanence. The Dry Stream stalagmite shows the 321 degrees delineation of the geomagnetic pole at the 23 ka shifting to 357 degrees by 19.5 ka and westward drift of 27 degrees from 19.5 to 12 ka. Both speleothems reveal parallel eastward trends in declination from 10 to 7.5 ka. The declination of the flowstone shifts westward at 7.5 ka from 93 degrees to 52 degrees at 2.5 ka. The Dry Stream stalagmite declinations continue a minor eastward drift from 7.5 to 5 ka. It is speculated both records diverge due to the lower temporal resolution of the Dry Stream stalagmite record in contrast to the higher temporal resolution of the flowstone record. The Dry Stream stalagmite record parallels the trend of the declination of ^{14}C dated cave sediments from 6.7 to 5 ka.

Paleomagnetic directions of the steeply sloped Holocene flowstone are consistently higher than the paleomagnetic directions previously reported for Fish Lake in southeastern Oregon. A proposed hypothesis to explain this pattern is the dip-slope control on some speleothems which orients magnetic movements along steeply sloping surfaces.

A PRELIMINARY STUDY OF THE SEDIMENTS AT THE CAVE OF THE WINDS, MANITOU SPRINGS, COLORADO

Fred Luiszer

The Cave of the Winds, a Phreatic, multilevel cave system, contains many passageways that are filled with sediment to varying degrees. The uppermost beds of sediment consist of silt, sand, and/or gravel, and range in thickness from 10 to 200 cm. The lower section, over 4 cm thick in some cases, consist of massive red clay that can be laminated

with silt and fine sand near its top. The origin of the red clay is an enigma. Authors have variably suggested that it is from pedogenic sources, a residuum related to dissolution of limestone, or from extracave fluvial sources. Comparison of the mineralogy of material from some of these sources to the mineralogy of the red clay will help resolve its origin.

The sand, silt, and clay have acquired a permanent magnetization parallel to the geomagnetic field at the time of deposition, a type of magnetization called depositional remanent magnetization (DRM). Preliminary studies demonstrate that the sediments exhibit reversals in paleomagnetic directions. This data can be used to develop a magnetostratigraphy which provides a means for correlating the sediments throughout a passageway and even between passageways. By comparing the magnetic polarity zonation of the cave sediments with well dated sections elsewhere, the age limits and sedimentation rates of the cave sediments can be estimated.

CAVE SEDIMENT FLUXES IN AN ALLOGENIC KARST

S. R. H. Worthinton

Sediment fluxes have been examined in Friars Hole Cave System, West Virginia. The lithologic setting (limestone overlain by impermeable strata), hydrology (fluviokarst) and good dating control (U Series and Paleomagnetism) have facilitated calculation of total fluxes carried through the caves. Allogenic streams are the principal source for sediments ($1.4 \times 10^7 \text{ m}^3$ of shale, sandstone, limestone and coal), but most are carried out of the cave. The small proportion remaining (10^{3-4}) usually represent final fluvial conditions in any cave passage immediately prior to abandonment. Entrance facies (eolian, mass movement, or organic sediments) and authigenic sediments (solute, breakdown, residual minerals after bedrock solution) are minor source components ($2 \times 10^5 \text{ m}^3$ and $2.1 \times 10^7 \text{ m}^3$ respectively), but have higher persistence (both 10^5) as they tend to be deposited away from the major drainage routes of the cave.

Once a cave passage is abandoned by the stream that formed it, there is an excellent probability of preservation of any sediments present until the cave is removed by surface erosion — some 5 to 20 million years later at Friars Hole.

SEDIMENTS EXAMINED AT NARROWS CAVE, MANITOU SPRINGS, COLORADO

Fred Luiszer

Narrows Cave, a sediment-filled phreatic cave 10 m above the floor of Williams Canyon, is 1 km north of Manitou Springs. The sediment consists of layers of gravel, sand, silt, and clay. The lowest bed, which is over 100 cm thick, is massively bedded red clay with silt lamina near its top. Above that is a diamicton that varies in thickness from 0 to 50 cm. The next bed up is composed of 5 to 60 cm of well-sorted brown sand that contains climbing ripple crossbeds. Above that is a 20 to 200 cm thick, tabular-crossbedded, well-sorted, feldspathic gravel. The uppermost bed is a 3 to 10 cm thick, brown to tan, laminated silty mud. There is a 10 cm

air gap between the top bed and cave roof that appears to be the result of shrinkage of the red clay during desiccation. It appears that the sand and gravel beds mimic a deltaic type of sedimentation. The sands are similar to the bottom-sets of a prograding delta, whereas the gravels, which have cross-sets 1 meter high, are very much like the fore-set beds. The bedding forms and grain sizes suggest velocities of 20 to 50 cm/s for the sands and 1 m/s for the gravels; the flow was about 1 m³/s. The silt above these beds represents the waning of the flow regime. The gravels and sands could have been deposited in two ways. Possibly, the stream cut its canyon downward to the level of the cave and filled it in, or the stream, which was below the cave, aggraded up to the cave entrance and filled the cave.

Aggradation due to rapid erosion upstream from the cave may have been caused by a forest fire. This is suggested by the charcoal found in the sand and gravel.

*SALTPETRE IN FOUR EUROPEAN CAVES:
CHEMICAL, HISTORICAL, AND
MINERALOGICAL ASPECTS*

David A. Hubbard, Jr., Janet S. Herman, Richard S. Mitchell, and Elmar Hammerschidt

Known saltpetre caves in Spain, France, and West Germany were visited to study the nature of saltpetre occurrences. Evidence of mining activity was found in Sophienhohle (West Germany), which has a saltpetre history dating from 1490. Fourteen efflorescent wall- and floor-crust samples and nine sediment samples were collected from the four caves. Nitrate minerals, which are deliquescent, were not found in any of the crust or sediment samples. The nitrate minerals niter [KNO₃] and nitromagnesite [Mg(NO₃)₂·6H₂O] did form by the evaporation of leachates from the cave sediments of representatives from each of the caves, never fully evaporated even in relative humidities ranging from 33 to 43 percent. Data from chemical analyses of the unconcentrated leachates indicate the five specimens have nitrate (NO₃) concentration greater than 500 parts per million (ppm). From cation and anion compositions it can be inferred that with lower humidity five sediment leachates would yield the highly deliquescent mineral nitrocalcite [Ca(NO₃)₂·4H₂O]. Chemical evidence confirms that Cova del Salnitre (Spain), Grotte d'Enfer (France), Grotte Salpetriere (France), and Sophienhohle (West Germany) contain saltpetre.

*SUBAQUEOUS HELICTITES AND
STALACTITE-LIKE SPELEOTHEMS IN
LECHUGUILLA CAVE, NEW MEXICO*

Donald G. Davis

Remarkable displays of vermiform calcite helictites have been found submerged in three pools in Lechuguilla Cave. Like subaerial helictites, they have central canals of capillary dimensions, but are perfectly accordant with the shelfstone pool margins and have definitely grown underwater. Each helictite pool lies downslope from a partly-dissolved gypsum block, and the helictites are probably products of interaction of gypsum-rich inflow with the

calcite-saturated pool water, causing localized calcite crystallization via the "common ion effect".

Related growths, apparently also subaqueous in origin but more stalactite-like, extend from the crusts lining old lake basins in two other places in the cave. In one locality, clusters of these up to one foot long are connected by unexplained U-shaped loops of stone. In another site, red to blackish "skeletal" stalactites and hollow columns up to four and a half feet long appear rich in heavy metals. These seem to have grown in a body of water fed by seepage from condensation-corrosion of walls above the water level, possibly under hydrothermal conditions as the former water table was falling below the cave. As with the helictites, mixing of dissimilar solutions may have been involved.

Since underwater variants can exist of speleothems formerly thought to grow only in air, genetic histories of some caves may need to be reconsidered, especially where there is evidence for unusual chemistry.

*NON-CARBONATE MINERALOGY IN CALIFORNIA
CAVES: BLISTERS, FLOWERS, AND FLAKES IN THE
GOLDEN STATE'S UNDERGROUND*

Bruce W. Rogers

Twenty-eight non-carbonate minerals, mineraloids, and related inorganic compounds have been identified by x-ray diffraction, X-ray fluorescence, and optical methods in California caves. Oxides and hydroxides, including Birnessite, Goethite, Hematite, Ice, Limonite, Manganite, Pyrolusite, and "Wad," most commonly form crusts and stalactites, but draperies, flowstone, helictites, crystals, columns and stalagmites are also known. Halite forms stalactites, flowers, crystals, crusts, flowstone, and stalagmites. Tinalconite forms crystals and crusts. Sulfates, including Barite, a barium sulfophosphate hydrate, Gypsum, Jarosite, Melanterite, Mirabilite, and Thenardite, commonly form crusts, crystals, flowers, cotton, and flowstone; rarely blisters, coralliods, blister fillings, or moonmilk. Phosphates including Fluorapatite, Hydroxylapatite, or Taranakite usually form moonmilk of flowstone, less often crusts, blisters, blister fillings, conulties, or stalagmites. Siscates including Amorphous Silica, Cristobalite, Quartz, and Silicates commonly occur as draperies, microgours, crystals, or blister fillings. Asphalt has been identified as "flammable" flowstone; Basaltic Lava as stalactites, draperies, flowstone, helictites, coralloids, and stalagmites; Uric Acid as pink flowstone and stalactites; and Mud as stalactites, draperies, and flowstone.

GEOLOGY OF BLACK HILLS CAVES

DYE TRACES AT WIND AND JEWEL CAVES

Marsh A. Davis, E. Calvin Alexander, Jr., and Scott C. Alexander

Rhodamine WT and Fluorescein dye traces conducted at Wind and Jewel Caves have demonstrated direct hydrologic connections between surface development and the cave immediately below. Rhodamine WT was flushed into the Jewel Cave sewage line in September 1985. Sporadic, short dye pulses were recovered at three sites along the scenic tour route within one week of the dye input. A second Rhodamine WT trace in July 1987 from Jewel Cave parking lot produced long lasting pulses in drips along the spelunking tour. Fluorescein and Rhodamine WT traces at Wind Cave in June 1986 and August 1986, respectively established connections between parking lot drains and cave passages below.

A more ambitious Rhodamine WT trace was begun June 22, 1987 from where Beaver Creek sinks about two miles north of the Wind Cave visitor center. Rhodamine WT began to be detected in the Wind Cave water supply well on August 25, 1987. While we believe this dye to be from the June 1987 dye input on Beaver Creek, it may be from the August 1986 trace.

WATER CHEMISTRY AT WIND CAVE AND JEWEL CAVE

Marsha A. Davis, E. Calvin Alexander, Jr., and Scott C. Alexander

Water samples collected from drips and pools in Wind Cave and Jewel Cave have been analyzed from temperature, pH, major and minor dissolved species. A wide range of chemical compositions have been found. The Mg/Ca molar ratios in Jewel Cave are often >1 while the Mg/Ca values in Wind cave are usually <1. PCWATEQ is being used to calculate the saturation indices of the water relative to various minerals. Initial results indicate that the Mg-rich waters of Jewel Cave are saturated with respect to huntite and magnesite as well as calcite, dolomite, and aragonite, which is consistent with the presence of Mg minerals in Jewel Cave. The source of these Mg-rich waters is problematical. Elevated levels of nitrates are sporadically present in the waters of both caves beneath surface structures and appear to be indicative of surface pollution.

A CHEMICAL AND ISOTOPIC INVESTIGATION OF THE THERMAL SPRINGS OF THE SOUTHERN BLACK HILLS

Marsha A. Davis, E. Calvin Alexander, Jr., and Scott C. Alexander

We have conducted studies that include mapping and chemical and isotopic analyses of thermal waters from springs and wells as part of a hydrologic investigation of the southern Black Hills karst. All of the waters were analyzed

for temperature, pH, major and minor cations and ions. Selected samples were also analyzed for ^{14}C , ^{13}C , ^{18}O , ^2H , U, $^{234}\text{U}/^{238}\text{U}$ A.R., Rn and ^4He . The field studies and the chemical and thermal resurgences in which waters with different chemistries and temperatures emerge in the same areas. Three separate components appear to be present: waters that have dissolved only calcite and dolomite; waters which have dissolved large amounts of calcium sulfate and gained magnesium presumably via dedolomitization reactions; and waters containing sodium chloride. Both the chemical and isotopic data indicate that the water's warmth comes from radiogenic heat production and/or enhanced local heat flow—not from chemical heat sources or a hypothetical local magma body.

U-SERIES STUDIES OF CALCITE PRECIPITATES IN LOWER WIND CAVE

Derel C. Ford, Arthur N. Palmer, and Peggy Palmer

Fifty U-Series measurements have been made on fragments of broken calcite wall crust and pool raft debris collected along the traverse between the cave entrance and the Lakes. They reveal that the lower cave has been draining as a backwater (as it is today) during the past 350,000 years. The water table fell at an irregular rate with temporary returns to higher levels. $^{234}\text{U}:^{238}\text{U}$ ratios in the water have been remarkably constant, pointing to a deep, regional source. This constancy permits the regional uranium best estimate (RUBE) extrapolation method to extend the dating range; it appears that these conditions have probably pertained for 600,000 years.

Earlier, the water table stood higher and $^{234}\text{U}:^{238}\text{U}$ ratios were variable. It is suggested that there was active discharge of thermal waters through the cave at this time, with a more significant admixture of meteoric waters to cause the U:U ratio to vary. A general model for the evolution of the cave will be presented.

GEOLOGIC HISTORY OF THE BLACK HILLS

Arthur N. Palmer

The origin of caves in the Black Hills is intimately linked to the diagenetic and erosional history of the Pahasa Limestone. Beds of gypsum and possibly anhydrite were deposited contemporaneously with the limestone, particularly in the middle dolomitic beds. Mobilizations, recrystallization, reduction, and solution of the sulfates caused fracturing and brecciation of the surrounding rock in lenticular zones, some nearly vertical and others sub-concordant with bedding. Remaining sulfates were replaced by calcite and quartz, producing competent calcite veins and incompetent friable textures within the adjacent bedrock fragments. Late Mississippian karst features preferentially followed these zones of weakness, although most dissolution was limited to the upper limestone beds, above the former sulfate zones. Caves formed at this time in the mixing zone between fresh infiltrating water and deeper saline water. They consisted mainly of irregular vaulted rooms, although some were fissures connected directly with the overlying karst surface. The surface depressions and

most of the caves were filled with clay and quartz sand early in the Pennsylvanian Period.

The present caves formed during the Tertiary Period in response to groundwater flow whose source varied with time from deep-seated inputs to surface inputs. Interpretation of their origin is complicated because they intersect both the ancient sulfate zones and the Paleokarst. Many of the upper levels are exhumed and enlarged paleo-caves, whereas most of the lower levels follow the former sulfate zones. Most of the present cave pattern is therefore inherited. The network outline of the caves is closely related to the stresses within the uplifting Black Hill during the late Cretaceous and early tertiary Laramide Orogeny. Yet the cave patterns were determined long before, during the Mississippian Period. Apparently the Black Hills uplift had a minor Mississippian precursor that established the present fracture system which were merely reactivated during the Laramide.

WIND CAVE: AN ANCIENT ARTESIAN SYSTEM MODIFIED BY HYDROTHERMAL ACTIVITY

Tom Miller

Radiometric dating of extensive calcite wall precipitates at Wind Cave, South Dakota, has established its age in excess of 350,000 years BP. Faulted conduit tubes, tilted precipitate surfaces, and extensive weathering accumulations suggest the cave may be millions of years in age.

Geophysical evidence indicates a local dike intrusion beneath the cave. This is a probable cause of the present high geothermal gradient in the cave, and its intrusion may have caused the dated precipitation event. This event has been attributed to hydrothermal waters.

The first hydrochemical survey in the cave, and earlier hydrologic data, support previous theories of artesian development for the cave, with later hydrothermal modification.

CAVE CLIMATE AT WIND CAVE

James A. Nepstad and James A. Pisarowicz.

Previous research has indicated that barometric winds account for Wind Cave's name. These winds have been recently recorded in excess of 150 km/hr. Studies of air movements and changes in temperature and relative humidity have exhibited different patterns for summer and winter and whether the man-made entrances to the cave are sealed or let open. In winter an open entrance leads to excessive, unnatural drying in the studied areas with relative humidity deviations of 10-15% compared with relative humidity measurements with the man-made entrance sealed. Temperature fluctuations of as large as 7 degrees have been recorded over 150 m into the cave depending on whether or not the man-made entrance is sealed or opened. Such changes were not recorded in the summer months. Implications of these findings for cave fauna and the management of the cave will be discussed.

HISTORY

GAGE CAVERN: A BRIEF HISTORY

Emily Davis Mobley

Recently James Gage donated Gage Cavern and forty acres of land to the National Speleological Foundation. Hopefully this land will be managed by the National Speleological Foundation. This is the most recent event in a long chain which started around 1831.

Gage Cavern was reportedly first discovered by Peter Ball. Since that time it was raped of its formations by John Gebhard Sr., John Gebhard Jr., and John S Bonny. It was visited heavily in the mid-nineteenth century. William H. Knopf even planned to commercialize it in the 1850s.

Within the twentieth century, Gage Cavern has become a very popular sport cave. A ladder was placed in the entrance in the mid-1950s by James Gage and a crew from the Schoharie County Jail. Since then the cave has been visited by thousands of scout and outing club groups. Although most of the formations were removed in the nineteenth century, the cave still has challenge and beauty.

ENDLESS CAVERNS, VIRGINIA, AND THE EXPLORERS CLUB

Russ Gurnee

Zirkle Cave, New Market, Virginia, was discovered and developed one year after the discovery of Luray Caverns. It was closer to the railroad, but lacked good management. It was not until the 1920s that the cave attracted the interest and investment of one Col. E. T. Brown. He was an enterprising business man, promoter; and his son, Major Edward M. Brown, was a member of The Explorers Club in New York. One of the Colonel's promotions was to have members of The Explorers Club search for the "end" of what is now called ENDLESS CAVERNS. The expedition was to attract national attention and focus interest on all of the many caves in the Shenandoah Valley of Virginia.

LEGEND OF THE BOOJUM, NORTH CAROLINA'S CAVE DWELLING "BIGFOOT"

Cato Holler, Jr., and Oliver Holler

Several American caves are associated with stories of Sasquatch or Bigfoot creatures. Ape Cave and Bigfoot are two of the better known. Not as many cavers are familiar with the Peter Bottom Cave monster of the Ozarks and fewer still with North Carolina's legendary Boojum.

The Boojum's Cave is reportedly located atop one of the rocky crags of the Plott Balsam Mountains. The creature is said to be related to the Abominable Snow Man of the Himalayas but is different in that it has developed an unusual fondness for certain precious stones of the Carolina mountains.

Dean H. Snyder

Cold Air Cave is a talus cave located just south of Delaware Water Gap in eastern Pennsylvania. Long known as a local curiosity because of the strong air flow emerging from its entrance, the tiny cave was commercialized by the turn of the twentieth century. Visitors could escape oppressive summer heat by enjoying the coolness of the cave air, a light lunch, and a pleasant stroll along the shaded walkways adjacent to the cave. Old postcards of those early days show a building constructed over the entrance, although only part of a foundation remains today. A general decline in tourism to the Poconos after World War II led to the closing of the cave. Cold Air Cave is on the property of the Delaware Water Gap National Recreation Area.

A BRIEF HISTORY OF LINVILLE CAVERNS

Nancy Holler

The cavern's presence was probably known by the native Americans whose artifacts have been found in rock shelters near the cave mouth. It is likely that soldiers of the American Revolution visited the cave on their way to the Battle of Kings Mountain. Probably the first written reference to the cave was that of Charles Lanman in his Letters from the Allegheny Mountains in 1849. In 1858 Henry Colton in writing for the North Carolina Presbyterian gave what is perhaps the best and most vivid description of the cave. Several years later, Civil War deserters used the Caverns as a hideout.

Other prominent explorers over the years have included Heriot Clarkson, who was later to become senior justice of the North Carolina Supreme Court, and geologist W. E. Hidden.

Following two expeditions led by Bill Neal in 1925, the Caverns receive considerable publicity in the Raleigh News and Observer. In 1937 commercial develop was begun by J. Q. Gilkey and several others who formed a local corporation. Unfortunately, a devastating flood his the area in 1940, closing the cave. It was then sold to the Collins family who spend considerable effort in cleaning up from the flood, and have turned the cave into one of the top tourist attractions in North Carolina.

TEMPLE CAVES OF THAILAND

William R. Halliday

Unlike the well-publicized temple caves of India, and some of those of China, which are man-made excavations, the temple caves of Thailand are natural karstic features. A visit to some of these caves in December, 1987, revealed an impressive interface of history, religion, art, cave management and conservation, biology, and much more, with an extraordinary potential for research interrelated with Buddhist art, Thai history, and similar topics.

SHOW CAVE SIGNS: A PASSING ART

Susan Holler

Public law 89-285, known as the "Highway Beautification Act of 1965", along with the other influences of time, education, and sophistication are continuing to press into history many of the colorful and interesting signs, billboards, and barn paintings advertising show caves.

Photographing these advertising media is one way to preserve such passing cave art forms.

GAGE CAVERN: A BRIEF HISTORY

Emily Davis Mobley

Recently, James Gage donated Gage Cavern and forty acres of land to the National Speleological Foundation. Hopefully, this land will be managed by the foundation. This is the most recent event in a long chain which started around 1831.

Gage Cavern was reportedly first discovered by Peter Ball. Since that time it was raped of its formations by John Gebhard, Sr., John Gebhard, Jr., and John S. Bonny. It was visited heavily in the mid-nineteenth century. William H. Knopfel even planned to commercialize it in the 1850s.

Within the twentieth century, Gage Cavern has become a very popular sport cave. A ladder was placed in the entrance in the mid-1950s by James Gage and a crew from the Schoharie County jail. Since then the cave has been visited by thousands of scout and outing groups. Although most of the formations were removed in the nineteenth century, the cave still has challenge and beauty.

DEMISE OF THE DOMESTIC SALTPETER INDUSTRY

Angelo I. George

With the close of the War of 1812 during the early months of 1815, the saltpeter industry died in Kentucky (Bidermann, 1815; and Faust, 1967). Saltpeter mines either closed or scaled back to pre-war levels of production. Was the end of the war, duty free imports (Meriam, 1844), cave closure and or scaled back production really the reason for the end of the domestic saltpeter industry?

To help answer this question, digested saltpeter purchase records of the I. E. du Pont de Nemours Powder Works gives insight into first quarter nineteenth century saltpeter mining in Kentucky, Missouri, Tennessee, and Virginia (du Pont, 1829). Important observations are the fluctuations in purchase price of saltpeter in response to national and international political climates, which prompted widespread investment, speculation, and growth in the short-lived domestic saltpeter industry. Development of the domestic powder industry relied upon the importation of cheap saltpeter from India. Increase in price occurred when that international source was cut from the American market in 1808. Price increases are related to Embargo Act (December, 1807), Nonintercourse Act (1809), and the War of 1812 (declared June 18, 1812). All of the saltpeter was then domestically produced from caves and rockshelters in Kentucky, Missouri, Virginia, and Tennes-

see. There were caves commercially mined prior to 1808, yet the great bulk of hundreds of smaller sites employed from 1808 to early 1815 is the result of these embargos and war with England.

E. I. du Pont (1829) said, "the caves of Kentucky, which had furnished the principal supply until 1814 were then generally exhausted, the richest had been worked and could produce no more; the Saltpetre manufacturers had to work caves of an inferior quality and at a greater expense." This would explain why there are so many small saltpeter caves mined. Poor cave management of the renewable resource exhausted the largest saltpeter sites and prompted the expansion of the mining industry in 1814, to more of the caves in Tennessee and Missouri. The height of active investment speculative saltpeter mining in Kentucky is bracketed from 1808 through 1813. With peace restored, du Pont and his competition could again receive cheap saltpeter from India. The last domestically produced saltpeter purchased by du Pont was in 1817.

HAROLD ANTHONY'S EXPEDITIONS TO THE GREATER ANTILLES

Fred Grady

Between 1916 and 1920 Harold Anthony, a mammalogist at the American Museum of Natural History, led three expeditions to the Greater ANTILLES: one each to Puerto Rico, Cuba, and Jamaica. Dr. Anthony was in search of caves containing living and fossil mammals and was quite successful in finding both. From June through July of 1916 he explored some 54 caves in Puerto Rico, covering virtually all parts of that island. A trip to Cuba in early 1917 was curtailed due to a revolution, and only a few caves were examined. Anthony's Jamaican expedition from November, 1919 to March, 1920, was the most ambitious, with more than 70 caves visited.

INTERNATIONAL EXPLORATION

CAVING IN TABASCO MEXICO

Jim Pisarowicz

Two seasons (1987 and 1988) of caving in Tabasco, Mexico has yielded 9.6 kilometers of surveyed cave. For the most part the caves mapped are in the lowland karst of Tabasco. The largest system of caves, as yet to be integrated into a single cave, is Sistema Agua Blanca. To date 5 km have been mapped in this area with approximately 4 km explored but not yet mapped. The largest single cave in this complex is Istac-Ha with a surveyed length of 2524 meters. Although not as extensive as the above mentioned caves, Cueva De Villa Luz (1150m) is an unusual sulphur cave. In this particular cave, the walls literally ooze sulphuric acid. Wall secretions in this cave had a measured pH of 1.

HUAUTLA PROJECT EXPEDITION 1985-1988

James H. Smith, Jr.

Prior to 1985, Sistema Huautla consisted of Sontano San Agustin and LiNita. During the 1985 expedition to Nita Nanta, three deep camps were fielded in two caves. A one week camp allowed explorers to survey the most remote penetration of Nita Nanta. Flooding prevented further exploration. Two eight day camps in Sontano San Agustin attempted forcing a connection to Nita Nanta, but instead a connection to La Grieta was discovered. The goal of the 1987 expedition was to attempt a connection between Nita Nanta and Sistema Huautla. Camp IV at the end of Kinepac Canyon was established to support a scuba dive. A connection through the Scorpion Sump linked the two caves. Additional exploration added two kilometers of vertical and seven kilometers of horizontal cave.

The 1988 Huautla Project Expedition met the three goals, to make a 16mm color movie, conduct extensive dye tracing, and continue exploration. Thousands of man-hours and a nine day camp were required to film Sontano San Agustin. Eleven dye traces revealed new deep hydrology routes and the resurgence to Sistema Huautla. Attempts to bypass the lowest sump by technical aid climbing failed. The exploration of Nita Ka added a new deep vertical cave.

PROYECTO PAPALO 1988 OAXACA, MEXICO

Carol Vesely and Bill Farr

In December 1986, Bill Farr and Carol Vesely began the explorations and survey of Cueva Cheve and the surrounding karst area located at 2700 meters elevation in the Sierra Juarez Mountain range of northern Oaxaca, Mexico. Subsequent trips in March 1987 and December 1987 pushed Cheve down 17 ropes pitches to -728 meters depth and 4.1 km length. In March 1988, 15 cavers returned and extended the cave to -1038 meters deep and 9.18 km long and still going strong. A higher cave was connected to Cueva Cheve making Sistema Cuicateca the 4th deepest cave in the Western Hemisphere. A stream flows into the main entrance and is joined by seven infeeders making the water flow at the deepest point of penetration about 0.5m³/s. Passages are generally spacious, clean-washed and contain a constant cool breeze (cave temperature is 47 degrees F). Average passage dip is 30 degrees. Another cave in the area, Osto de Puente Natural, has been explored down 15 wet pitches to 442 meters and is also still going with air flow and water. It is likely that both caves are part of one large system with the potential to be over 2 km deep.

RECENT EXPLORATIONS OF SISTEMA PURIFICACION, MEXICO

Dale Pate

Sistema Purificacion, located in the northeastern state of Tamaulipas, is currently the longest surveyed cave in Mexico. An eight day camp was set in the system during March, 1988 for the purpose of continued explorations and surveying. Camp I, located approximately 600 meters inside the lower entrance of the system, Cueva de Infiernillo, had

been utilized numerous times in the past. One of the most accessible portions of the system from this camp is the Confusion Tubes, where much of the 1988 explorations were concentrated.

The Confusion Tubes are a massive maze with many unexplored and unsurveyed passages. Numerous surveys were made in the eastern portion of the tubes, which have been less thoroughly investigated than the western tubes, but many were left unexplored. In an area off of the western tubes known as Ithilien, a number of new passages were also surveyed. On the eastern flank of the system, about 500 meters of new passage were surveyed in the Jersey Turnpike area.

An unexpected discovery was made via a climb into a high lead in the D survey, one of the areas of the cave first explored. The new section, named Arrakis, is a series of very dry passages that climb up and to the east. Nearly 2 kilometers of passage was surveyed in this area with numerous leads remaining.

The 1988 expeditions in sistema Purificacion netted 4 km of new passages, bringing the total traverse length of the cave to 71.6 km.

UNEXPLORED KARST AREAS OF MEXICO

Peter Sprouse

Over the past 25 years, exploration of Mexican karst has revealed some of the longest and deepest known in the world. The spectacular deep shafts in Mexico's tropical karst have attracted much interest in the speleological world. Yet much of Mexico's karst remains unexplored. The areas primary focus thus far have been the Sierra Madre Oriental, in the northeastern part of the country, and the Sierra Madre del Sur, south of Orizba. Even in these areas of intensive exploration, much remains to be found. Many other areas have scarcely been looked at. A number of large, high elevation karst areas in the southern states of Oaxaca and Chiapas appear especially promising as indicated by recently published topographical maps. It is hoped that these will attract the kind of quality caving projects that the world class caves to be found there deserve.

SUMIDERO OF THE RIO ATIMAS, HONDURAS T Z'UL MAS NIM, GUATEMALA

Steve Knutson

The exploration of the Sumidero of the Rio Atimas in Honduras proved to be one of the most technical and difficult ever done in the western hemisphere. The 2.5 km long through trip required 54 riggings involving a kilometer of rope and lots of hardware.

The Tz'ul Mas Nim is a large cave in the Guatemalan Highlands and was the focus for an NSS expedition in February and April 1988.

AEC/NSS JOINT EXPLORATION PROJECT

Douglas P. Dotson

During the Christmas holidays of 1987-1988, members of the NSS traveled to Costa Rica to meet with members

of the Association Espeleologica Costarriense and investigated the potential for major caving projects in Costa Rica. The second goal was to deliver a donation of vertical and surveying equipment to the AEC and provide training in vertical, cave surveying, and cave rescue techniques. The overwhelming success of this effort has established a close relationship between the AEC and the NSS and has established the potential for major cave systems in southern Costa Rica along with the discovery of several unique forms of cavernicolous fish and crustaceans. This slide presentation will describe the accomplishments of the 1987-1988 expedition and show the potential for further speleological studies.

THE NSS MAYA CAVES PROJECT: BELIZE, CENTRAL AMERICA

Barbara Schaefer and Buck Cobb

The NSS Maya Caves Project began in 1988. The project is ongoing, working in conjunction with archaeologist Dr. Rex Walters (Trial Research Service) in southern Belize. The goals are to (1) survey and document the known caves in the study area, (2) do a comprehensive survey to locate other caves in the area, (3) gather as much information as possible on the cave related work already done in Belize, and make this information available to the Department of Archaeology of Belize, the NSS, and others doing research in the area. The 1988 expedition worked in three areas (Laguna Cave, Roberto's Cave, Roberto's Shelter Cave, HokebHa), and doing reconnaissance in the Deep River Area. The caves all have archaeological significance, and the maps will be used in conjunction with the work in the Blue Creek, Deep River, and Rio Grande areas and initial exploration in the Edwards Central area.

CAVE EXPLORATION BELIZE: A HISTORICAL OVERVIEW THE CHIQUIBUL EXPLORATION IN COLUMBIA

Tom Miller

Maya Indians explored Belizean caves primarily between 650-950 A.D. Consequently, all cave exploration must be acknowledged by the Belize Dept. of Archaeology.

Deep water was the primary barrier to the Mayans. Cave entry occurred in the centuries following British settlement, but with little record until about 1890.

Modern exploration began in about 1958, with visits by W. Ford Young and Frank Norris. Barbara Macleod and Dave Albert of the United States first visited Belize in about 1970. Macleod was later joined by Carol Jo Rushin, and with the aid of locals Harriot Topson and Lucilo Sosa, and visitors such as Tom Miller, Logan McNatt, and members of the Sligo Grotto (Maryland USA), a small program of cave exploration and survey was begun, chiefly concentrating on the caves branch system.

The current phase began in 1976-1977 with the first of many field studies by Tom Miller. Aided by Logan McNutt and others, mapping 40 km in the Caves Branch area was completed by 1970. After 1979, most mapping occurred in the 50 km long Chiquibul Cave System during National Geographic-sponsored expeditions (1984, 1986)

*THE 1987 JAMAICA COCKPIT PROJECT AND
THE 1988 JOHN CROW MOUNTAIN KARST
RECONNAISSANCE EXPEDITION*

directed by Miller. The Rio Grande Project, initially led by Percy Dougherty, began in 1984 in southern Belize. A British university expedition and a return Chiquibul Expedition dominated 1988 exploration.

The sink of the Chiquibul river was first visited in 1970 by Mike Boon, but logs prevented entry. A solo visit by Tom Miller in 1982 found the sink open, and located fossil entrances.

With funding by National Geographic, the participants, the NSS, and the Explorers Club, groups of 8-10 men and women geologists, archaeologists, and cavers from five countries explored the system for two months in 1984, surveying 23 km of passages up to 110 m wide. The largest room in the hemisphere was discovered: 300 m long and 150 m wide. Many Mayan artifacts were recovered and a new species of cave life identified.

The 1986 expedition was again funded by the National Geographic for a two month cave camp. It surveyed an additional 27 km of passage up to 150 m wide and followed the river beneath the border to emerge at its 200 m wide resurgence in a Guatemalan gorge. The 50 km total passages included the largest cave in Central America and the deepest cave in Guatemala.

A third expedition is scheduled for May, 1988.

Colombian cave exploration began in 1851 when a priest, Romualdo Cuervo, was lowered 120 m by basket into the Hoyo del Aire, the world's deepest descent at that time.

Presently, a few score caves have been recorded, mostly of limited extent and distributed primarily along the length of the eastern Andean cordillera and in the Magdalena River Valley. Most are of vadose development, and far exceed phreatic caves in size and frequency.

The recent age of the Andean uplift limits the beginning of cavern genesis in most of the country to the Pleistocene of post-Pleistocene. Colombian Geologic history implies that future karst discoveries will be primarily within these same areas and in the Cretaceous carbonates that are the great karst formers of the Caribbean and circum-Caribbean region.

CAVES OF BRASIL

James C. Magnusson

On a recent trip to Brasil I visited about a dozen caves. Brasil has many, many karst areas, some very different from the others. They have mountainous karst in a beautiful tropical forest, karst in some very arid regions, karst in woodlands, and karst in jungles. A majority of their caves contain water and/or a river. Very few are completely dry. Many caves exhibit a dendritic pattern, but there also exist joint controlled maze caves. These are in the minority. The longest cave in Brasil, Gruto do Padre, is 15.8 kilometers long. It was discovered 1986. The speleothems and their abundant numbers were most interesting to me. Calcite rafts, helictites, cave pearls, flowstone, and giant rimstone dams are incredibly abundant, as is virgin passage. Best of all are the volcanoes, found only in Brasil. They are still not adequately understood. The slides in this presentation were taken by Jose Ayrton Labegalini, an NSS member, and I am presenting them on his behalf.

Mike DiTonto

In February 1987, an eleven member crew assembled for two to three weeks in the southern cockpit country. Despite problems, due to military actions in the interior of the Cockpit, many caves were discovered. A major resurgence was explored and over a kilometer was surveyed with nine blowing leads remaining; two other resurgences were explored and partially surveyed and they still go.

A six member crew backpacked into a limestone mountain range on the eastern tip of Jamaica. This mountain consists of a limestone mountain formation approximately 1000 feet thick, reaching an elevation of 3,750 feet dipping to the northeast at 12-15 degrees to sea level, which is four miles away. It is covered with a virgin, upper montane rain forest and elfin woodland receiving in excess of 300 inches of rainfall per year. Will this limestone prove to contain a major cave system?

*AUSTRALIAN CAVES AND CURRENT
ONGOING EXPLORATION*

Bru Randall and Barb Schomer

Australia, one the most ancient of continents, is cave poor by American standards. But it has some of the most intensely decorated caves known. This presentation will cover some of the better known caving areas of Australia, as well as some of the little known and rather remote ones. We will also be able to answer questions for people planning a return visit sometime in the next few years.

*PRELIMINARY RESULTS OF THE 1988 CRF
EXPEDITION TO SOUTHERN CHINA*

Ron Bridgemon

In March, 1988, the Cave Research Foundation sponsored an expedition of twelve caves to karst regions in southern China. The expedition was a cooperative venture between the foundation, the Speleological Society of South China Normal University (Guangzhou), and the Institute of Karst Geology (Guilin).

Karst, caves, and associated fauna were studied in Guangdong, Hunan, and Guangxi Provinces. The previously unentered Tong Tian Luo Shaft (80 m across x 100 m entrance drop) in Northern Guangdong was surveyed and examined. In southern Hunan, efforts were centered around the spectacular Wahhuayan Caves. The expedition mapped over 8 km of cave passage.

Team members representing the National Park Service, the Bureau of Land Management, and British Columbia Parks presented papers and suggestions for cave preservation and the development of tour caves in China.

PALEONTOLOGY

MAYAN CAVE EXPLORATION IN BELIZE

Tom Miller

Mayan cave activities in Belize are largely known as a by-product of cave surveys (>110km) acquired by geomorphic research in river conduits and collapse chambers. Caves were visited for ceremonial and utilitarian purposes related to Mayan mythology (burials, clay and water sources, etc.), and were rarely used as dwellings. Most Mayan entry occurred in their Classic Period (300-900AD).

Exploration evidence comprises artifacts (ceramic, lithic, skeletal, torch remains etc.), foot- and hand-prints, and trails. Most activity was in the twilight zone, but in large, dry passages the Maya penetrated at least 2000 meters. Exploration was usually barefoot, using pine torches. Ladders and cut footholds accessed ledges, pits and surface shafts to 150 meters depth. Cave lakes were effective barriers, crawlways were not.

Three broad divisions of usage are indicated: 1) Chiquibul assemblage: internal wall construction and lack of skeletal remains broadly correspond with surface agricultural terraces; 2) Caves Branch: a general absence of cave walls and surface terraces, and a higher frequency of burial remains; and 3) Toledo: an area of limited visitation with mixed ages and styles.

IN THE BASEMENT OF THE ROCK: CAVES OF ALCATRAZ

Bruce W. Rogers and John Martini

Avoided by the Mi-Wuk and Costanoan Indians for over 4700 years as an island that "no good will come from," Alcatraz is a 12 acre block of sandstone and shale situated in the middle of San Francisco Bay. It is a portion of the "suspect" Alcatraz terrane of the Franciscan assemblage. Fossil clams, oysters, shrimp, and crabs date the rocks as lower Cretaceous, 132-138 million years old. Discovery and charting of "The Island of the Pelicans" by Juan Ayala in 1775 gave notice to the sea birds that their little island was about to be usurped. The US Army fortified Alcatraz from 1853-1907, building a large brick citadel. Between 1907-1933 it was used as a Military Prison. The Federal Bureau of Prisons rebuilt and used it as a maximum security facility from 1933-1963. A short Native American occupation, 1969-1971, preceded inclusion in Golden Gate Recreation Area. Rumors of "Spanish dungeons" and "Caves leading to the sea" proved to be remains of the brick citadels passageways, cisterns, and drains, a concreted-shut sea cave and several open sea caves with intact marine communities.

HAMILTON CAVE, WEST VIRGINIA: PALEONTOLOGY UPDATE

Fred Grady

The screening of cave earth for fossils from Hamilton Cave in Pendleton County, West Virginia has been an ongoing project since 1983. Various taxa have been sent out

to respective experts. Based on microtine rodents the age of the main fauna in Hamilton Cave is believed to be about 800,000 years making it the oldest well documented cave fauna in the Central Appalachians. One new microtine rodent is being described and a bog lemming shows an interesting intergradation between two forms. Work is nearly completed on the description of the large cheetah like cat.

FOSSIL VERTEBRATES COLLECTED BY THE NSS JAMAICA EXPEDITIONS

Fred Grady

Fossil vertebrates were discovered during the 1986 NSS Jamaica Cockpit Expedition. During the expeditions of 1986 and 1987 samples were collected from four caves, the most significant from Bonafide Cave. Remains of amphibians and reptiles are numerous but not yet studied in detail. At least 8 different birds are recognized including hummingbirds, a swift, a dove, an owl, cuckoo, and several different perching birds. Among the mammals which have been studied in more detail than other groups so far, there are 10 different bats and 3 different rodents. One bat species, *Brachyphylla nana* is extinct and this is the first record of it in the cockpit country. Carbon-14 dating of the lowest levels of the Bonafide Cave deposit suggest that it goes back to the late Pleistocene. In addition to vertebrates, significant collections of gastropods have been made.

ABORIGINAL SKELETONS AND PETROGLYPHS IN OFFICER CAVE, TENNESSEE

P. Willey, George Crothers, and Charles H. Faulkner

In 1987 NSS Cavers discovered human skeletal remains and petroglyphs in Officer Cave, White County, Tennessee. The petroglyphs are four human heads of faces scratched into the limestone wall of the cave. They are similar in style to glyphs and other art forms dating to the Mississippian period (AD 900-1500). The skeletons may or may not be associated with the glyphs. At least 15 individuals (2 infants, 3 children, 1 adolescent, and 9 adults) are represented. Officer Cave is one of two caves now known in the southeast to contain both aboriginal skeletons and petroglyphs. This important find would have gone unnoticed without the efforts of NSS cavers.

MAYA CAVES ARCHAEOLOGICAL PROJECT: 1988

Dr. Gary Rex Walters

The on-going Maya Caves Archaeological Project is designed to define the various manifestations of ceremonial cave use by the ancient Maya of Southern Belize and relate them to surface sites that occur in the region. These goals are being accomplished by (1) an extensive, long-term, settlement pattern survey/surface collection program to locate cave/archaeological sites and determine their approximate temporal placement, and (2) a series of intensive, short-term, site specific, mapping/surface collection/excavation programs to clarify, quantify, and elaborate previously gathered data within this area. Southern Belizean

caves explored during the course of the project's 1988 field session (Feb-Apr) appear to have been used, varyingly, by the ancient Maya as/for (1) possible sources of drinking water, (2) sources of "virgin" water for religious rites, (3) religious rites, (4) art galleries used, perhaps, in connection with religious rites, (5) burials, and (6) depositories for ceremonially placed/discarded pottery vessels and/or other utensils.

SURVEY AND CARTOGRAPHY

KARST RESEARCH AND KNOWLEDGE: DO WE NEED KARST INFORMATION SYSTEMS?

John Ganter

Karst study, both as theoretical and applied research, and in the service of engineering, considers problems which are fundamentally spatial. Examination of three explanatory studies (at regional, karst basin and cave passage scales) reveals that information is dealt with at several logical and measurement levels, covers a remarkable size range, and is stored in a variety of formats. Hypothesis generation, induction, and analogous reasoning all seem to involve cognitive processing (setting up, refining, and correcting a "mental model"), tacit thought (problem-solving drawing on short and long term memory), and the generation of explicit knowledge in both propositional (text) and image form. A cycle ensues in which the geologist interacts with both this "created knowledge" and the phenomenon, testing and refining each against the other. The possibility of using digital means to provide increased interaction between geologist and information is examined, and some design criteria are presented.

STATISTICAL ASPECTS OF CAVE SURVEYING

Langford Brod

Station line lengths were compiled from the survey notes of several large caves in Arizona and Missouri, and the lengths were tabulated in one-foot increments. Cumulative distributions of number vs. length were plotted to obtain the means, and histograms were prepared. The length plots were unimodal but not Gaussian, with the means dependent upon cave geometry. Curve fitting showed that the distributions most closely fit the equation $N - KL \exp(L)$ where L is proportional to station line length. For small angular errors, the displacement error was considered to be perpendicular to the station line and proportional to the product of compass angle error and station line length. Total displacement errors, were generated using Monte Carlo methods in a computer program. The total displacement error was a function of assigned error parameters.

MICRO-BASED CAD FOR CAVE MAP DRAFTING

Miles Hecker

In the 1986 convention at Tularosa the author presented the results of the first large scale full cave map attempted on a computer. The map of three mile lone Fossil

Mt Ice Cave presented at that time was done almost totally on a VAX minicomputer costing \$100,000. Since that time the techniques used have been successfully transferred to work on an IBM PC or PC/AT microcomputer costing less than \$1,500. The software techniques and hardware used to produce the new map of six mile lone Horsethief Cave on such a system will be discussed.

USE OF LORAN-C EQUIPMENT FOR KARST INVENTORY PROJECTS

Robert Hoke

LORAN-C is a radio navigation system that allows ships to determine their absolute latitude and longitude easily. Relatively cheap (\$650) portable units have recently become available and one is being used to pinpoint caves and karst features in Pendleton County, West Virginia. Despite the area's rugged terrain the unit is normally able to determine locations within 200-300 feet when proper operating procedures are followed. Accurate location of a karst feature depends on numerous factors, including area of the county, LORAN signal strength, proximity to a known geological location, weather, and terrain. Standard procedure normally involves calibrating the LORAN unit at a nearby road intersection that can be accurately located on a topo map, then walking to nearby karst features. The LORAN unit constantly displays the correct latitude/longitude as the user walks to each feature. This unit is being used gathering location data for a planned publication documenting the caves of Pendleton County.

AN EVALUATION OF THE AUTOHELM PERSONAL COMPASS FOR CAVE SURVEYING

Roger V Bartholomew

A battery operated electronic fluxgate compass with a digital liquid crystal display readout developed by Nautech, Ltd. in England has recently become available in the US. The compass is used for sailing navigation and is water-proof. specification: fluxgate compass $\pm 1^\circ$, basic accuracy $\pm 2^\circ$, repeatability over three bearings within 3° . No compass needle means no settling time and no delay: just point and press a button. A ten minute memory stores up to nine bearings, as fast as you can click the record button. It has a stopwatch: 0 to 10 hours count up or a ten minute to zero countdown. The compass looks like a stretched Suunto (6"x2.25) and has gunsight devices along both top edges. Although the accuracy is rather poor, its speed and elimination of Suunto scale fogging problems may make it useful in difficult cave surveying situations. Results of closed loop traverses will be presented.

DISPLAY OF SURVEY CLOSURE ERRORS

Robert Thrun

With the routine computer processing of cave survey data, we are able to evaluate survey closure errors. The closure errors are approximately the lower bound on the random errors in the survey. The problem is how to evaluate the closure errors to see how these errors compare between

surveys. A simple one-number average is not satisfactory. Different parts of the survey have different error. Various quantities may be plotted on a graph: absolute adjustment (error), percentage adjustment, comparison with assumed error, length of adjusted string, number of shots in string. These may be plotted with linear, log, or cumulative scales. The purpose of this paper is to show how the computer output may be displayed so that we can evaluate the survey errors. Only then may we begin evaluating surveys.

PLANETABLE, THEODOLITE OR COMPASS? SEARCH FOR ACCURACY IN SURVEY OF A LAVA TUBE RESEARCH PRESERVE IN HAWAII

Fred D. Stone, University of Hawaii at Hilo; and Darrel Tanaka, University of Hawaii at Manoa

As a condition for establishing a proposed cave research center and preserve on the island of Hawaii, the state Land Management Division required an accurate survey of a lava tube. Due to closure errors, we surveyed the tube 3 ways using the same stations; with planetable and alidade, with theodolite, and with two tripod mounted compasses. We used Lotus 1-2-3 to analyze and compare survey data and to produce the cave maps with land boundaries superimposed.

Survey accuracy was determined from a 650m transect between two entrances with a 658m surface closure, and by comparison of the 3 surveys. Closure errors for the 3 surveys were: alidade, 12m; theodolite, 18.7m; compasses, .4m. Although theodolite sightings were the most accurate (2 per station, average difference 4.5' std 4.8'), and compass the least (avg. diff. 21' std 1°44'), total closure gave opposite results. The reason is that both theodolite and alidade sightings are turned from previous sightings, so errors are cumulative, while compass sightings are independent, and errors cancel. Effects of paleomagnetism and iron minerals on compass readings were apparently not critical. Use of the planetable allowed detailed mapping of cave features, and future work will combine 2 tripod mounted compasses with planetable mapping.

UNITED STATES EXPLORATION

LECHUGUILLA CAVE PROJECT

Richard Bridges

An overview of the discovery, exploration and mapping of Lechuguilla Cave in Carlsbad Caverns National Park. Lechuguilla's entrance pit and 250 feet of passage had been known since the early 1900's, but it wasn't until May 1986 that a digging effort broke through into significant new cave. As of February, 1988 there have been five expeditions resulting in 12.86 miles of cave mapped to a depth of 1207 feet. Much of this passage is large borehole and walkways with no significant crawlways. Over 95% of the cave is developed deeper than 600 feet below the entrance and many leads remain at depths of 750 to 1100 feet. More than 125 people from 16 states and 3 foreign countries have participated in the exploration and mapping.

Slides and color line plots, as of the May 1988 expedition, will be presented documenting the discoveries and important formation areas. The basic geology, methods of expedition organization, mapping, computer use in the field and future explorations will also be discussed.

EXPLORATIONS IN SPANISH CAVE, COLORADO

Jerry Hassemer

Captain Elisha Horn claims to have found a cave in the Sangre De Cristo Range in 1869 with a cross painted on a rock at the entrance and a skeleton in a suit of armor nearby. In 1919 an Indian woman claims to have played at the same cave as a child while Indians and Spaniards took gold from the cave via a lower entrance. It was not until 1932 that any known recorded exploration took place. Old wooden ladders and a crude windlass were found, but no gold. Then in the 1950s members of the Colorado Grotto make several trips to the cave and mapped the lower section of the cave to the "Gold Diggings". Between 1958 and 1962 Donald Davis led explorations that resulted in finding a higher entrance and connected it with the main entrance. In 1973 members of the Colorado Grotto mapped the major passages in the upper section of the cave. Located between 11,000 and 12,000 feet, the cave is cold, damp, and truly a caver's cave.

A WET DREAM: THE EXPLORATION OF HONEY CREEK CAVE, TEXAS

George Veni

Following a lead from a state geologic report of a spring discharging from a cave, Bill Russell first visited Honey Creek Cave in 1961. The cave was large conduit averaging 5 m wide and 8 m high, most of that height being filled with water, and was explored 400 m to breakdown. The cave continued on the far side of the breakdown, but with deep water and little airspace. With the advent of modern wet-caving techniques, the present Honey Creek project began in 1980 swimming past the breakdown into more than 26 km of mapped passages. Honey Creek Cave is a well integrated underground stream network requiring a full wetsuit and flippers for several kilometers of swimming in the main passage. Wading and "salamandering" is the norm for the cave's side passages. New meaning has been given to the term "low airspace" as explorers have pushed on with as little as 2 cm of air in Honey Creek Cave. Over 160 leads remain in Texas' longest cave, which certainly qualifies as one of the best water caves in the world.

THE BIGHORN CAVE PROJECT AND AREA OF LITTLE MOUNTAIN, WYOMING/MONTANA

Scott Fee

The third and final NCRI field camp ended on August 16, 1987. This year the multi-mile cave was pushed, explored, surveyed, and photographed by 42 cavers from all over the US and one caver from the Netherlands. The project volunteers were organized into survey, inventory,

geology, and photomonitoring teams. The program will be a generalized overview of the scenic Little Mountain Area. Emphasis is on Bighorn Cave though Horsethief Cave and Natural Trap will also be highlighted.

TITAN CAVERNS

Robert Montgomery, Darrell Austin, and Monte Harmden

A significant cave discovery was made in the Little Mountain Cave area of Wyoming in 1987. On October 11, 1987, after several sessions of digging by members of the Bighorn Project and the Main Lead Grotto, a breakthrough was made and the cave entered. At the end of the room encountered by the entrance dig a small hole, with substantial air movement, was enlarged to allow access to the major section of the cave. This part of the cave consists of a very large room approximately 900 feet long, with a flat sediment floor, ranging from 50 to 200 feet wide and 6 inches to over 50 feet high, along with several leads. On October 17-18 the cave was explored and surveyed as a part of the first Speleological Survey. Over 2800 feet was surveyed and a chamber discovered containing many formations. Presently the cave has been surveyed to a length of 2883 feet with a floor area of 142,242 square feet and a volume of 2,087,486 cubic feet. There is a great potential for additional passage to be found due to the air movement near the entrance and additional passage that has been discovered. The discovery of additional passage will probably require more digging, however.

SULLIVAN'S CAVERN, BOWLING GREEN, KY

Philip P. Reeder and Nicholas C. Crawford

Sullivan's Cavern is ideally located to possibly provide access to the truly "lost" portion of Lost River Cave downstream of the terminal breakdown at the Alexander Entrance into the system. Access to this downstream portion of Lost River Cave is desired not only to add length onto the system, but foremost to locate the Lost River's flow route, thus indicating the path that contaminants would flow beneath the city.

Exploration and mapping began in Sullivan's Cavern in March 1986, with the most substantial efforts occurring in February and March 1988. In late February 1988, a dig sufficiently enlarged a crawlway to allow entry into a 200 foot stream passage that sumped at each end. This stream was dye traced and found to be the Lost River. Exploration in late March located a route around the upstream sump and yielded 800 feet of trunk passage in which the Lost River was flowing. Unfortunately this passage also sumped upstream. Exploration continues to bypass the upstream and downstream sumps, thus providing further information on the Lost River's flow route and possibly connecting Sullivan's Cavern with Lost River Cave.

SEA CAVES OF THE NA PALI COAST, KAUAI, HAWAII

Dave Bunnell

A 5-man expedition to the Na Pali coast in August 1987 mapped almost 2 km in a dozen large sea caves, the

largest over 350 meters long. The team used a motorized inflatable raft and inflatable kayak to reach the caves. The caves were found to be formed in Pliocene age volcanic rocks along dikes which offer less resistance to littoral erosion. Pillow lavas were noted in some caves and apparently have not been previously reported in Kauai.

EXPLORATION OF OLAA CAVE, HAWAII

Bob Richards

40 kilometer long lava flows erupted down the northeast slope of Kilauea from a parasitic lava shield. Lying high on this flank of Kilauea is Olaa Cave, an exciting wild cave, with numerous lava falls, some up to 20 meters in height. Over 6 kms were surveyed, to a depth of 221 meters during August, 1987. Olaa is a vast, sinuous tunnel, with up to four levels stacked on top of each other, sub-circular passage sections and a roof that in places is draped with conical stalactites, indicating that for much of its length the active tube carried full-bore flow.

It is believed that there are many extremely long caves in the region, only a few of which have been entered because the area is covered by dense forest. The Big Island holds the promise of enormously long lava tube caves, some of which may possess a vertical range of the deepest limestone caves; Olaa Cave is just one of them.

**ABSTRACTS OF THE
NATIONAL SPEOLOGICAL SOCIETY
ANNUAL MEETING, July 31 - August 4, 1989
Sewanee, Tennessee
Norma Peacock, Editor**

ANTHROPOLOGY AND ARCHAEOLOGY

*AN EXAMINATION AND ANALYSIS OF AUSMUS
BURIAL CAVE (3CE20)*

Carole E. Tucker, Dept. of Anthropology, University of Tennessee

Ausmus Burial Cave (3CE20), a small limestone pit cave, located in Claiborne County, Tennessee, was first analyzed by W.D. Funkhouser and described by William S. Webb in Webb's 1938 report An Archaeological Survey of the Norris Basin in Eastern Tennessee. The physical and archaeological remains from the cave are being reanalyzed in order to respond to several questions concerning human internment in pit caves. This sample is important because so few remains recovered from burial caves have been reported and/or published.

The cave dates to the Late Woodland/Early Mississippian period (700-1100 AD). At least 24 individuals were recovered from the cave on three separate occasions. These individuals range in age from infant to adult with both sexes represented. Several pathologies are noted on the bones, namely: craniostenosis, dental caries, arthritis, and possible treponemal infections.

The descriptions of the remains and the cave itself lead to comments concerning how archaeological and physical anthropological techniques have changed from the 1930s, and how comments and conjectures made by archaeologists during this period should be questioned by present-day anthropologists.

*BONE MATERIAL RECOVERED FROM A WOOD RAT
MIDDEN FROM OFFICER CAVE, TENNESSEE*

Walter E. Klippel and Lee Meadows, Dept. of Anthropology, University of Tennessee

The taphonomic processes that occur to human and nonhuman skeletal material are of interest to physical anthropologists as well as zooarchaeologists. Modification of bone may occur in several forms such as carnivore chewing, burning, postmortem breakage, and rodent gnawing among others. The present study investigates the activity of wood rats and the effects these rodents may have on sites, particularly those in caves. An abandoned wood rat midden located in Officer Cave (40WH98), White County, Tennessee, was excavated and examined for any bone material. The bones recovered included both human and nonhuman material. All of the bone material was examined for chewing. Of the 260 bones (fragments and teeth), chewed bone

represents 27% of the total. The six burned or cremated bones do not show any evidence of chewing, which may indicate that the calcined bone was either too hard or was lacking in the nutrients the rodents were seeking. This study has shown that wood rats do collect and carry bone to their nests or middens and that wood rats do chew on this bone. While only 27% of the bone from this study was modified, a large number of the bones showed no evidence of wood rat activity other than collection. Rodent activity can have very important consequences when dealing with site composition, faunal analysis, and intrusiveness.

LITTLE BEAVER CAVE, BARTOW COUNTY, GEORGIA

Joel and Carole Sneed

In the early Spring of 1986, a cave was discovered by Joel M. Sneed that, while quite small in size, has proven to be a worthy addition to the study of Indian usage of caves for burials, and it may, in fact, be one of the few remaining Indian burial caves that have been undisturbed. While Joel and his wife, Carole, were mapping the cave, pottery and bones were discovered, which were then brought to the attention of Dr. P. Willey at the University of Tennessee.

Little Beaver Cave, located in Bartow County, Georgia, is formed in a small knob of Knox Dolomite. The cave consists of only some one hundred fifty feet of passage, with a vertical entrance drop of nineteen feet as well as another entrance that sumps after a short distance. Little Beaver Cave offers an interesting history from early Indian times up into the twentieth century.

*ARCHAEOLOGY AND HUMAN BONE CONTEXT IN
LITTLE BEAVER CAVE*

George M. Crothers, Dept. of Anthropology, University of Tennessee

Preliminary investigations in Little Beaver Cave indicate that it was used as a Copena-like burial cave during the Middle Woodland period (ca. AD 200-600). Although human burials were probably placed in the cave in a relatively intact anatomical position, geological and hydrological forces have altered the bone deposits. Human remains recovered in a small test excavation represent several individuals, but it is difficult to reconstruct individual skeletons without careful, controlled excavations. The results of our attempt to combine osteological and archaeological information to reconstruct individual skeleton is presented.

*EXCAVATED HUMAN SKELETON FROM LITTLE
BEAVER CAVE*

P. Willey, Dept. of Anthropology, University of Tennessee

A one-meter square was excavated on Little Beaver Cave, Georgia, to recover human skeletons. A preliminary analysis of the human bones recovered from the excavation is presented.

Parts of at least seven individuals are presented. They represent most age groups: namely, one infant (?), two children (3-4 years and 6-8 years), and four adults. Both sexes (three females and one male) are present. From this

distribution, it appears that all age groups and both sexes were included in cave burial.

Several cultural practices are evident from the remains. Pronounced cradleboard flattening is present on one of the two adult skulls recovered, indicating a child-rearing practice. Dental attrition is moderate, indicating a gritty diet that is typical of many aboriginal groups. Some of the elements are completely burned, indicating cremation for some of the individuals or parts of individuals.

Taphonomic processes can be inferred from the remains. Based on the presence of small bones from the extremities, at least some of the burials were primary deposits, not decomposed or dismembered above ground and then placed in the cave. Exposure of the bones in the cave varied as indicated by difference in bone weathering and rodent chewing.

*BIOARCHAEOLOGY OF SEMINOLE SINK:
A VERTICAL SHAFT TOMB FROM THE LOWER
PECOS-RIOS GRANDE CONFLUENCE*

M.K. Marks, Dept. of Anthropology, University of Tennessee; J.C. Rose, Dept. of Anthropology, University of Arkansas; and S.A. Turpin, University of Texas

In 1984, comingled human skeletal remains representing at least 22 individuals from two archaeological periods (Archaic and protohistoric) were exhumed from the talus cone of a large subterranean solution sinkhole in Seminole Canyon Historical Park, Val Verde County, Texas.

The lifeways of Archaic cultures have been alternatively characterized as either harsh and maladaptive or adequate and successful. To determine the adaptive "efficiency" with which the Seminole Sink Archaic culture adapted to their particular arid ecology, we employed four specific objectives to our osteological analysis" 1) Taphonomy, 2) Paleodemography, 3) Paleoepidemiology, and 4) Dietary reconstruction.

The individuals were lowered into the sinkhole in fleshed, articulated condition where they were reduced to at least 5,00 small bone fragments by decomposition, water action, roof spall crushing, root scattering, and rodent gnawing. The Archaic burials consisted of at least eleven subadults and ten adults, which include at least three males and one female between 20 and 24 years. While the adult stress markers reveal low infection, osteoarthritis, osteophytosis, and trauma rates, the relatively high number of subadults in the sample and the high frequency of dental enamel hypoplasia (a childhood stress indicator) suggest high childhood morbidity and mortality.

The abnormally high caries rate and extensive dental attrition suggest consumptions of a coarsely prepared, high-fiber diet that contained large quantities of carbohydrates and sugars. Early loss of the mandibular molars to caries resulted in exposure of vulnerable root surfaces in the surrounding teeth which gradually lead to an edentulous condition. Such a phenomena has been reported in other West Texas Archaic skeletal series.

*PRELIMINARY RESULTS OF THE ARCHAEOLOGICAL
INVESTIGATION OF BERING SINKHOLE: A STRATIFIED
SINKHOLE CEMETERY IN CENTRAL TEXAS*

Leland C. Bement and Solveig A. Turpin, Texas Archaeological Research Lab, University of Texas

Human and cultural remains recovered from Bering Sinkhole, 41KR241, a karst feature in central Texas, show that this vertical shaft cavern was used as a cemetery during at least 6 major episodes between 1000 and 6000 years ago. A minimum number of 26 individuals, including both sexes and all age groups, indicate the sinkhole served all members of society. The recovery of articulated elements indicate the burials were primarily interments with the exceptions of at least two cremations. Grave furnishings including tubular bone beads, projectile points, deer antler, freshwater mussel shell, and a cache of 14 large bifaces and 1 drill suggest the sinkhole functioned as a true cemetery with all the social implications, rather than just a convenient repository for the dead.

*EXPERIMENTAL REPLICATION OF EARLY WOODLAND
VEGETAL FIBER SLIPPERS*

Joan Miller

Certain twined artifacts from the Mammoth Cave, Kentucky, area are described, together with a detailed analysis and experimental replication of the twining procedures by which they were constructed.

*GEOLOGIC FACTORS IN THE PRESERVATION AND
MANAGEMENT OF THE MAYA NAJ TUNICH CAVE
PAINTINGS, PETEN, GUATEMALA*

George Veni, Dept. of Geosciences, Penn State University

Naj Tunich is a cave of the Peten of Guatemala and contains the largest assemblage of Maya cave paintings known. Finely composed Late Classic scenes and glyphs are drawn onto the cave walls with a black, carbon-based paint. The walls are a brecciated limestone and some differential paint absorption occurs between the clasts and matrix. The paint does not contain a fixing agent for it to properly set and so the paintings can be easily smeared. The primary cause of deterioration of the paintings is due to the geologic nature of the cave walls. The paintings are in a very dry section of the cave. The walls are covered by a veneer of fine silt which is a weathering product of the wall's slow dissolution. The paintings deteriorate as this silt, with paint attached, slowly falls off the walls. Visitation of the cave has also resulted in the destruction of some paintings. Stricter management procedures are necessary for any tours that view the paintings. Research is needed on the increase in atmospheric carbon dioxide in the cave, due to human traffic, which will increase the rates of deterioration of the cave walls by dissolution of the limestone.

PREHISTORIC PICTOGRAPHS IN
SOUTHEASTERN CAVES

Charles H. Faulkner, Dept. of Anthropology, University of Tennessee

Since 1982, prehistoric art has been found in the dark zone of several caves in the southeastern United States. This art can be classified as petroglyphs, mud glyphs, and pictographs. Petroglyphs are the most common of the rock art and are incised or pecked into the rock walls. Mud glyphs, drawings made in the soft mud on cave walls and floors, were not reported until the study of Mud Glyph Cave in Tennessee in 1982. These glyphs have subsequently been discovered in two additional caves. Pictographs are drawn on rock walls with pigments such as ocher or charcoal. These drawings have been reported in caves, probably because most cave walls are covered with historic graffiti, predominantly drawn with charcoal or carbide. During our research in petroglyph caves, prehistoric pictographs were discovered associated with incised and pecked decorations. These have been found in petroglyph and mud glyph art. Like the latter prehistoric wall decorations, these pictographs are believed to be ceremonial art. Their rarity may be due to their fragile nature or to the fact that they have been misidentified as historic graffiti.

MODELING PREHISTORIC SITE
SELECTION IN MAMMOTH CAVE
NATIONAL PARK, KENTUCKY

Guy Prentice, Archaeologist, National Park Service, Southeast Archaeological Center

The National Park Service has just completed a three-year archaeological survey of selected portions of Mammoth Cave National Park in order to develop a site settlement model for different periods of prehistoric occupation in the Mammoth Cave area. The survey sampling strategy and the results of the survey will be discussed along with the various factors which predict where prehistoric sites will occur and why certain localities were selected prehistorically for settlement.

DESICCATED HUMAN PALEOFECES FROM
BIG BONE CAVE (40VB103), VAN BUREN
COUNTY, TENNESSEE

Charles T. Faulkner, Dept. of Pathobiology, University of Tennessee

Eight desiccated human feces recovered from Big Bone Cave (40VB103) were analyzed for dietary contents and evidence of endoparasitic infection. Radiocarbon dated torch material from the cave indicated that it was the locus of human activity 2177 ± 145 years ago. The dietary contents of the feces were primarily composed of three domesticated plant species: *Iva annua*, *Chenopodium berlandieri* ssp. *jonesianum*, and *Helianthus annuus*.

Parasitic species infecting the population using the cave were: *Enterobius vermicularis*, *Ascaris lumbricoides*, and protozoan-like cysts identified as *Giardia*. The only reported *Giardia* in a prehistoric context is the identifica-

tion of cysts in two 1800 year old paleofecal specimens from a cave in Israel. *Giardia* has never been reported from paleofeces in the New World.

RECENT INVESTIGATIONS INTO THE PREHISTORIC
MINERAL MINING OF THE MAMMOTH CAVE SYSTEM

Kenneth B. Tankersley, Patrick J. Munson, Cheryl Ann Munson and Patty Jo Watson

This paper illustrates archaeological evidence which further suggests that the Mammoth Cave mummy, known as "Lost John", was indeed mining selenite and satin spar crystals from sulfate-rich sediment on Mummy Ledge shortly before his death. Artifacts photographed *in-situ* (16mm movie and still photos) during the recovery of the mummy in 1935 will be compared to those recently photographed on Mummy Ledge. Two additional forms of prehistoric sulfate mineral mining will be discussed - ledge and floor mining.

BIOLOGY

REPRODUCTIVE STRATEGIES OF THE
RHAPHIDOPHORIDAE OF THE GENUS *CEUTHOPHILUS*
OF CARLSBAD CAVERN

Diana E. Northup, Centennial Science & Engineering Library, University of New Mexico

Dissections of female rhabdophorids from three sites in Carlsbad Cavern (Bat Cave, Sand Passage, and Left Hand Tunnel) showed that *C. longpipes* had significantly larger and fewer eggs than did the less cave adapted species, *C. carlsbadensis*. No seasonal pattern of egg presence was discerned. However, an examination of patterns of presence of sub-juveniles in both species did show some seasonal trends with numbers of sub-juveniles peaking in spring-summer in Sand Passage, and to a less definite extent, numbers peaking in winter in Left Hand Tunnel and Bat Cave. Possible explanations for these patterns are discussed.

Keywords: cavernicolous rhabdophorids, reproductive strategies, egg presence, size, and numbers, *Ceuthophilus*.

DIFFERENTIAL UTILIZATION OF ENTRANCE AND DEEP-
CAVE AREAS BY GRAVID FEMALE CAVE CRICKETS
(*HADENOCECUS SUBTERRANEUS*)

Kathleen H. Lavoie, Michelle M. Cyr, Eugene H. Studier and Kelly L. McMillin

Cave crickets from the Mammoth Cave area are capable of reproduction throughout the year with peak reproduction in January and February. Crickets show differential utilization of cave passages. Areas near entrances (Frozen Niagara and Crystal Cave Entrances, Walnut Hill Cave, and White Cave) contain crickets of all ages with the great majority adults. Deep caves areas (Sophy's Cave and deep Great Onyx Cave) have predominantly adults and very small crickets with a nearly total absence of mid-sized crick-

ets. Gravid females from entrance areas contain constant numbers of eggs over the year (6.0-7.4 ova/female) compared to one winter sample from Sophy's with 18.1 ova/female. Caged adult females lay more eggs in the first two days of captivity than in later successive two-day intervals and create many false oviposition holes throughout the testing period. Peak egg-laying frequency occurred in December and February tests. Females from deep cave sites laid more eggs than females from entrance areas. Estimated annual egg-production in cave crickets is 96-371/female.

PROTECTING AQUATIC CAVE SPECIES: QUESTIONS OF SCALE

David C. Culver, Daniel W. Fong, Dept. of Biology, The American University

The minimum population size or area needed to protect a species can be evaluated from three perspectives—distributional, ecological, and evolutionary. Based on our studies in the Greenbrier Valley of West Virginia, we suggest that from a distributional perspective, relatively small upstream sections of caves contain most of the aquatic species. From an ecological perspective, the entire upstream portion of a drainage needs protection to minimize chances of extinction due to groundwater contamination. From an evolutionary perspective the entire drainage system needs protection in order to maintain the integrity of the gene pool. Implications for cave protection include increased emphasis on upstream sections of cave drainages, deemphasis on entrance acquisition, and increased emphasis on aquifer protection.

A COMPARATIVE STUDY OF THE EYE MORPHOLOGY OF SPRING-DWELLING AND CAVE-DWELLING POPULATIONS OF GAMMARUS MINUS (AMPHIPODA; GAMMARIDAE)

Daniel W. Fong and Ning Dai, Dept. of Biology, The American University

The eye morphology of four spring-dwelling and four cave-dwelling populations of the amphipod Gammarus minus were examined under light microscopy. The compound eyes of specimens from spring populations average about 35 ommatidia, and show a two layered structure encapsulated within a basal membrane. The distal layer consists of crystalline cone cells. The proximal layer consists of glial cells and the nucleus-containing bodies of the reticular and reflecting pigment cells. No differences in eye structure between the four spring populations were found. In contrast, cave-dwelling specimens typically show five or fewer ommatidia and reductions in the size and complexity of the elements of the compound eye. The fine details of the reductions in the complexity of the eyes show much greater, and repeatable, differences among individuals between the cave-dwelling populations than within populations. We interpret this pattern of differences in eye reduction to suggest that the different cave populations have evolved independently, and that the pattern is a result of the accumulation of different sets of selectively neutral mutations in different cave populations.

BIOGEOGRAPHY, GENETIC STRUCTURE AND SPECIATION OF PROGLOBITES

Thomas C. Kane, Dept. of Biological Science, University of Cincinnati

Traditionally, phylogenetic relationships among populations of troglobites and among troglobite taxa have been inferred from morphological data. Although similarity in morphology may reflect close evolutionary affinity, it is also clear that similarity in troglomorphic features can result from parallel or convergent evolution in independently evolving lineages. Data obtained from allozyme electrophoresis indicate that many morphologically similar populations of troglophiles and troglobites can be highly differentiated genetically. Allozyme variation appears to more accurately reflect evolutionary history and phylogeny because, unlike troglomorphic features, it appears to be much less influenced by selection pressures of the cave environment. These results have important implications for current models of troglobite evolution.

CONSERVATION AND MANAGEMENT

NONPOINT SOURCE POLLUTION IN KARST: REMEDICATION AND RESEARCH NEEDS

William S. Berryhill, Jr., Water Quality Group, Biology & Agriculture Engineering Dept., NC State University

Water quality studies in karst areas have been reported in a number of recently published items in the literature. These included investigations of ground water geochemistry and flow tracing of ground water and contaminants. Agricultural activities, storm drainage, and other nonpoint sources of karst ground water pollution have been identified. The fate and effects of specific pollutants such as nitrate, pesticides, and bacteria were also discussed.

Only a few reports have been found, however, on remediation of pollution in karst. These mainly included engineering programs such as sinkhole management and manmade subsurface wastewater drainage networks. Others discussed measures as diverse as agricultural best management practices and cave cleanup projects.

This paper is a review of representative nonpoint remediation systems from the literature. It concludes with a discussion of areas that in the author's opinion need more attention, such as reduced input agriculture and policies to control storm drainage injection wells.

STATE-OWNED SHOW CAVES: SHOULD THEY BE SELF-SUPPORTING?

Russell Gurnee

(Approximately) 700 caves throughout the world have been modified and made accessible to visitors as show caves. Some are privately owned; some are maintained as religious shrines; but most are state owned and operated. State-owned caves are administered by public officials and

dependent upon government appropriation for their protection. All are valuable natural attractions and often points-of-destination for citizens and tourists. Their value (private, religious, or public) is dependent upon continued protection and sustained maintenance. Their success can influence the economy of an entire region.

Management of show caves requires the same skills and expertise as a private business enterprise. However, public caves do not have to make a profit to survive, but most outstanding show caves are self-supporting and generate more revenue than they require for maintenance and upkeep. The exhibition of caves requires major modifications to the natural conditions and constant attention to the environment if the public experience is to be safe, educational, and pleasurable.

Publicly owned show caves, developed using tax dollars and later charging admission for visitors, are in competition with private enterprises. The administration should provide for depreciation, maintenance, and replacement of capital investments from the revenue generated - before the generated income is returned to the state for budget assignment.

Examples of management plans of state-owned show caves of several countries are given. Recommendations are made for cooperation with citizen/speleological/scientific organizations to monitor the impact on the cave by visitors. The recognition by the government of the unique needs of the cave environment and the long-range consequences of neglect of maintenance is the first step for sustained conservation of this resource. Investment of income generated by cave admissions should be allocated to the preservation of the cave. State-owned caves can, and should, be self-supporting.

THE MANAGEMENT OF A NATIONAL DATA COLLECTION SYSTEM ON CAVE USE BY CAVERS

John M. Wilson, Chairman, NSS Caver, Caving, and Cave Visitation Study Project

The various trade-offs to be considered in managing a cave register program are evaluated. These factors involve increasing the percentage of signers of the registers, and the retrieval of data at reduced effort on the part of the people maintaining the registers.

The revised draft format cave register is intended to provide more information of value to cave managers, conservationists, and cave organization leadership. The four new questions on purpose, size of group, length of trip, and how the respondents found the cave will provide useful information on the type of caving, its impact on the cave, and a variety of other factors.

The new format increased the number of questionnaires on each page in order to facilitate the maintenance of the registers. Other interrelated maintenance factors are: the cost of maintenance; interest of cavers in volunteering their time; durability; simplicity of maintenance; and anticipated results. The lighter weight 4-inch diameter style register may provide a cost-effective container.

The techniques in operating a register program, including building the containers, analyzing the data, vali-

dating the data, interpreting the results, and using the information will also be discussed.

CAVE REGISTER AND DATA GATHERING WORKSHOP

John M. Wilson, Chairman, NSS Caver, Caving, and Cave Visitation Study Project

The goals of each person and group interested in using cave registers will be weighed and compared in order to achieve a synergistic effect in the design and implementation of the best overall system of cave register and data collection methods, with the widest possible number of uses.

The participants of this workshop will discuss the cave register questionnaire, register design, and other ways to meet the goals and needs of all NSS groups using registers. The ideal goal will be to agree on a standardized format and methodology to improve reliability of comparisons across the country and to take advantage of the economies of scale.

SEMINAR ON THE CAVE VANDALISM DETERRENCE REWARD

John M. Wilson, Chairman, NSS Caver, Caving, and Cave Visitation Study Project

With the passage of the Federal Cave Resources Protection Act, there is an opportunity for the NSS to expand the effectiveness of the deterrence reward. This seminar will have a brief introduction of the goals and methods of the Commission. The group will then participate in an open discussion on ways the reward might be improved. This session should help the commission develop more effective recommendations for the BOG.

The Cave Vandalism Deterrence Reward Commission deters cave vandalism by offering a reward to anyone who provided information leading to a conviction for a person under the protection laws of the of the several states, or the United States, or for conviction under related laws such as trespassing in a cave.

GEOLOGY AND HYDROLOGY

KARST HYDROLOGY OF STEELES RUN, PRESTONS CAVE-MCCONNELLS SPRING AND GARRETTS SPRING BASINS, LEXINGTON, KENTUCKY

Larry Spangler

Dye tracing in the Inner Bluegrass Karst (Ordovician) near Lexington, Kentucky has delineated three large and a number of smaller groundwater basins which exhibit considerably different flow patterns and discharge responses. Direct yellow, rhodamine WT, fluorescein and optical brightener dyes were utilized for water tracing, resulting in twenty-one flow connections in the Steeles Run, Prestons Cave-McConnells Spring and Garretts Spring groundwater basins. Fluorescein and rhodamine WT dyes were detected on activated charcoal while optical brightener and direct yellow dyes were absorbed onto cotton fabric.

Steeles Run Spring is characterized by multiple rises and exhibits a drainage basin which largely originated by diversion of surface water underground within a large valley and its tributaries. Prestons Cave-McConnells Spring basin is characterized by a double karst window which trends perpendicular to flow in the upper portions of this basin. The spring drains a large area of the western suburbs of Lexington. Garretts Spring basin also contains two karst windows which are located along separate flow paths to the spring, resulting in a bifurcated drainage system. Much of the output of Garretts Spring originates from a large blind valley.

Discharge estimates of these springs from October, 1986 to March, 1987 indicates base flow of 2.0 to 3.0 CFS (cubic feet per second), with peak flows exceeding 20.0 CFS. Drainage basin size ranges from 5.0 to 7.0 square kilometers, with travel times within any basin consistently less than one week, regardless of flow. Structural, stratigraphic and hydrologic factors all influence groundwater flow in these basins. In addition, though caves are present in all three basins, they tend to be developed on tributaries within the overall drainage pattern of each basin.

SULFUR BACTERIA AND THE DEEP PHREATIC ENVIRONMENT OF THE EDWARDS AQUIFER

Andy G. Grubbs

Sulfur reducing bacteria are present at the contact between fresh water and a zone of bad water deep in the Edwards Aquifer. The bacteria may be using dissolved gypsum and anhydrite of the bad water zone as a food source. Other higher organisms are using the bacteria for food. Hydrogen sulfide and extremely acidic water come from wells in this zone. Some areas of the aquifer show a mixing of the two types of water under some flow conditions. Wells drilled into deep areas near the mixing zone indicate an area of very large voids; well yields there are 2000-3000 gal/min. Further investigation of this area may help to understand the role of biological action in speleogenesis.

METEOROLOGY OF ICE CAVE, TROUT LAKE, WASHINGTON

Kyle Martin, Northwest River Forecast Center, 220 NW 8th Avenue, Room 121, Portland, OR 97209; and Dr. Robert R. Quinn, Dept. of Geography, Eastern Washington University

Ice Cave is a segmented lava tube that traps cold air during winter permitting the development of ice speleothems. Four separate visits allowed weather data, collected over 18 hours, of this microclimate system located in a mature coniferous forest microclimate in southwest Washington.

January visits in 1986 and 1987 reveal temperatures of -4° and +1°C, respectively, in the stable cave interior. The pattern varies in response to differing weather regimes.

May and July 1987 visits reveal a gradient of temperature from cave entrances to the interior with the deep interior 1° and 2°C, respectively. Mean temperatures (and range) of 4 (1-8)°C and 14 (8-20)°C existed just outside the west entrance during visits in May and July 1987, respec-

tively. In May 1987 sustained interior cave winds blew 30 cm/sec.

Stability in temperature and relative humidity increased with distance into the cave. Small temporal variations in temperature (0.5-1°C) and relative humidity were detected at all stations, indicating turbulent processes can extend throughout the cave. Relative humidity in Ice Cave averaged 92% and 87% on the May and July 1987 visits, respectively.

Ice speleothems reveal seasonal and spatial variation in growth and decay. From May through July 1987 ice melt rates exceeded 1.8-2.1mm/day near the main entrance compared to 0.27-0.65mm/day in the isolated sections of Ice Cave.

THE METEOROLOGY OF THE BUTLER CAVE - SINKING CREEK SYSTEM

Fred L. Wefer, MITRE Corp

The Butler Cave Conservation Society, Inc. (BCCS) is conducting a study of the meteorology of the Butler Cave - Sinking Creek System in west-central Virginia. The Sinking Creek System is made up of a Trunk Channel located near the syncline of the valley, with side passages feeding in from both sides. The meteorological study consists of three projects: an Entrance Project dealing with data from the passages forming the route from the Entrance down to the Trunk Channel at Sand Canyon; a Trunk Channel Project dealing with data from this approximately 8000 ft long passage deep in the cave, and a Miscellaneous Project providing comparison data at various other places in the system. Approximately 400 pairs of temperature measurements (wet-bulb and dry-bulb) have been made since the study began in April 1984.

This paper reports the results of the Entrance Project. The variations of the temperature, relative humidity, and partial pressure of water vapor have been studied as functions of time (season) and distance from the Entrance. The data are consistent with a multiple entrance cave system in which the Butler Entrance (here called the Entrance) is at the highest elevation. In the summer when air flows into the Entrance, temperature and partial pressure effects can be seen only as far as about 100 ft from the entrance. In the winter when air flows out of the Entrance, surface conditions have little effect on the meteorology of the entrance passages.

Deep within the system meteorological conditions are remarkably stable. The approximately 50 measurements made at Sand Canyon yield the following means and standard deviations: dry-bulb temperature 51.4 (±0.4F), relative humidity 98.8 (±1.0%), and partial pressure 0.374 ±0.0004 inches Hg.

THE DOLOMITE KARST OF SOUTHWESTERN WISCONSIN

Philip P. Reeder and Michael J. Day, Dept. of Geography, University of Wisconsin-Milwaukee

The driftless area of Southwestern Wisconsin contains various karst landforms including hundreds of kilome-

ters of dry and ephemeral valleys, several hundred sinkholds and over 200 caves. These caves are generally small with none exceeding 1000 meters in total length, and the vast majority are under 500 meters. In part this is because area carbonates (predominantly dolomite) dissolve slowly, also most caves are located on hilltops or hillsides and represent remnants of formerly more extensive cave systems now dismembered by valley incision. Current rates of carbonate erosion have been investigated in Southwestern Wisconsin, as well as the origin, distribution and morphology of 263 documented sinkholes. Research has also been conducted concerning area hydrology and the utilization of area carbonate rocks and minerals as an economic resource.

GEOLOGY OF THE RIO CORREDOR KARST

John C. Hempel, Tom Wilkinson, Penn State University

The Rio Corredor River basin is located in the extreme southern part of Costa Rica near the Panama border. The river acts as base level for local groundwater systems and transects several thrust blocks of Eocene Limestone as it flows to the Pacific.

The limestone in these blocks appears to represent reef deposits formed in a shallow sea. Caves and karst features developed quickly in these up-thrown ridges, due to the large amounts of rainfall in the area.

The 1989 NSS expedition to Costa Rica mapped and described the caves and geology of a 10-sq.-mile area encompassing most of the recharge basin for Rio Corredor and this report describes the results of that research.

MORPHOMETRIC ANALYSIS OF SINKHOLES AND CAVES IN TENNESSEE — COMPARING THE EASTERN HIGHLAND RIM AND VALLEY AND RIDGE PHYSIOGRAPHIC PROVINCES

Albert E. Ogden, William A. Curry and James L. Cummings, Dept. of Earth Sciences, Tennessee Technological University

Sinkhole subsidence has proven to be a problem along Tennessee's highways and during construction at major building sites. To better understand the origin of sinkholes, a morphometric analysis of sinkholes and caves was made of two different physiographic provinces in Tennessee. On the Eastern Highland Rim of Central Tennessee, flat-lying Mississippian carbonates crop out producing broad sinkhole plains. An analysis of the percent area in sinkholes versus geologic formation was made. The St. Louis Limestone has the largest percentage land area in sinkholes followed by the Warsaw, Fort Payne, and Monteagle limestones.

Slope appears to be the dominant factor with lithologic character being secondary. Orientation diagrams of 677 sinkholes axes and 978 long cave segments were made. Cave passages show a very marked trend in a north/northeast direction as do the long axes of the sinkholes. The short axes of the sinkholes show little correlation to cave passage orientation.

A similar analysis of dolines was made for caves and sinkholes in eastern Tennessee which occur within the intense folded and faulted Ordovician carbonates of the

Valley and Ridge Province. Due to the steep dips in the area, caves were strongly oriented due north and between N30-50E. The long axes of sinkholes strongly correlated with cave orientations. The short axes of sinkholes were oriented nearly perpendicular to the long axes. Few cave orientations matched the short axis directions of sinkholes.

The resultant conclusion regarding factors affecting sinkhole occurrence in the two physiographic provinces is that where rock are flatlying, sinkholes and caves form along a wide range of orientations by dissolution along joints and fractures. In steeply bedded rocks, most cave passages and sinkholes are aligned along strike where dissolution has occurred along bedding planes within favorable lithologies. This enables the prediction of sinkhole formation and growth much easier in the Valley and Ridge Province compared to the Eastern Highland Rim.

OBSERVATIONS ON THE CONE AND TOWER KARST OF SOUTH CHINA

William B. White, Dept. of Geosciences, Penn State University

The cone and tower karst of Guangxi Province, South China, offers useful contrasts to the cone and tower karst of the Caribbean. The Chinese karst is developed on folded and fractured Devonian and Carboniferous limestones. These are dense, massive rocks with much less primary permeability than the Tertiary limestones of the Caribbean. Although some of the residual hills are irregular, many are geometrically perfect cones. Others are near-vertical towers. Between are rounded towers of various shapes. Vertical fractures appear to play a role in development of the vertical sided towers by providing zones of weakness for spalling of bedrock. Geometrically perfect landforms in strongly folded limestones show that hydraulic controls and the chemical reaction of runoff water with the limestone dominate over structural control. Like the Caribbean cone karst, the bedrock surface is sculptured into complex karren forms which provide many small openings into the bedrock. Normal sheet flow is impossible on the slopes of the cones and towers. Other than the requirement of a sufficient thickness of carbonate rock, the characteristic geometry of the residual hills is a direct reflection of the weathering process; special lithologic or structural settings are not needed.

DANGER OF KARST COLLAPSE IN THE LEHIGH VALLEY OF PENNSYLVANIA

Percy H. Dougherty, Dept. of Geography, Kutztown University

The Lehigh Valley is part of the Great Valley of the Appalachians, stretching across Pennsylvania in a northeast to southwest trend from New Jersey to the Maryland border. It is the purpose of this paper to investigate the causes and spatial distribution of sinkholes and karst collapse in the Valley and determine the correlation between sinkhole collapse and physical variables such as geologic formation, human use of the environment, seasons, etc. This is of importance for once a pattern or cause can be found, mitigation measures can be instituted to minimize economic loss.

Although appearing to be a simple valley, the underlying geologic structure results from a diverse structural and stratigraphic history. The flat valley floor is composed of five major Cambro-Ordovician limestone formations, bounded on the southeast by Lower Cambrian quartzites and Precambrian crystalline rocks. All of the carbonate formations contain a variety of karst features, but few caves. Karst collapse is a major economic problem in this area since the valley contains over one million people primarily in the cities of Allentown, Bethlehem, Easton, and Reading. Damage from karst collapse results in over \$1 million loss per year.

Topographic maps, air photos, newspaper reports, field inspections and State and utility data bases were used to locate sinkholes. It was found that the formation with the most numerous sinkholes was the Beekmantown Formation, with construction activities being the major cause for the formation of many small sinkholes. The Leithsville Formation had the largest sinkholes but with a very low recurrence interval. These large collapses are of the suffusion type for the Leithsville Formation is mantled by a deep colluvium because of its location at the base of South Mountain. In addition, it is shown that human interference with the natural system results in an increase of collapse for most occurrences resulted in poorly designed retention ponds, where drawdown from wells occurred, where previously present karst features were covered, where the surface cover was stripped, and where public utilities were improperly installed. Several minicase studies are presented to illustrate the major collapse mechanisms at work in the Lehigh Valley.

RADON IN HOMES, SOILS, CAVES AND GROUNDWATER OF NORTH CENTRAL TENNESSEE

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Radon was measured with carbon canisters in 50 homes and 5 caves in Putnam and Jackson Counties, Tennessee and in 10 soil types using track-etch monitors. The basements of houses ranged from 0.7 - 37.6 pCi/L with mean 3.7 and median 2.4 pCi/L. Caves ranged from 7.2 to 64.2 pCi/L, averaging 24.8 with a median of 18.6 pCi/L. Well-drained soils ranged from 106 - 339 pCi/L, and poorly drained soils ranged from 72.5 - 90.1 pCi/L.

Radon concentrations in homes and soils did not show significant variation among different soil or rock types when isolated high measurements were excluded. Anomalous high radon concentrations were in every case either very near a cave or in basements of houses that were deeply excavated. A similar connection was shown between higher than average radon levels and proximity to sinkholes and photo-lineaments.

A Ludlum ratemeter was used to measure radon concentrations in basements and adjacent soils of 20 houses and in 10 bathrooms both before and after running a measured quantity of water in the shower. Radon concentration of water was approximated using a distribution ratio

of 1/10000 and assuming 70% transfer of radon from liquid to gas phase in cold shower water. Calculated radon concentrations in water ranged from 29 to 2125 pCi/L with the highest values associated with springs emerging on top of the uranium-rich Chattanooga shale and wells bottoming out in the shale.

Homes with concrete foundations were found to have higher radon concentrations in general than homes without foundations. Several basement concentrations were only slightly lower than soil measurements, irrespective of the presence or absence of a concrete slab. Construction in karstic terranes should be preceded by an evaluation of the soil radon content to determine the possible necessity of mitigative construction practices. Within existing structures, cracks appear to be the dominant route of radon entry and should be mitigated through application of sealant and if necessary with a ventilation system.

OXYGEN AND HYDROGEN ISOTOPE RATIOS IN SPELEOTHEMS IN GARDNER CAVE, WASHINGTON: PRELIMINARY RESULTS

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Ratios of $^{18}\text{O}/^{16}\text{O}$ in paleo and modern calcite and D/H in paleo dripwater trapped as fluid inclusions (FI) were studied. A $^{234}\text{U}/^{230}\text{Th}$ dated stalagmite and flowstone span 244 ka.

Mean isotopic temperatures of modern samples are 7°C colder than 6°C *in situ* values. Within error limits, drip water D/H and $^{18}\text{O}/^{16}\text{O}$ plot on the global meteoric water line implying non-evaporation (i.e., rapid loss of CO_2). Modern and paleo $^{18}\text{O}/^{16}\text{O}$ in calcite differs in separate cave sections implying non-isotopic equilibrium near the entrance. Modern samples suggest isotopic equilibrium may occur 164 m into the cave.

FI analyses of paleo calcite give values 6-8°C warmer than expected. Laboratory processing may contribute to some of the error. It is possible that during the Late Quaternary glaciers insulated the cave, trapped geothermal heat, and raised cave temperatures. A modern geothermal analog (at Castleguard Cave beneath the Columbia Icefield) suggests 1°C of the increase.

Hence, FI analyses in this case cannot generate reliable absolute temperatures. However, some climatic signals, whether or not coincidental, do appear.

The maxima of continental ice sheets appears as a minimum in $^{18}\text{O}/^{16}\text{O}$ records. This signal appears by 18 ka in the Gardner Cave stalagmite record and by 17.5 ka in a stalagmite others report for Coldwater Cave, Iowa. Thermal maxima is implied from the Gardner Cave record by 5-6 ka.

*PETROGRAPHIC AND MORPHOLOGIC INDICATORS OF
MIXED-WATER DISSOLUTION IN CAVES OF SAN
SALVADOR ISLAND, BAHAMAS*

Peter N. Vogel and John E. Mylroie, Dept. of Geology & Geography, Mississippi State University; and James L. Carew, Dept. of Geology, The College of Charleston

Subaerial horizontal dissolution caves currently found in the tectonically stable Bahamas must have formed during past high glacioeustatic sea level events on San Salvador. Small island size, young rock age, and limited duration of high sea level events require that the caves formed quickly by a potent geochemical mechanism. Mixing of vadose water, phreatic fresh or brackish groundwater, and tidally-pulsed marine water, are known to produce dissolutionally aggressive water in carbonate coastal aquifers elsewhere, and that mechanism most likely led to the formation of the subaerial caves on San Salvador.

The presence of chemically active water within aragonite-rich carbonate rock has been implicated in a variety of diagenetic alterations, in addition to widespread dissolution of the rock. Conversion of aragonite and high-magnesium calcite to low-magnesium calcite, the precipitation of dolomite, and the development of high porosity are believed to occur in cave wall rocks. These characteristics (except dolomitization) have been observed in currently submerged caves of the Yucatan region of Mexico, where in addition the cave wall rock is characterized by dramatic etching and roughness. On San Salvador, the degree of cave wall rock diagenesis is much less, and the cave walls exhibit a smooth, curvilinear texture. Widespread occurrence of halite, gypsum and trace amounts of dolomite in the wall rock of San Salvador caves is attributed to evaporative precipitation by infiltrating, sea spray-contaminated vadose groundwater that forms secondary crusts.

The differences between the features observed by other workers in the Yucatan and those observed by the authors on San Salvador may be the result of a thicker, more rapidly discharging freshwater lens in the Yucatan, and secondary vadose modifications of the now subaerial San Salvador caves. Because of the limited duration of freshwater lens position at the necessary elevations, dissolution rates on San Salvador must have been rapid, despite small lens size and discharge volumes.

*FRACTAL ANALYSIS OF STAGEBARN CRYSTAL CAVE,
SOUTH DAKOTA*

Rane L. Curl, University of Michigan; and James A. Nepstad, Wind Cave National Park

The Linked Modular Element (LME) method of Curl (1986), previously applied to Little Brush Creek Cave, Utah, has now been applied to Stagebarn Cave, South Dakota, to determine the distributions of sizes of cave passage, the ratio of sizes of adjacent LME, and to identify passage clusters of larger than proper modulus.

The distribution of LME sizes in Stagebarn Crystal Cave is hyperbolic, and exhibits a fractal dimension of 2.5, similar to but significantly different from Little Brush Creek Cave, Utah, whose fractal dimension was found to be 2.8.

Both data sets exhibit lower cutoffs of 0.6m, identifiable as the lower size limit of exploration, and upper cutoffs of ca. 5m, possibly related to structural stability of passages.

The distribution of ratios of sizes of touching LME is very narrow, about 1.0 (standard deviation of about 0.1), unimodal and non-normal, but a theory for its form is not yet known. However, the distribution can be used to generate graphic depictions of cave passages with realistic size patterns.

Analysis of sizes of passage clusters may form the basis for prediction of the extent of unknown passage.

*FEATURES OF CONDENSATION CORROSION IN CAVES
OF THE GREENBRIER KARST, WEST VIRGINIA*

Roy A. Jameson, Dept. of Geology and Geophysics, University of Minnesota

Distinctive features, including drop dents, rills, and edge patches result from dissolution by condensation waters. The features modify the surface texture of bedrock walls, ceilings, and breakdown. When moist, the drop dents and rills resemble the drop and drip trails that form on insides of windows in the winter. However, the actual drop dents and rills are negative features produced by dissolution of soluble bedrock. The relief of drop dents and rills is usually 1 mm or less. When dry, drop dents and rills impart a rough-appearing surface texture that partially disguises them. Thus they are often overlooked, even where they cover tens of thousands of square meters, as in Greenville Saltpetre Cave or Snedegar's Cave. When wet, drop dents and rills impart a dendritic, patterned glistening character to sloping bedrock surfaces.

The diameter and shape of drop dents, and the width, length, and pattern of rills, depend on properties of the surface (the inclination, curvature, down-slope length, composition, and pre-existing texture of the surface). They also depend on the physical and chemical properties of the drops and thin films that make up the fluid (rate of condensation, rate of flow, thickness of flow, PCO_2).

Condensation corrosion occurs near entrances. Warm, moist surface air enters the caves between May and September. Most condensation occurs where moist surface air on ceilings and upper walls is directly cooled by cold ($10^{\circ}C$) bedrock. Condensation is common in entrance passages where warm surface streams sink. Much condensation also develops as mixing clouds (fogs) where warm and cool air parcels mix, and moisture is then deposited onto dry surfaces.

*PALEOMAGNETISM OF SPELEOTHEMS IN GARDNER
CAVE, WASHINGTON*

Kyle Martin, Northwest River Forecast Center, 220 NW 8th Avenue, Room 121, Portland, OR 97209

Cores were extracted from a late Quaternary stalagmite and flowstone from Gardner Cave. Dates provided by $^{234}U/^{230}Th$ methods gave an age range from 24 to 4 ka.

The stalagmite paleomagnetic record is comparable with paleomagnetic records others report for Fish Lake in Oregon from 12-4.1 ka and for a Vancouver Island

stalagmite during 18.5-15 ka. NRM intensities of Gardner Cave calcite samples were 10^{-8} T. Specimens were demagnetized at 15mT.

Some agreement exists between the Grotto cave sediment (2 m alternating clay and fine sand laminae) paleomagnetic record ($N = 17, n = 8$) and the directions reported by others for Fish Lake, and, to a lesser extent, Mara Lake in British Columbia. Grotto specimens were AF demagnetized to 50 mT. Grotto sediment is bracketed by two corrected ^{14}C dates giving an age range 6.7-2 ka.

The flowstone paleomagnetic data are 40-70° to the east in declination and 5-40° steeper in inclination relative to the Fish Lake record. A hypothesis is proposed that a hydrodynamic control, rather than dip-slope control, may have reoriented magnetic moments on flowstone in the upslope direction. The results tentatively imply an internal topographic test using paleomagnetic directions applied for stalagmites may not be valid for flowstone.

HISTORY

CAVE SPRING FARM: A KENTUCKY PIONEER SETTLEMENT

Gary O'Dell and Samuel M. Cassidy

Cave Spring Farm, in Fayette County, Kentucky, contains the Boggs Cave, a classic example of karst processes in the Bluegrass region, and historically significant for a number of reasons. The cave was explored and surveyed by Gary O'Dell in 1970 and 1978 and consists of a single bedding plane passage nearly 1,000 feet long. Early pioneer Robert Boggs in 1775 chose the cave spring location to claim and settle, of all those Kentucky lands he had helped survey with John Floyd's party. The buildings surrounding the entrance date from before 1800 and are excellently maintained. The Boggs family and descendants have occupied Cave Spring farm for 167 years of the 214 since its settlement. The co-author of this paper, Samuel M. Cassidy, is a descendant of Robert Boggs and repurchased the homeplace from outsiders in 1964. In February of 1970 he gave shelter to two cold and wet cave explorers emerging from his cave and began a lasting friendship. Mr. Cassidy, at age 88, still has an avid interest in caves and his previous description of Boggs Cave was reprinted in the 1970 edition of *Speleo Digest*. This is perhaps cave owner relations at its finest.

CAVE MAPS AS A SPATIAL HISTORY OF THE NSS

John H. Ganter, Dept. of Geography, Penn State University

Mapping is an essential part of cave exploration. Cave maps have been used since the earliest periods of systematic exploration both as analytical tools and stores of knowledge. As such, they are artifacts which shed light on the genesis (unavoidable change) and evolution (motivated change) of caving techniques, groups, regions, and individuals. As caves grow scarce, cavers extend their ranges, abilities and expectations. I use maps to illustrate three major phases in NSS cavers' activities, motivations and beliefs: The Weekend Reconnaissance (1940s-50s); The

Cave System (1960s); The Cave Project (1970s-present). These phases have each imposed needs for spatial information, and have forced cavers to re-evaluate the limits of endurance and work quality which they set for themselves and others. Throughout, the cave map has served both as tool and trophy.

SALTPETER ARTIFACTS FROM THE CAVES AT TROUT ROCK, WEST VIRGINIA

Fred V. Grady

There is now considerable evidence of saltpeter mining in two caves at Trout Rock, Pendleton County, West Virginia. The mining started before 1800 and continued intermittently through the Civil War in the 1860s. Burton Faust and William Davies recorded some artifacts from Trout Cave, most of which seem to have been lost. More recently, many small tools and other artifacts have been found in both Trout and New Trout Caves, especially the latter. While most are wooden, including faggots, paddles, bag spreaders, and keg parts, a hammer made from a file was found outside Trout Cave in the 1960s and likely dates from the mining period.

JOSE STOREK, PIONEER SPELEOLOGIST IN GUATEMALA, CENTRAL AMERICA

Russell Gurnee

Born Josef Storek, he was driven from his native Czechoslovakia by World War II, emigrated to Guatemala and passionately adopted the new country and culture. He learned Spanish, changed his name to Jose Storek Fingerhut, and pursued his profession as a geologist.

He had been an ardent caver in his student days in Prague, and he continued his interest in the limestone regions of Guatemala. To learn about the country, he wrote to all of the mayors of the towns in the limestone mountains and asked about (and visited) their caves. He became the most knowledgeable man regarding the caves and natural features of the back country.

In 1951 he began a correspondence with Burton Faust about the caves he had visited, urging U.S. cavers to visit Guatemala. In 1957 a small group from the NSS accepted his invitation, and this visit began a ten-year study and a friendship with a most remarkable man.

His contributions to the knowledge of caves in Guatemala has been the basis for search, study, and survey by teams from Europe and the United States. Mercurial, energetic, enthusiastic and sincere, he influenced people he met and left remembrances in anecdotes, stories, and tales that are now part of the legends of the region.

THE NAMING OF THE TOWN OF CAVE CREEK, ARIZONA

William R. Halliday

Some delightful tall tales of relatively modern origin enliven the history of Cave Creek, a suburb of Phoenix, Arizona. The sober truth is dull indeed: the creek for which the town is named was named because of sizeable shelter caves not far from the present city center.

LITTLE-KNOWN TOURIST CAVES OF
NORTH CAROLINA

Nancy Holler

When most individuals think of a Tar Heel cave open to the public, commercially developed Linville Caverns comes to mind. There are, however, a number of lesser-known caves on private and state lands which are of interest to the general public as well as the speleologist.

CAVE HISTORY IN NEWSOME SINKS

Charles A. Lundquist

Newsome Sinks in Morgan County, Alabama, is a landlocked valley some four miles long and up to a mile wide. All water runoff is through underground drainage and caves. The traceable history of the caves of the Sinks seems to begin with saltpeter mining in the 1860s. Two caves, Wolf and Hughes, had significant operations, and extensive evidence remains in them. Two others, Newsome Saltpeter and Bullfrog Caves, have lesser evidence.

Up to roughly the middle of the 1900s, the flat land on the floor of Newsome Sinks Valley was cleared and farmed. A few farmsteads existed, and a family cemetery is present. A knowledge of at least the major caves surely persisted in this community. By 1955, when the Huntsville Grotto formed, only one uninhabited home remained in the valley, and a barn stood at another place. Most fields were abandoned or soon became so.

Because Wolf Cave and Hughes Cave were well known, and were only a few minutes drive south of Huntsville, they were visited early by the Grotto membership. The members quickly recognized that the Newsome Sinks contained many caves, and they initiated an organized effort to locate and explore them. Progress on this effort was reported by the author at the 1957 NSS Convention at Natural Bridge, Virginia.

Activity in Newsome Sinks waned after 1961 when the Huntsville Grotto attention shifted to Fern Cave and after 1969 to New Fern Cave in Jackson County. In Morgan County, the Decatur Grotto (no longer extant) continued their interest. In 1974 Newsome Sinks was designated a national landmark. This stimulated the Decatur Grotto to produce a special issue of the *Decatur Caver* devoted to Newsome Sinks. This excellent document contains a section on history, including a land ownership map for 1890. It notes that earlier land records were destroyed.

About 1981, the author and William W. Varnedoe began more scientific investigations in the area, which generated several papers. In 1987, a group of residents of the area near Newsome Sinks formed the Newsome Sinks Grotto. They have renewed intensive exploration, have found additional caves, and have made major extensions in several others. Thus Newsome Sinks caves have seen human attention for at least 120 years, but much yet remains to be learned.

AN INTRODUCTION TO THE HISTORY OF CAVE
EXPLORATION IN TENNESSEE

Larry E. Matthews

Archaeological investigations show that Indians used cave entrances and rock shelters in Tennessee as temporary and permanent dwelling sites for thousands of years. Recent studies in Big Bone Cave in Van Buren County and Mud Glyph Cave in East Tennessee prove that some Indians explored deep into caves. The Big Bone Cave artifacts indicate a mining operation for gypsum and/or salts, similar to those in the nearby Mammoth Cave area of Kentucky. The Mud Glyph Cave site contains numerous drawings which appear to be of religious significance. Clearly, Indians were the first cave explorers of Tennessee.

THE MINING OF LEAD FROM CAVES IN
SOUTHWESTERN WISCONSIN: A HISTORICAL AND
GEOLOGICAL PERSPECTIVE

Philip P. Reeder and Michael J. Day, Dept. of Geography,
University of Wisconsin-Milwaukee

During the Wisconsin stage of the Pleistocene in North America, the Driftless Area of the Upper Midwest probably was not glaciated, hence preserving pre-existing geology, including the Middle Ordovician Galena Dolomite, which was the host rock for paragenesis of lead deposits. From hydrothermal solutions mixing with groundwater, crevice lead sulfide ores were deposited along lines of weakness resulting from bedding, collapse of breccias, and preferential dissolution of joints. Organized mining of these deposits began around 1815, with the greatest mining activity occurring in the 1840s. The earliest gathering of surface deposits progressed to shallow diggings and removal of ore from caves that were uncovered during excavation or had natural entrances. Caves of note that were mined in Southwestern WI include Atkinson Mine Cave, from which over 900 metric tonnes of ore was removed between 1862 and 1877, and Snake Cave (St. John Mine). Remnant evidence of mining in caves includes drill holes, discarded mining tools, spoil piles and modified passages. The mining of lead in Southwestern WI was more than a sequence of discovery, exploitation and abandonment; it led to the opening of the territory, settlement of a frontier, and growth of the region.

EARLY PHOTOGRAPHIC IMAGES OF THE "TAG"
CAVING REGION

Marion O. Smith

Slides of different aspects of the Tennessee, Alabama, and Georgia cave area, spanning from historical to contemporary, will be shown.

William W. Varnedoe, Jr.

A chronological list is given of references to Alabama caves, from Indian legend to the current Alabama Cave Survey. From this list some conclusions are drawn on how the caves were viewed by the population of a given time.

INTERNATIONAL EXPLORATION

ROMANIA 88: THE 1988 NSS SPEOLOGICAL PARTNERSHIP EXPEDITION TO TRANSYLVANIA

Robert Cronk and Carolyn Englund Cronk

ROMANIA 88 was a joint Romanian-American expedition to investigate some recently discovered caves in the Bihor Mountains of Transylvania. The expedition was sponsored by the Emil Racovitza Institute of Speleology in Bucharest, Romania and supported by the National Speleological Society through an International Speleological Partnership Grant. Goals of the trip included the exchange of information and equipment and the development of cooperative efforts between American and Romanian cavers. The team consisted of 5 Americans, 6 Romanians, and a West German. The Romanians included staff members of the Institute and leaders of the Polytechnic Speleological Club (CSP) from Cluj. CSP is leading the exploration effort in the Bihor region.

Romania contains several major karstic areas - even though only the size of Oregon, over 10,000 caves have been cataloged. The region of the Bihor Mountains in Transylvania is only now coming under intense exploration and several major discoveries have been made. The expedition team investigated many caves during July 1988, the most important of which was Piatra Altarului, a large, highly decorated cave discovered less than a year earlier.

The success of the expedition has led to closer relations with speleologists and cavers in Romania, and will form the foundation for future jointly-planned efforts.

1987 SELMEH PLATEAU EXPEDITION, SULTANATE OF OMAN

John H. Ganter, Dept. of Geography, Penn State University

The remote Selmeih Plateau contains a desert mountain fluviokarst with drainage area, flow length, and relief unusual for the Middle East. All cave entrances are 350 to 600 foot shafts leading to flood routes containing stagnant water and extensive gourd deposits. In 1987 an intensive 14-day, 5-person expedition, airlifted by military helicopters, mapped 3.8 miles of passage to depths of 1000 feet. While some passages are sizeable (and one room is among the world's largest) conditions were generally hostile. Surface temperatures approached 130 degrees, but the largest cave required extensive swimming and wind speeds clocked at 14 mph made surveying chilly at best. Much work remains to be done, but the area is among the most inaccessible in the world.

Carlos Goicoechea and C. Aparto

A pictorial view of the caving areas and caves of Costa Rica by a Costa Rican NSS member. Slides and discussion of the different Karst areas in Costa Rica and the potential for finding new caves.

THE EXPLORATION AND SURVEY OF CUEVA DE BORBOLLON

Maureen Handler

On March 18, 1989, fifty cavers from three countries met in the city of San Luis Potosi to explore a cave recently found by the cavers of San Luis Potosi. The personnel included 26 Mexicans from S.L.P., 22 from the US ranging from CA to NY and 2 Canadians from Ontario.

The aim of the expedition was to explore Cueva de Borbollon, located approximately 30 miles east of San Luis Potosi. The cave had initially been explored by the Mexicans. They had surveyed the entrance passage and the first pit, which had a measured depth of 218m (718 ft.). They found four more pits below the first but were unable to continue the exploration or survey due to lack of time.

Our teams continued the exploration and survey, using international teams whenever possible. We found an additional 20 pits in series yielding a total surveyed depth of approximately 700m (2300 ft.). The exploration teams were stopped by a low air space water passage. In total 1000 man hours were spent in the cave in 4 1/2 days with 47 descents and ascents of the pit made on various exploration, survey and photography trips. A measurement of the big pit was performed using an electronic distance measuring instrument showing a depth of 217.3 m. This makes it the second deepest in-cave pit in Mexico and North America. Plans are to continue the exploration next year with another Mexican/American joint expedition.

This expedition was unusual in that it was the first time a truly joint expedition was planned and carried out with basically equal numbers of Mexicans and Americans. The whole trip worked smoothly and the language barrier was soon overcome by everyone attempting to learn the other's language. In addition to exploring and surveying Borbollon, many vertical sessions, rig building sessions and ridge walks were held. All in all, much information passed hands and many of the expedition objectives were accomplished. Hopefully the idea of joint expeditions between countries will occur more often in the future. We have much to learn from the Mexicans and they from us.

REPORT ON THE EXPLORATIONS OF THE 1989 NSS EXPEDITION TO COSTA RICA

John Hempel, Norma Peacock, Douglas Dotson, and Jim Powers

The 1989 NSS expedition to Costa Rica was very successful. Over 5km of caves were mapped, 30 entrances discovered, and many scientific studies begun. This report highlights the work done by the 30 participants during the three-week trip.

*THE CAVES AND KARST OF BATUAN, BOHOL,
PHILIPPINES*

Philip P. Reeder, Michigan J. Day and Peter B. Urich, Dept. of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI 53201

The Philippines is a nation made up of over 7,000 islands. Located in the southern portion of the archipelago about 400 km southeast of Manila is Bohol, an island partially composed of limestone. In Batuan, which is located in the central part of the island, the Pliocene and Pleistocene aged Maribojoc Limestone is exposed. Area topography is dominated by mogote-like residuals locally named Chocolate Hills. Over 1000 such residual hills exist over a fairly small area. Other karst features in the area include sinkholes, dry valleys, blueholes, spring resurgences and caves.

During March 1989 a preliminary investigation was conducted in Batuan involving a general reconnaissance of the area to determine if future study was warranted. Working with the local Department of Agriculture, the utilization of cave streams as agricultural water supplies was investigated. Over a 2 week period 10 caves were located but not entered because of time restrictions. From this preliminary investigation enough encouraging data was gathered to warrant further study.

*NEW DISCOVERIES IN NAJ TUNICH, PETEN,
GUATEMALA*

George Veni

Naj Tunich is a cave in the Peten of Guatemala and contains the largest assemblage of Maya cave paintings known. Expeditions in 1988 and 1989 found new groups of paintings, the only ones recorded as undisturbed and in complete ritual context. Other discoveries include upper level extensions to a new trunk passage, and mapping among the Maya in other jungle caves. Recent local problems have indefinitely closed Naj Tunich to all visitors except those carrying a research permit from the Guatemalan government.

PROYECTO PAPALO '89

Bill Farr and Carol Vesely

Sistema Cuicateca is located in the Sierra Juarez Mountains in the state of Oaxaca, Mexico. This year's six-week-long Proyecto Papalo Expedition pushed the Sistema Cuicateca to -1265m deep and over 15km long, making it the second deepest cave in the Western Hemisphere and the eighth deepest cave in the world. All exploration at the bottom of the cave was from Camp 2 at -850m depth and 5km in from the entrance. The cave was extended past several more sumps through large boreholes separated by breakdown. The current limit of exploration is a massive breakdown pile at the end of the A.S. Borehole, a kilometer-long passage 40m in diameter. Also in the area, Osto de Puente Natural, a cave with a higher entrance was pushed from -450m to -900m deep where it finally connected to the main cave system. Several other caves with higher entrances

were located and partially explored and surveyed. Finally, work was begun on three caves located near the probable resurgence of the system. A return expedition is planned for next year.

PHOTOGRAPHY

WHAT'S IN A FLASHCUBE?

Charles A. Plantz

The four flash lamps in a flash cube are high tech devices; they contain shredded zirconium foil which burns in an atmosphere of oxygen at up to ten atmospheres pressure. Flash lamps in magicubes are ignited by a primer in a tube protruding from the base of the lamp. The primer is exploded by a spring wire snapping the tube. Demonstrations will be given of primers going off in opened lamps.

Attempts to use opened flashcube lamps to ignite aluminum foil in homemade flashbulbs have been unsuccessful.

USING UNUSUAL FLASHBULBS

Roger V. Bartholomew, NSS 9349

A cave photographer can find a variety of unusual flashbulbs for sale at reasonable prices. Caveable flash holder/reflector devices have been developed by cave photographers from standard off the shelf items to operate these bulbs. Unknown bulb/reflector guide numbers can be calculated or experimentally determined. The light blue 82A (B8) filter converts clear flashbulbs for use with daylight film.

A socket used for household incandescent lamps, a twenty-two volt battery, a 100 microfarad capacitor and a push button switch will fire bulbs with a screw base such as #22 and #50. Solder in a pc cord and it will sync with a camera shutter or solder on a light trigger for a remote slave unit. Extension sockets for flashcubes and magicubes can be converted to flashguns. A standard automobile running light socket will hold bayonet base bulbs such as the #5 or #6.

SURVEY AND CARTOGRAPHY

RIVALRY ERROR IN TWO-EYED SUUNTO SIGHTINGS

Roger V. Bartholomew, NSS 9349

If two eyes are used to sight the Suunto compass as the manufacturer recommends, "so that the hairline [seen by one eye] is superimposed on the target" [seen by the other eye] there will always be what I shall call a rivalry error in the azimuth.

In any two-eyed Suunto sighting, the system is forced to superimpose images of hairline and target station, each located at different distances from the eye. This causes a rivalry over which eye will control the convergence angle of the optic axes of the eyes. This misuse of the human binocular vision system causes rivalry error. Heterophoria,

a biological condition, can add another error which may increase or decrease rivalry error but heterophoria is not the cause of rivalry error.

Experiments show that rivalry error is normally greater than $1/2^\circ$.

USEFUL TECHNIQUES FROM SURVEY AND CARTOGRAPHY STANDARDS FOR THE ROMANIAN SPELEOLOGICAL INSTITUTE

Robert Cronk

Several techniques for cave survey and cartography were learned from the recent NSS expedition, ROMANIA 88, a joint Romanian-American expedition to investigate some recently discovered caves in the Biho Mountains of Transylvania. The expedition was sponsored by the Emil Racovitz Institute of Speleology in Bucharest, Romania and supported by the National Speleological Society through an International Speleological Partnership grant.

Romania contains several major karstic areas. Over 10,000 caves have been catalogued. The region of the Bihor Mountains in Transylvania is only now coming under intense exploration and several major discoveries have been made. The expedition team investigated many caves during July 1988, the most important of which was Piatra Altarului, a large, highly decorated cave discovered less than a year earlier.

The map of Piatra Altarului is used to illustrate several interesting techniques which could be applied to large-scale survey and cartography efforts: (1) passage contour lines, (2) standards for total passage length measurements for caves with large rooms, (3) markings on plan views for passages intersecting at different levels, and (4) independent inspection/verification of accuracy.

UNITED STATES EXPLORATION

FIRST REPORT OF THE KENTUCKY RIVER AREA CAVE SURVEY (K.R.A.C.S.) 1986-1989

The result of three years of field work in the Wilmore and Little Hickma Quadrangles of Central Kentucky are presented. The study is limited to the profusely jointed dolomitic limestones of the Highbridge Group, Middle Ordovician. A geologic description of the area is given, the karst features are described and discussed in the context of important structural and lithologic controls. Additionally, joint surveys of the several caves are tabulated and are shown to correlate with local faults. Finally, the influence of bentonite beds on groundwater flow in the Highbridge Bend is discussed in light of some recent dye traces. Among the karst features detailed are the commercial Highbridge Springs, the multi-drop wetsuit Highbridge Cave and Kentucky's new deepest single drop, Blakeman's Well.

CURRENT EXPLORATION OF HIGHBRIDGE CAVE, JESSAMINE CO., KY

Christine M. Gerace

Highbridge Cave, just in excess of 1 mile at this time, is comprised of a series of vertical drops, interspersed with 100 foot domes and walking stream passage, which downcuts through the Camp Nelson Formation of the Highbridge Group. The cave follows the prevailing joint patterns of the area. The entrance sits in the bottom of a limestone quarry and bottoms out 150 feet below at a sump, which joins the Kentucky River. Going side leads bring in additional stream flow, some of which lead to bolt climbs and perched sumps. Any takers?

The quarry itself has 5 1/2 miles of underground rooms and pillars which is used by a storage and bottled water company. Water from an unchecked cave in the ceiling at the north face of the mine is collected behind a dam with a storage capacity of 5 million gallons. Overflow runs along the mine floor and exits the underground workings where it immediately goes underground and enters the cave at the top of the 43 foot entrance drop. This makes the use of a wetsuit very appealing. This may be the only cave that is protected by high fences, big dogs, motion detection sensors, videocameras, and the local police force

NEW DISCOVERIES IN THE LECHUGUILLA CAVE, NEW MEXICO

Patricia Kambesis

Lechuguilla Cave continues to grow under the exploration and survey of the Lechuguilla Cave Project, Inc. Twenty miles of passage has been surveyed since August 1988 and new discoveries continue to be made with each expedition. The Southwestern area of the cave has yielded new extensions off the Prickly Ice Cube Passage area (Chicken Little and High Hopes) and the Voids (Big Sky Country). Successful climbs in the eastern arm of the cave (Apricot Pit area) have accessed major upper levels and a bypass to the Apricot Pit Series. The 196 foot Aragon nightmare climb, located in the easternmost Moby Dick Room, was finished in May of 1989 and survey teams pushed and mapped over 4000 feet of passage in the upper level Land of Enchantment. A short stretch of fissure/rift type passage in this area has proven to be the gateway to the long sought after Eastern Borehole. In one trip two survey teams were able to map over 6000 feet of boneyard borehole with no end in sight. The major extension is trending north towards Big Manhole Cave on BLM land and northeast to parts unknown.

James H. Smith

T.A.G. Country is the most prolific cave region in the United States with 8,000 known caves. The southeast is most famous for its beautiful single shafts and multi-drop vertical caves. With a vertical potential averaging 500 feet there are 90 multi-drop vertical caves between 300 and 1,063 feet in depth. The heyday of deep cave exploration occurred in 1976 when 10 multi-drop caves over 400 feet deep were explored. During one weekend an unprecedented two vertical cave systems were explored. Many of the vertical cave systems averaged six shafts and contain as many as thirteen, often very wet, separated by low bedding plane crawls, and in many cases required digging to extend the cave to physical limits. In recent years exploration of deep multi-drop caves has required employing advances in technology in order to realize the potential of new deep caves. Big wall dome climbing techniques has yielded three caves with a vertical extent over 400 feet and two over 300 feet. Digging alone has been responsible for the realization of more than 40 caves over 300 feet in depth. In addition, more than a hundred pit entrances and smaller multi-drop caves has been uncovered or extended by digging. Sump diving has also been utilized to extend the depth or connect lower spring entrances to vertical caves.

ABSTRACTS OF THE NATIONAL SPELEOLOGICAL SOCIETY

ANNUAL MEETING, July 8 - July 14, 1990
YREKA, CALIFORNIA
Norma Peacock, Editor

ADVANCED CARTOGRAPHY

MAPPING NON-LIMESTONE CAVES

Carol Vesely, 709 S. Primrose Ave. Apt A, Monrovia, CA 91016

In California there are many different kinds of non-limestone caves: lava tubes, granite "purgatory caves", "mud caves" and sea caves, each of which present their own challenges to the map-maker trying to survey and represent them. Moreover, the techniques used to portray these "unusual" caves are applicable to limestone caves as well. In surveying sea caves and mud caves, cartographers have been forced to develop new symbols and to wrestle with the difficult questions of "what is a cave?" and "where does it begin?". In granite caves, we encounter the problem of portraying complex routes through breakdown. In pseudokarst areas one of the most significant aspects of the individual caves is how they related to the surrounding geology and to each other. Extensive use of small area maps have helped give the maps of these small caves more meaning.

THE SURVEY OF UNDERWATER CAVES

Ron Simmons, 2414 Barracks Road, Number 4 Charlottesville, VA 22901

This will be a general overview of how underwater caves are surveyed. The techniques are different from the survey of air-filled caves due to the need to take a life line support system along and the limited time available to accomplish the goal. There is also a difference in the quality and accuracy of the finished map depending on the diving conditions. The survey of sumps tend to be only a line plot while the survey of underwater caves in Florida or the Yucatan can approach the best surveys of air-filled caves.

CARTOGRAPHY AT LILBURN CAVE

Peter Bosted, 4000 Farm Hill #310, Redwood City, CA 94061

Lilburn Cave, located in Kings Canyon National Park, California, is an 11+ mile long three-dimensional maze cave formed in banded marble. The passage complexity presents special cartographic challenges which are being met using a variety of computer-generated and hand-drawn maps. The computer maps use either gray tones or color to portray the various passage levels (plan view) or distance from the viewer (profile). Passage shapes are calculated from a smoothing algorithm. Hand-drawn maps which show passage detail are being produced for both the entire cave and, in quadrangle format, for each level in a given area.

LECHUGUILLA CAVE - A CARTOGRAPHER'S NIGHTMARE!

Patricia Kambesis, 1026 South Candler St., Decatur, GA 30030-4464

The complexity of Lechuguilla Cave has presented the project's Cartography Committee with the challenge of portraying this cave on paper. On a grand scale, Lechuguilla Cave can be divided into four distinct regions: the Upper Cave and Rift, the Western Borehole, the Southwestern Borehole, and the Eastern Branch. Within each of the major sections, the morphology and interrelationships of the passages take on the character of a series of intricate three-dimensional mazes (boneyard).

The great lateral extent of Lechuguilla has made it necessary to partition the cave into quadrangles (1000 feet long by 1500 feet wide) that tie into the same quadrangle system used at Carlsbad Cavern. Line plots are superimposed on the quad grid and each quad is plotted out separately. Because some of the quadrangles consist of cave passage on at least four different levels, it has become necessary to generate "isopach plots" i.e. distinct layers of cave passage with upper and lower boundaries defined by depth from the entrance. These depth defined isopachs can be layered on top of each other to show the relationships within the various areas of the mazes. Currently the quads are used as work maps to guide exploration, to define trade routes and as pieces of the beginnings of an interactive database. There are still many problems inherent in depicting Lechuguilla Cave. These include: use of cross sections, the most effective vertical profile, continuous influx of new data, and producing a "publishable" map.

CAVE VISUALIZATION USING VOXELS

Richard L. Breisch, 4735 Mt. Ashmun Drive, San Diego, CA 92111

"Voxel" stands for "volume element". It is a method of storing image data about 3-dimensional objects in a computer database. The objects are represented by a 3-dimensional array of small cubes. Each voxel has user-defined attributes such as 3 coordinates, color, material type, translucency, or any other factor which has been specified by the creator of the database. By using voxels, it is now theoretically possible to create cave scenes which can be manipulated in realtime by the viewer as if he were walking through the cave. Cave mapping, stereo-photography, and fractal computations are required to create the voxel database. Using voxels to create realistic cave scenes would be very expensive, but it is an alternative to commercializing a fragile cave.

CAVE MAPPING FOR THE FUTURE

Peter Sprouse, 1104 Applegate, Austin, TX 78753

While there have been significant improvements in cave mapmaking in recent years, it seems likely that major changes are still to come in the realm of automated data processing and presentation. It is also likely that in using the advanced tools available to them, future cave mapmakers

will find many deficiencies with our present-day surveys. Speculation on future mapping technologies can suggest ways to improve our current surveying quality, so that our surveys will retain a high yield over a longer period.

As we progress past computer-plotted survey baselines to plotting walls and floor detail, we can look ahead to detailed, accurate cave modeling in true 3-D. Stereo computer monitors, holographic projections, and programmable three-dimensional media are all possible ways that we may someday create miniature replicas of the caves we survey. Accurate surveys and detailed sketches will of course be needed, but most urgent will be the need for more 3-D data in the form of complete profile sketches and prolific cross-sections. While someday advanced instruments may make all necessary measurements for 3-D modeling, we can still contribute to better maps tomorrow by better using our sketchbooks today.

BIOLOGY

ARTHROPOD SPECIES DIVERSITY IN CARLSBAD CAVERN

Diana E. Northup, James M. Hardy, Kenneth L. Ingham
Arthropod species diversity was studied initially from 1984-1987 in Bat Cave, Sand Passage, and Left Hand Tunnel of Carlsbad Cavern. The results showed differences between Left Hand Tunnel, and Bat Cave and Sand Passage, with Left Hand Tunnel values closer to one, while Sand Passage and Bat Cave had higher values; indicating relatively more even proportions of each species than in Left Hand Tunnel. In 1988 these results were investigated at a larger scale using a transect through the Big Room and Left Hand Tunnel. The resultant patterns of species diversity, richness, and abundance are discussed.

CALIFORNIA EXPLORATION

CALIFORNIA COPIA

Dave Bunnell and Djuna Bewley, 320 Brook Drive, Boulder Creek, CA 95006

This multi-projector dissolve program will introduce the California exploration session. It will serve as a pictorial introduction to the diversity of caves in the state, featuring images of solution, volcanic, littoral, and corrasional (granite) caves and their surrounding environments set to music.

THE MARBLE VALLEY PROJECT, 1974 THROUGH 1989

Steve Knutson, P.O. Box 572, Boring, OR 97009

In 1974, a significant alpine karst area was discovered in Marble Valley in the Marble Mountain Wilderness of Northern California. Since then, the Klamath Mountains Conservation Task Force has pursued exploration and map-

ping, yielding very significant results. A total of 21.5 miles of cave, linked by 15 miles of surface traverses, involving a total of 5500 survey stations, makes this the greatest concentration of alpine caves in the United States as well as the greatest caving area west of the Continental Divide. Bigfoot Cave, the largest in the Valley, is a little over 12 miles in length and is the longest American alpine cave; at -1205 feet of depth, it is also one of America's deepest.

NEW DISCOVERIES IN LILBURN CAVE, CALIFORNIA

Peter Bosted, 4000 Farm Hill Blvd. #310, Redwood City, CA 9406

Lilburn Cave, located in Kings Canyon National Park, California, is a complicated three-dimensional maze cave formed in banded marble. Exploration from the mid-1940's through 1980 revealed 7.8 miles of passage in a mapping project led by Ellis Hedlund and Stan Ulfeldt. A new project by the Cave Research Foundation to re-map the cave began in 1980.

To date, over 11.4 miles have been charted. The new passages mostly have been in the southern part of the cave, where the advent of PVC caving suits has facilitated exploration of these often wet and muddy passages. While most of the discoveries have not extended the overall boundaries of the cave, the recently-found Hog Heaven passage is heading into a blank section of the map.

THE ARROYO TAPIADO MUD CAVES

Scott A. Schmitz, 4012 Antiem Street, San Diego, CA 92111

The Carrizo Badlands of California's Anza-Borrego Desert State Park contain what may probably be the largest non-volcanic pseudo-karst area in the United States, if not the world. The area is the site of numerous caves, at least sixteen of which are enterable. The two largest caves, Carey's Big Cave and Chasm Cave, have over 1000 feet of passages.

All the caves are found in narrow tributary canyons that penetrate the narrow band of pseudokarst extending on either side of the arroyo. The pseudokarst covers a total area of approximately 0.54 square miles. The caves can be divided into at least three evolutionary stages of development based on passage shape and size; each with formations has occurred from the percolation of water through the gypsiferous claystone (mudstone) that makes up the pseudokarst. It is the chemical composition and physical properties of this mudstone, along with their location in a hot and dry desert environment, that has allowed the caves to form in this geologically unique way, resulting in their size and the variety of their features.

SEA CAVES OF THE SOUTHERN CALIFORNIA COAST

Carol Vesely, 709 S. Primrose Ave. Apt A, Monrovia, CA 91016

Since its inception in 1971, the Southern California Sea Cave Survey has been diligently surveying sea caves along the coast from Montana de Oro State Park (San Luis

Obispo County) in the north to Baja California (Mexico) in the south. Excluding the hundreds of sea caves on the Channel Islands, we have surveyed 110 caves over 10 meters long along the coast; 20 of these exceed 100 meters in length and 38 exceed 60 meters in length. The caves are developed in a variety of host rocks, from basalt to colorful sandstone and often contain a rich assortment of tidepool life. The sea caves of La Jolla and Sunset Cliffs in San Diego have an interesting history of legends and sporadic commercialization.

SEA CAVES OF SANTA CRUZ COUNTY, CALIFORNIA

Peter Bosted, 4000 Farm Hill Blvd. #310, Redwood City, CA 94061

Over 120 sea caves have been mapped in the past eight years in Santa Cruz County, California by members of the Santa Cruz Sea Cave Survey. While many of the caves are relatively short, there are fifteen caves over 60m (200 feet) long. The most impressive include Forbidden Fissures (230 m long, with four entrances), Sand Hill Bluff (206 m, two entrances), Big Mother (170 m), and Sarawak (148 m, with a large room).

SEA CAVES OF THE CALIFORNIA CHANNEL ISLANDS

Dave Bunnell, 320 Brook Drive, Boulder Creek, CA 95006

This presentation will highlight exploration work on Santa Cruz and Anacapa Islands, which has yielded over 165 caves, 27 of which exceed 100 meters in length. Current focus is on Anacapa, which, though much smaller than Santa Cruz, shows considerable cliffs. The second and third largest (Catacombs, 808 feet and Cathedral, 790 feet) of the Channel Islands sea caves surveyed to date have been found here.

COMMUNICATION AND ELECTRONICS

ERROR SENSITIVITY OF CAVE-RADIO DEPTH MEASUREMENT

Frank Reid, NSS 9086, P.O. Box 5283, Bloomington, IN 47407-5283

Methods for measuring the depth of a magnetic-induction "cave radio" transmitter are reviewed. The slope of the depth function is determined and used to establish criteria for acceptable error sensitivity: Vertical-null angles between 17 and 70 degrees appear to yield best depth accuracy.

AUTOCORRELATION TECHNIQUES FOR CAVE RADIO

Frank Reid, NSS 9086, P.O. Box 5283, Bloomington, IN 47407-5283

Autocorrelation is a weak-signal recovery technique which should improve the range of low-frequency cave radio, and can be used for data communications. Autocorrelation requires extreme frequency stability which

is difficult to achieve underground where standard-frequency broadcasts are unavailable. Autocorrelation theory is reviewed, and simplified techniques applicable to caving are presented.

CONSERVATION AND MANAGEMENT

A MAJOR CHANGE IN THE NSS REWARD TO DETERRENT CAVE VANDALISM

John M. Wilson, Chairman, Cave Vandalism Deterrence Reward, Commission, 7901 Dalmain Drive, Richmond, Virginia 23228

The NSS has changed the Cave Vandalism Deterrence Reward to a flexible reward with a minimum of \$250 and a maximum of \$1000. The reward will be given to the person or persons providing information that leads to a conviction for cave vandalism. This reward will replace the \$500 reward that has been in effect since 1982. The changeover date was 1 June 1990.

The Commission is recalling all of its previous posters, replacing them with the new version. Sponsors are being sought and encouraged by listing their names on the poster. A one-time contribution of \$250 will list you or your organization on the vandalism deterrence poster for as long as the NSS offers the reward. These notices will be posted at show caves, managed caves, and other places in cave areas.

All NSS internal organizations and all other environmental groups are encouraged to participate. The notices will be more effective in deterring vandalism in those areas where local groups have pledged their support and their names appear on the poster.

EFFECTIVE CONSERVATION OF KARST THROUGH PUBLIC EDUCATION

Ernst H. Kastning, Karen M. Kastning, Department of Geology, Radford University, Radford, Virginia 24141

Karst regions throughout the United States are experiencing unprecedented environmental stresses imposed by development of surface lands for industry, commerce, recreation, and construction of residences. Large sections of karstlands are succumbing to urbanization as cities and towns continue to grow. Major demands imposed on the land include availability of flat topography for construction of buildings, readily accessible water supplies, corridors for transportation, and cleared land for construction.

Changes in land use intensifies environmental problems and may result in derangement of natural drainage (both surficial and subterranean), alteration of hydrologic flow regimes, collapse or flooding of sinkholes, contamination of groundwater, degradation of cavernous ecosystems, and overuse of caves for recreation by the local population.

It is impossible for those concerned with preserving the karst to single-handedly confront all of these problems through remedial action, including cleanups of caves and sinkholes, legal action to prevent development or to seek

restitution from violators of environmental law, or other reactionary measures. Although these efforts will help on a case by case basis, they will not keep pace with the impact of progress. The most effective means of preservation of the karst environment is through public education.

Perhaps the best approach to sound environmental awareness is within the context of primary and secondary education. The characteristics and mechanisms of karst and how they differ from other terranes must be made graphically clear in the classroom, particularly in counties or cities that lie within karst areas or are in close proximity to them. Another avenue for contact within this age group is through youth programs including scouts, 4-H clubs, and other outdoor-oriented organizations.

Secondly, the news media can be effectively employed in carrying environmental messages to the public at large. Graphic explanations of active karst processes in layman's terms can go a long way toward conveying the need to preserve fragile karst features, water supplies, and cave ecosystems. The use of photography, video-recordings, graphic arts, and writing, especially in conjunction with case histories, has been shown to be effective in reaching citizens living on karst. Distribution of this information can be in various forms, including presentations of papers or multimedia programs at local, regional, or national meetings; posters, (e.g. the recent cave conservation poster of the Virginia Cave Board); local clean-up and fund-raising events with attendant publicity in the media, exhibits at commercial caves, museums, scout shows, and other community events; and literature for distribution to the public and to landowners.

STATUS OF THE AMERICAN CAVE AND KARST MUSEUM

George Huppert, Vice President of the American Cave Conservation Association, Department of Geography, University of Wisconsin, La Crosse, WI 54601

Renovation of the building to house the American Cave and Karst Museum was started late in November of 1989. This first phase of the project is nearing completion. Additional funds of approximately \$1,300,000 will be needed to complete and install the museum exhibits. A fund drive has been started to generate these monies. It is hoped that the bulk of the cost will be covered by state and federal grants. In the future more expansion is anticipated with Phase II and Phase III.

The American Cave Conservation Association is continuing its community activities through the hiring of an educational officer from grant money. This position is likely to be renewed for another year. One of the Association's major thrusts have been the support of the Cleveland Sanitation Authority's efforts to become fully operational.

NUTS AND BOLTS OF THE NSS CAVE REGISTER PROGRAM

John M. Wilson, Chairman, Cave and Caver Study Project, 7901 Dalmain Drive, Richmond, Virginia 23228

The newly revised cave registers have been in use less than a year. Some of the most recent results will be presented. The revised format cave register is intended to provide more information of value to cave managers, conservationists, and cave organization leadership, and early results indicate that the new format will be more beneficial than the old registers.

This session will include a short "how to" presentation on operating a register program. Analyzing and validating the data, interpreting the results, and using the information will also be discussed. A small supply of registers and containers will be available to any NSS member planning to conduct a register program. Order forms for requesting supplies from the study project can also be obtained at this session.

THE TEXAS CAVE MANAGEMENT PLAN FOR THE TEXAS PARKS AND WILDLIFE DEPARTMENT: A REVIEW OF THE 1989 PROPOSAL

Ronald W. Ralph, Texas Parks and Wildlife Department

The Texas Cave Management Association offered a plan to the Texas Parks and Wildlife Department during the National Cave Management Symposium at New Braunfels, Texas, in October 1989. The plan addresses access procedures, a permission-permit system, cave classifications, group leaders, conservation policy, management philosophy, release and waivers, and current state laws. Kickapoo Caverns State Park with 15 inventoried caves is used to demonstrate both how volunteers can provide the Texas Parks and Wildlife Department with cave management recommendations and how the proposed plan works. The cave research project at Colorado Bend State Park also will be discussed.

A CAVE MANAGEMENT STRATEGY FOR THE FOUR MOUNTAIN PARKS OF THE ROCKY MOUNTAINS OF CANADA

Jon Rollins, Alberta Speleological Society, 314 Jackson Place NW, Calgary, Alberta T3B2Y3

Park policy as regards caves and caving is in the midst of transition. Until now, caving in the national parks of the Canadian Rockies without prior permission of the Park's Superintendent has been an illegal activity. This situation has been allowed to continue mainly due to a lack of information on the extent of the resource, i.e., the number of and locations of cave systems within the parks; and secondly, the nature of the resource, i.e., the fragility of certain caves in terms of their contents and the perception of caves as inherently dangerous.

The philosophy of the dominant caving organization in Alberta, the Alberta Speleological Society, has unwittingly supported this policy. For many caving organizations, secrecy has been the mainstay of cave protection policy. By restricting information on cave locations and not encourag-

ing the sport, caving organizations such as the Alberta Speleological Society have attempted to protect this delicate resource. Indications are that in the future such a policy will not prove adequate, especially for the more accessible caves. Increasing acts of vandalism in the form of spray painting, littering, and the removal and breakage of formations, on caves outside the parks mean that land owners and cavers need to take a more proactive approach. Despite the existence of large areas of limestone in the Canadian Rockies, relatively few significant caves have been discovered, and of these, only a small number lie within the park's boundaries.

While it is evident that many cave systems remain to be discovered, it is possible that repeated periods of glacial activity have either removed or buried many caves. It is characteristic of Canada's alpine caves that they tend to contain little in the way of delicate formations or fauna, and thus can take a moderate amount of visitation without showing signs of deterioration. Although there are some marked exceptions within the parks, it is probable that the majority of caves will fall into such a category, and thus not require any access restrictions. For those caves considered more sensitive to usage, it may be necessary to restrict or monitor visitation through a permit system. In order to establish such a system, an inventory of known caves, contents, and their durability will need to be carried out.

To date, apart from the yearly granting of permits for Castleguard, caves and the activity of caving has not been an issue of concern for the parks. Caving in the parks has continued spasmodically, mainly in the form of exploration by a few individuals intent on discovering new systems, all such finds being documented in the "Canadian Caver" magazine. Recently, the Alberta Speleological Society has signed a contract with the parks to develop a cave resource inventory and classification system. This move toward cooperation marks a positive change in relationships between the Four Mountain Parks and Albertan cavers.

STUDIES IN THE CAVE RIDGE AREA: PRELIMINARY REPORT

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Members of the Central Carolina Borehold Grotto have initiated a comprehensive investigation of the karst in the Cave Ridge area in southwestern Virginia. A couple of years ago we became acquainted with local residents and began exploring some of the caves nearby. It has become apparent, however, that this area offers many opportunities for scientific studies as well. There are numerous caves, springs, and sinking streams; low lying areas became flooded following heavy rainfall.

The Cave Ridge area is remote, sparsely populated, and predominantly rural. It is not believed to be threatened by development pressures. It is thus an ideal laboratory for investigations of hydrology, water quality, geology, biology, and ecology. Besides ongoing cave exploration and mapping activities, we have started tracing ground water flow paths. In addition to writing papers and progress reports, we plan to develop a set of procedures for the systematic evaluation of a karst basin, for which there is a growing need.

THE ROLE OF THE U.S. FOREST SERVICE IN CAVE CONSERVATION AND MANAGEMENT

Tom Lennon, Branch Chief, Trails and Wild Scenic Rivers, U.S. Forest Service, P.O. Box 96090, Auditor's Building, Recreation 4th Central, Washington D.C. 20090-6090

In July of 1987, the Forest Service issued cave management directions to the National Forests. In September of 1988, Associate Chief George Leonard signed a national agreement with the National Speleological Society to promote cooperation between local units of the National Forests and NSS grottos. In November of 1988 the Federal Cave Resources Protection Act was signed into law and draft implementation regulations have been developed. This presentation will discuss the Forest Service's efforts to develop and utilize these directives to manage caves in the National Forests and to make Forest Service land managers sensitive to cave issues. The draft implementation regulations will be discussed in detail, including the process proposed to establish the initial and subsequent listing of significant caves.

THE ORGANIZATION AND FINANCING OF A GROTTA PROJECT: A CASE STUDY

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The exploration of a newly discovered cave was halted because of the "bad air" (high CO₂) encountered in certain passages. The concentration of bad air was known to vary considerably in other caves in the area. In an attempt to predict when the concentration of bad air might be low enough to continue exploration, the Project was conceived. Meetings were held to discuss the goal or purpose of the project and to place limits on the extent of the study. What kind of organizational structure? What test equipment would be needed? Funding?

In October of 1987 members of the Mother Lode Grotto began a two year study of the bad air in two caves in Calaveras County, California. It soon became apparent that more funds than expected would be needed to continue the project. Early in 1988 an attempt to create a budget was undertaken. With this in hand, methods were explored to raise the necessary funds to continue the project. Methods included application for grants and solicitation of donations, both private and commercial; of both money and equipment. The manufacture, marketing and sale of T-shirts with creative logos that stimulated interest in cave research but with a "hook" that captures the imagination of the general public was a major source of funds. A recounting of the major expenses encountered to carry out the project and create the T-shirts, as well as the financial success of the latter will be made.

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95833

Caves with passages containing elevated levels of carbon dioxide and correspondingly lowered oxygen levels ("bad air") are found in a number of U.S. caving areas including Calaveras County, California. During the course of a two year study of air quality in several Calaveras County caves, it became apparent that information on the heat and safety aspects of bad air for cavers was needed, and a literature search was carried out. Carbon dioxide levels above 3 percent may provoke dangerous physical responses. The response to elevated carbon dioxide levels varies widely from person to person, and include increased respiration, reduced ability to do physical work, nausea, and metabolic changes to offset the increased acidity caused by exposure to carbon dioxide. Decreases in the available oxygen levels may exacerbate the effects and lead to other problems. Although tolerance to carbon dioxide varied between individuals, a maximum concentration of 4% carbon dioxide in air, easily tested with a butane lighter, provides a general safety guideline for short term exposure.

MODEL ETHICS SYSTEM FOR CAVERS

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This system of ethics, values comparison, and conflict resolution is intended for use as a model by cavers, who do not have the time to study moral philosophy, but want to know:

1. How to resolve in a just manner any disputes and conflicts involving cavers and others with cave interests.
2. How to resolve dilemmas in a rational manner.
3. What ethics requires of cavers.

This model is based upon the idea that many ethical systems have been useful components, that even if an ethical system is not appropriate for all situations, it may have components that are useful in some situations. This system is used to determine when and when not to use the various ethical tools. A practical application session will follow later in the day.

In order to use this system successfully, cavers should first determine and state their underlying assumptions, including their primary value. Then, each caver applies the methods of the first level to the dilemma or problem. One needs to use the methods of higher levels only if the problem is not resolved at a given level. There are four levels of ethical decision making. Each level is designed to match the effort and cost of the ethical procedure with the need and benefit. They are also designed to be user friendly for cavers.

Level 1. Legalism establishes routine decision making procedures for normal functioning. Level 2. Contractarianism applies the principles of overlapping consensus and the rule to act as if the action were to become universal law. Level 3. Utilitarianism measures the overall value and compares the values of different courses of action

in terms of their utility. Level 4. Consequentialism evaluates all the consequences of an act, including the consideration of incommensurable values and incompatible measurements, using all appropriate measuring systems. The weights given to each variable may be determined situationally.

GEOLOGY AND GEOGRAPHY

GEOLOGY OF THE KLAMATH NATIONAL FOREST

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The Klamath National Forest occupies three distinct physiographic provinces, the Klamath Mountains, Cascades, and Modoc Plateau. The Klamath Mountains Province lies generally to the west of Interstate Hwy 5, while the Cascades and Modoc Plateau Provinces are to the east.

The Klamath Mountains Province is structurally very complex, and consists of numerous distinct geologic terranes which range in age from Ordovician to Jurassic (500-135 million years B.P.). The Cascades Province consists of Tertiary volcanic rocks which have been subdivided into two units; the Western Cascades consists of Oligocene to Pliocene (40-11 million years B.P.) tuffs, breccias, sandstones, and lavas. The High Cascades consist of Pliocene (11 million years B.P.), and Holocene (10 thousand years B.P.) basaltic and andesitic lavas with minor pyroclastic rocks. The Modoc Plateau is an undulating platform of low relief, composed of Miocene to recent basalt flows, many of which contain lava flows.

SUBORDINATION OF STRUCTURE, LITHOLOGY, AND CLIMATE TO GEOMORPHOLOGICAL CONTROL OF CAVE DEVELOPMENT - THE EXAMPLE OF MEANDER CUTOFF CAVES

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The development of meander cutoff cave through the necks of incised meanders in carbonate rocks is an example of the geomorphological setting exerting control over cave development. Modifications in structure such as faults and jointing, variations in carbonate lithology such as grain size and degree of metamorphism, and climatic differences such as latitude and placiation are subordinate to the geomorphology in controlling the overall conduit trends. Meander cutoff caves developed in glaciated Precambrian marble of the Adirondack Mountains of New York show a remarkable similarity of pattern to meander cutoff caves developed in flat-laying Mississippian limestones of the Pennyroyal Plateau of Western Kentucky. While structure and lithological variation control passage morphology and orientation on the small scale, the large scale trends of meander cutoff cave development are independent of these factors. Late Pleistocene placiation has not been a sufficient climate variable to produce a difference between New York and Kentucky meander cutoff caves.

*GENERAL GEOLOGY AND DEVELOPMENT OF
LAVA TUBES IN NEW MEXICO'S EL MALPAIS
NATIONAL MONUMENT: CONFIRMING EPSOMITE
IN THE FIELD BY TASTE TESTING*

Bruce W. Rogers, Cave Research Foundation, 1143 Pine Street, #4, Menlo Park, CA 94025

The el Malpais area is located in northwest New Mexico at an elevation of approximately 2200 m. Open juniper-pine woodland and sage-rabbitbush vegetation cover the Pliocene to Holocene-aged lava fields which lie on pre-Cambrian to Cretaceous-aged sedimentary rocks. The crustal xenolith-bearing basaltic lavas appear to have compositionally changed throughout their eruptive history. The flows containing the known caves are bracketed by 0.75 to 1.3 my old and 400 year-old lava. Five large craters with disgorged lava flows containing tubes in varying states of preservation. The Bandera Crater flow is 45 km long and contains 28 km of identifiable tube, most of which is collapse trench. This flow contains dozens of caves ranging from a typical 300 to 400 m long caves to over kilometer long systems. The caves are mostly braided in pattern but unitary tubes are present. Wind-derived soils from the Cretaceous-aged sedimentary rocks have allowed a varied mineralogy to develop in the caves. So far, ice, calcite, gypsum, and epsomite have been identified from the caves. The Native Americans, Spaniards, and gringos apparently did not utilize the caves to any extent.

*GEOLOGIC SETTING OF THE SISTEMA CUICATECO,
OAXACA, MEXICO*

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The recent, world record breaking, visual-positive dye trace of stream flow between the Cueva Cheve resurgence (el. 2720 m msl) and a resurgence in the Santo Domingo canyon (el. ~250 m msl) (B. Farr, personal communication, 1990), along with an explored depth of approximately 1355 m, establishes Sistema Cuicateco, Oaxaca, Mexico as a premier, high-relief karst terrain. In high surface relief combined with extensive, natural subsurface exposures will provide intriguing opportunities for studies of the stratigraphy and structure of a complicated, little studied, and poorly understood region.

The presently explored, upper part of the system is in a Cretaceous carbonate in the lower plate of a Laramide-age thrust fault. The caves expose a rudist-bearing bioherm, laminated micrite, forereef breccia, thick-to-massive-bedded limestone, and laminated back-reef limestone. A Cretaceous(?) andesite is exposed within the cave and on the surface. On the surface, the carbonate terrane is surrounded to the south, west, and east by the Cuicateco Metamorphic Complex contained in the upper thrust plate. The surface outcrop of carbonate averages four kilometers wide from east to west. The surrounding metamorphic rocks are predominantly talcose volcanic rocks, and cataclastic sandstone, shale, and volcanic rocks, and chert-mica schist. Although little is known about the area, the region provides an outstanding opportunity for three di-

mensional examination of both a Laramide fold and thrust belt and of the rocks associated with a rudist reef complex.

*MORPHOLOGICAL EVIDENCE OF HYDROTHERMAL
DISSOLUTION OF NORTHEASTERN BASIN AND
RANGE CAVES*

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Using morphological criteria presented in recent papers on thermal dissolution of caves in the black hills (USA), Poland, and the USSR; similarly developed caves have been identified in the Basin and Range geologic province. A main feature of these caves are cupolas or hemispherical domes dissolved upward into the ceiling. In several instances the hot fluid paths can be traced from floor vents to wall and ceiling channels and upward into these domes. Especially interesting are fluid orifices between two large-volume chambers.

Thermal convective currents cause dissolution which ignores variations in bedrock solubility, creating smooth, undulating walls and ceilings unlike those seen in phreatic meteoric-water caves. Penetration of dissolving waters into guiding joints or faults is rarely seen. Evidence of thermal dissolution, then deposition of thermal speleothems, and subsequent re-dissolution has been documented.

By applying the above and many other criteria a conclusion is reached that nearly all dissolution caves in the region are of hydrothermal origin.

*GEOLOGY, AND GEOARCHAEOLOGY OF NAJ TUNICH,
PETEN, GUATEMALA*

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Naj Tunich is formed in Cretaceous age brecciated limestone in the southeastern Peten of Guatemala. Three distinct stages of development have been identified: phreatic, sulfate, and modern. During the phreatic stage the large trunk passages were formed, moving an average volume of 1.14 m³/sec, at an average velocity of 1.1 cm/sec. Following a drop in the water table and subsequent collapses, overflow drainage routes developed, as well as passages that extended down to the water. The sulfate stage began as the cave's upper levels dried out and when gypsum crusts (which later dehydrated to bassanite or anhydrite) were deposited along the cave walls. The sulfates were derived from a pyritic clastic formation overlying the cave. The cave's present or modern stage began with the removal of the clastic unit. Subsequent effects were the karstification of the land surface, the cessation of sulfate deposition in the cave, and the continued lowering of the water table. Archaeologic materials in Naj Tunich are useful in dating the rates and stability of its processes and conditions during the past 1300 years, as well as providing other geologic data. Similarly, Naj Tunich's geology contributes several insights to the Mayan culture, and to cave management factors in preserving its artifact and exquisite paintings.

*EFFECTS OF JOINTS AND GRUSSIFICATION ON
GRANITE CAVE DEVELOPMENT IN THE LOST
CREEK SYSTEM, COLORADO*

Louise D. Hose, Department of Geology, University of Colorado, Colorado Springs, Colorado 80933

The Lost Creek Wilderness Area in central Colorado is the site of seven known caves (using the cavers' definition of passage penetrable by humans that extend beyond the region of natural light). All of the cave are in the 1.0 Ga Pikes Peak Granite of the Tarryall Mountains batholith, a pluton within the Pikes Peak Composite Batholith. The rock is massive, coarse subequigranular to porphyritic granite with approximately 50% microcline perthite, 30% quartz, 15% sodic plagioclase, and 5% iron-rich biolite. The granite prominently displays a strong joint system with steep northeast and northwest sets and a nearly flat set, resulting in common exposure of sub-orthogonal joint sets. Differential weathering along the joints was assisted by extensive grussification of the ancient rocks. The discomposed grus was readily removed resulting in remnant corestones and the appearance of flat-bedded stratigraphy.

Cave development initiated as steep-walled stream canyons that probably formed by mechanical removal of loose grains previously disaggregated by grussification along sub-vertical joints that dip towards the open canyon. Surfaces are up to 60 m above the cave streams and several of the caves have extensive soil and forest covers.

*THE QUINTESSENTIAL CAVE GEOLOGY TALK;
NEVER TOO MANY RUBBER PIGS*

Bruce W. Rogers, Cave Research Foundation, 1143 Pine Street, #4, Menlo Park, CA 94025

Speaker surmounts podium, tripping over mike cord, coughs, shuffles papers, coughs again, then begins endless, mumbling talk punctuated with "uh...", "Is that in focus?", "I don't have a good slide of this but...". This talk, uh, will attempt to, uh, give a rough approximation of a, uh, boilerplate type guesstimation of how lots/too few overheads/slides which, uh, are... well, kinda sloppy and really poorly done like this crayon on brown paper bag overhead that, uh, I'm gonna make right here with a charred kitchen chair leg. The, uh, correct usage of unintelligible slides/overheads with blinding white backgrounds, employment of Mr. Bill rubber pigs, 3" long rock hammers, and blue 4" long microbus scales will, uh, be mumbled about. Lesson on, uh, how to dance around on the, uh, stage thus distracting everyone from looking at your, uh, never look at all those people out there in the, uh, dark will be shabbily demonstrated...maybe. Most importantly, how to totally, uh, not plan your talk and, uh, come off as a, uh, complete bore, thus killing any interest in your subject will be, uh, hopefully demonstrated. The use of quick, non-technical, and relatively CHEAP visual aids will be presented...computer jocks need not attend. Blame this all on Art & Peggy Palmer.

EFFECTS OF LIMESTONE ON CAVE FORMATION^[1]

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The composition of limestone is important to how a cave forms by dissolving of rock. If a limestone is pure and is mostly made of calcite, it should dissolve easily. But, if the limestone is low in calcite content and high in insoluble materials, caves will not form very well.

To test this hypothesis, a study was made of the beds seen in Grand Caverns, Augusta County, Virginia. The entire cave is horizontal, but all of the sedimentary beds have been tilted vertically. Some passages of the cave cut across the beds, providing easy access for taking samples of many beds. The largest and longest rooms and passages in the cave follow particular beds. These should be rocks that are more soluble than others.

Samples taken in the cave were cut into centimeter-size cubes that were dissolved in dilute hydrochloric acid for specific times. The amount of dissolving and the amount of residue left behind were measured. The results show that there is a great deal of variation in the rock.

The large cave passages have formed in very soluble rocks that have a high calcite content. These are dense, blackish, microcrystalline limestones. Blades of rock sticking out of the cave walls are generally not soluble. They are made of sand and clay and many are soft and crumbly.

Limestone composition was found to greatly affect where cave passages develop. Because of the vertically tilted limestone beds, Grand Caverns is an excellent examples of how important composition is during cave formation.

*TEPHROCHRONOLOGY AND SEDIMENTOLOGY OF
SINKHOLE DEPOSITS IN THE REDWOOD CANYON
KARST, KINGS CANYON NATIONAL PARK, CALIFORNIA*

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Clastic sediment interbedded with volcanic ash (tephra) provides clues to rates and processes of soil erosion in karst basins under mixed coniferous forest conditions on the western slope of the Sierra Nevada at the latitude of Fresno, California. Volumes of eroded sediment are estimated using hand-powered soil auger studies and isopach techniques. The tephra was erupted about AD 1240 from the Deadman Dome area, Inyo Craters volcanic chain, eastern Sierra Nevada, near Mammoth Lakes; on the basis of chemical analysis of glass separates. Basin size and slope parameters along with the sedimentation data reveal rates at which soil is eroded into the sinkholes. Few suitable sinkholes limit the geomorphic components analyzed; although

^[1] **Student contribution.** This study won first place in the Earth and Space Sciences Division at the Radford High School Science Fair, February 1990 and was a Grand Award winner at the Western Virginia Regional Science Fair, Roanoke, Virginia, April 1990. The author was a finalist in the 41st International Science and Engineering Fair in Tulsa, Oklahoma in May 1990.

principal conclusions and trends appear stable. Sinkholes containing abundant boulders and cobbles fail to trap tephra and fine clastic sediment and are prohibitively difficult to explore with a soil auger. Other sinkholes function as open conduits to the cave beneath, and convey water and sediment directly to subsurface Redwood Creek. Ideal are sinkholes which contain a mantle of soil and forest duff which effectively filter out most fine sediment and allow water to percolate into the subsurface. Sinkholes which have basins do not yield sediment rapidly in relation to rates of bioturbation; thus, recognition of the marker bed and post-tephra sediments becomes impossible or unreliable. Sinkholes which have "leaked" sediment since the ash was deposited result in underestimation of soil erosion rates. The tephra blanket apparently ranged from 1 to 5 cm thick in Redwood Canyon; rates of soil erosion range from 0.5 to 1.5 cm/yr.

MAGNETOSTRATIGRAPHY OF CAVE OF THE WINDS, MANITOU SPRINGS, COLORADO

Fred Luiszer, University of Colorado, Boulder, Colorado

By means of a specially designed hydraulic coring device, eight holes 2 to 10 m deep, were bored into fine grained sediments that had accumulated in the Grand Concert Hall area, Cave of the Winds. Oriented samples taken from cores at 3 to 10 cm intervals were, after initial measurement of their natural remanent magnetism, subjected to partial alternating field (AF) demagnetization. Demagnetizations at 10 to 15 mT indicated that magnetic signals contained in the sediments faithfully recorded the paleomagnetism. The resultant magnetostratigraphic record matches closely with the established magnetic-polarity time scale over the interval from about 4.5 to 1.6 Ma.

Sedimentation ceased when the surface stream drainage system incised deeply enough to cause drainage of the cave. The Plio-Pleistocene(?) Nussbaum Alluvium, remnants of which are located near Cave of the Winds, is thought to represent part of a widespread alluvial deposit, laid down by the surface streams just prior to down cutting. Amino-acid dating of fresh water snails within the alluvium establishes the age of the Nussbaum as 2.1 Ma, which collaborates a 1.9 Ma age given to magnetostratigraphically dated cave sediments that record stream incision.

THE ULTRASTRUCTURE AND COMPOSITION OF HYDROMAGNESITE BALLOONS FROM JEWEL CAVE NATIONAL MONUMENT AND CARLSBAD CAVERNS NATIONAL PARK

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Fallen hydromagnesite balloon fragments were collected from Jewel Cave during the summer of 1988, and from Carlsbad Cavern and Lechuguilla Cave in the summer of 1989. Scanning electron microscopy showed that the balloons were constructed primarily of tabular crystals up to 1 μm thick and from 5-80 μm across. The crystals are stacked

randomly over one another in plane view, but parallel in cross-section. Total wall thickness was variable, but 50 μm (.05 mm) was typical. The composition of the Jewel Cave specimen, based upon powder x-ray diffraction, was 79% hydromagnesite, 15% calcite, and 6% aragonite. Trace amounts of silica and evaporite salts were detected by dispersive x-ray spectroscopy; the silica appears to be the glue that binds the balloon wall components together.

The attachment point of balloons to the passage wall was, at best, difficult to observe. However, the Carlsbad Cavern specimen included the base of the balloon. The base, in this case, consisted of three hollow hydromagnesite spherules, each about 1.5 mm in diameter; the balloons had grown from the surface of the spherules. Hollow spherules of comparable size were also found in uninflated hydromagnesite moonmilk samples from Jewel Cave, but none with associated balloon growth.

Balloon fragments from Windy City, in Lechuguilla Cave, were noticeably different from the Jewel and Carlsbad specimens. The hydromagnesite walls were coated with a layer of aragonite approximately 50 μm thick. Balloons appear to grow where calcium and magnesium carbonate minerals are separated by evaporative fractionation; if air-flow through (or the infiltration rate of water into) a passage is altered, the zone of fractionation may shift.

MINERALOGY OF LAVA TUBE CAVES IN MEDICINE LAKE VOLCANO, CALIFORNIA

Bruce W. Rogers, Cave Research Foundation, 1143 Pine Street, #4, Menlo Park, CA 94025

Medicine Lake volcano lies in the northeast corner of California, just south of the California-Oregon border at an elevation of 2417 m. This Holocene to Pleistocene-aged Cascade Province volcano has developed a large shield over 33 km in diameter and is largely comprised on basalt, andesitic basalt, and andesite. In a zone on both the northern and southern flanks at approximately 1372 m in elevation are many basaltic cones from which long, tube-bearing lava flows emanate. Approximately 18% of these tubes are preserved and range from short grottos to braided systems over 7km long. Over 300 caves are currently known from these flows. Eleven minerals, mineraloids, and rocks found as speleothems in the tubes include, ice, goethite, pyroclucite, romanechite, gypsum, barite, calcite, cristobalite, silhydrite, amorphous silica, "wad", and basalt. There appears to be a rough elevation-controlled zonation of the secondary mineralization in the lava tubes which follows the availability of ground water, soil composition, and vegetation pattern. On the flanks of the volcano, oxides, hydroxides, and miscellaneous "minerals" form higher in the caves under areas where soils are well developed and ground water abundant. Silicates, carbonates, and sulfates are found further down slope in areas of thin soils and less ground water. Ice and basalt are found throughout the caves studied.

*KINETICS OF CALCITE DISSOLUTION IN KARST
AQUIFERS: FIELD MEASUREMENT AND
THEORETICAL PREDICTION*

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Reaction kinetics of mineral within karst aquifers (generally calcite) have been the subject of numerous laboratory experiments, leading to the development and testing of rate laws over a wide range of conditions. While these studies have provided a good understanding of the dissolution process under controlled conditions, field measurements of calcite dissolution have received little study. An approach that couples hydrologic field measurement with mass balance calculations has been used to evaluate the geochemical evolution of Laurel Creek, West Virginia as it flows through the Laurel Creek-Cross Road Cave System. An estimate of the surface area of mineral/water contact within the flow system has resulted in a calcite dissolution rate estimate of 1.7×10^{-8} mol $\text{cm}^{-2} \text{s}^{-1}$. A theoretical dissolution rate has been evaluated at points along the flow path using the rate law of Plummer, et al. (1978)⁽²⁾ and the average value calculated as 5.2×10^{-8} mol $\text{cm}^{-2} \text{s}^{-1}$. These rate estimates, made with very different approaches, agree within a factor of three, which is within the potential error of the field surface area measurement. This supports the use of the rate expression as a modeling tool in the study of geomorphic and hydrologic problems in karst terrains.

*HYDROCHEMICAL SURVEY OF CARBONATE
GROUND WATERS IN PUTMAN AND JACKSON
COUNTIES, TENNESSEE*

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Chemical and microbiological analyses of sixty-five carbonate well and spring waters were used to characterize the quality of ground water produced from the upper Ordovician Catheys and Leipers Formations and the Mississippian Fort Payne Formation in the Outer Central Basin and Eastern Highland Rim of central Tennessee. Although calcium/magnesium bicarbonate, calcium sulfate, sodium chloride, and mixed waters were also found.

Nitrate concentrations ranged from beneath detection to 31 mg/L (milligrams per liter) with 31 percent of the waters exceeding 2 mg/L. Fecal coliforms were detected in 38 percent of the samples. Central Basin and Highland Rim ground waters had statistically different means of all major ions at an alpha of 0.01 using the Mann-Whitney U test. The average total dissolved solids (TDS) content of Central Basin well waters was 252 mg/L while Highland Rim well water averaged 120 mg/L TDS, indicating that water in the

Ordovician aquifer is closer to equilibrium with the wall rock than is water in the Fort Payne aquifer. Calcium/magnesium molar ratios averaged 1.2 among Highland Rim waters and 3.5 among Central Basin waters, indicating the presence of dolomite in the Fort Payne. Scatter diagrams and Piper diagrams also enabled the distinction between Central Basin and Highland Rim waters and were the basis of interpretations regarding aquifer mineralogy and the relative importance of diffuse and conduit flow regimes in the two aquifers.

*HYDROLOGY AND CHEMISTRY OF CONDENSATION
WATERS IN SNEDEGAR'S AND GREENVILLE SALT
PETER CAVES, WEST VIRGINIA*

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Condensation water drops fill drop dents or hang from textural projections and clayvermiculations. Condensation water also forms films that descend rills in a fill and surge flow; the water collects at drip points or on projecting bedrock as edge films. Inclined surfaces support smaller drops (<4 mm diameter) and as much as 300 g $\text{H}_2\text{O}/\text{m}^2$. Horizontal surfaces accumulate larger drops (up to 8 mm) and up to 1 kg $\text{H}_2\text{O}/\text{m}^2$. Condensation rates vary with relative humidity, the rate of air flow, the temperature differential between bedrock and circulating surface air, and location within the cave. Many passages have high condensation rates on the ceiling and upper walls, but low condensations rates or even evaporation below an irregular subhorizontal wet/dry line. Condensation rates measured in Snedegar's Cave daily for eleven days in July, 1989 were 30-90 g/ m^2 /day for three vertical surfaces, and 45-200 g/ m^2 /day for five horizontal surfaces. The mean mass transfer rate for eight six-minute experiments with rill films on a vertical surface during peak condensation was 105 g/ m^2 /hr; the mean flow velocity was 4.5 cm/min.

Composite samples of condensation water were collected with syringes, filtered, and analyzed for pH and major anions and cations. Nine drop- and three rill-water samples were dilute Ca- HCO_3 waters. These samples were unsaturated with respect to calcite and dolomite. Mean pH for drop- and rill-waters was 7.78 and 7.79 respectively. Mean concentration (in ppm) of major ions were: Ca (29.8, 46.3) Mg (1.3, 10.5), HCO_3 (88.6, 112.7), SO_4 (2.5, 35.8), NO_3 (4.1, 44.4), and Cl (0.6, 2.2). Locally elevated SO_4 was associated with pyritic dolomicrites. The high NO_3 rill films may represent removal of NO_3 from NO_3 -rich clay coatings. Two additional samples (one drop water, one rill water) from Snedegar's Cave were concentrated Ca-Mg- NO_3 waters of uncertain origin. These samples had lower pH (7.23, 7.12) than normal condensation waters. Concentrations (ppm) of major ions were: Ca (2350, 4310), Mg (914, 1395), Na (199.3, 311), HCO_3 (40.5, 41.3), SO_4 (610, 525), NO_3 (11820, 21160), and Cl (695, 1350). The Ca-Mg- NO_3 waters are composite samples from areas with thin clay coatings on limestone bedrock; the samples were removed from drop dents and rills set in thick white crusts over the clay.

⁽²⁾ Plummer, L.N., T.M.L. Wigley, and D.L. Parkhurst, 1978, "The Kinetics of Calcite Dissolution in CO_2 - H_2O systems at 5 to 60°C and 0.0 to 1.0 atm CO_2 ," Amer. J. Sci. 278, (179-216).

*TIME SERIES ANALYSIS OF SPRING WATER
QUALITY FOR "WELL HEAD PROTECTION"
PURPOSES IN EAST TENNESSEE*

Kristie G. Hamilton, Albert E. Ogden, Center for the Management, Utilization and Protection of Water Resources, Tennessee Technological University, Cookeville, Tennessee 37604; Teresa Brown Cawood, First Tennessee Development District, Johnson City, Tennessee 37604

Nine municipal-used springs were studied in the folded carbonate rocks of east Tennessee to determine recharge areas and ground water quality for ascertaining pollution susceptibility. Dye tracing has shown that some of the limestone springs are rapidly recharged from nearby sinking streams and sinkholes, thus allowing them to be highly susceptible to contamination from point and nonpoint sources of pollution. Some of the springs emerge from non-karst rocks in which ground water pollution susceptibility is low. Diffuse recharge and flow to these springs makes delineation of wellhead protection areas more difficult.

Monthly water sampling of the springs has helped define the nature of ground water flow (diffuse versus conduit) and has shown the present levels of contamination. Conduit spring systems have greater fluctuation of water chemistry and higher levels of fecal coliform bacteria. Diffuse flow springs generally have better and more constant water quality. MTBE, a soluble gasoline additive, was not found in any sample, indicating that leaky underground storage tanks are presently not a problem. TOX levels are higher in the open conduit spring systems, but concentrations are relatively low. The recharge areas are primarily rural, thus septic tanks and agricultural practices are the most likely causes of contamination. Spills along highways pose the greatest threat to spring water quality.

*FLOW BEHAVIOR OF BIG SPRINGS, REDWOOD
CANYON KARST AREA, KINGS CANYON
NATIONAL PARK, CA*

John W. Hess, Michael Spiess, John C. Tinsley, Gary Mele, Brad F. Lyles, Cave Research Foundation, c/o Desert Research Institute, 2505 Chandler Avenue, Suite 1, Las Vegas, NV 89120

Hydrologic investigations of the Redwood Canyon Karst are aimed at a better understanding of the hydrology of the area including the ebb and flow behavior of Big Spring. In the fall of 1988, the recording station at Big Spring was up-graded from a strip chart recorder to a digital data logger, and sensors and a heated recording rain gage were installed in the headwaters of Redwood Creek. Data collection was sporadic during the winter and spring 1989 and has been almost continuous since early summer 1989. Parameters recorded at Big Spring include stage (discharge), water temperature, and electrical conductivity. Preliminary interpretation of forty-two day of the Big Spring stage hydrograph (March 23 - May 4, 1989) indicate some interesting flow behavior. The ebb and flow behavior can be observed from the beginning of the (March 23, 1989) through April 3, 1989. From that time on, the stage slowly drops with small diurnal cycles superimposed on the long

term decline. A detailed examination of a period of ebb and flow behavior at the end of March reveals that the stage generally varied from a low of 0.6 feet to a high averaging approximately 1.4 feet, including an interesting example of the stage going to near zero on March 25, 1989. Approximately 20 ebb and flow cycles per day occurred during this period. Water temperature varied between 5.6 and 6.0 degrees Celsius and electrical conductivity varied from 83 to 96 $\mu\text{mhos/cm}$ over the five days expect for the sharp increases on March 25, 1989. At the time of the almost zero stage event on March 25, 1989, discharges peaked on either side at approximately 1522 and 1607 hours. Minimum stage occurred at 1551-1556 hours. Peaks in temperature and electrical conductivity occurred at 1602 hours followed by the discharge peak at 1607 hours. The large increase in temperature and conductivity may be associated with the flushing of more stagnant water. It is possible that during this particular ebb and flow cycle, the water levels in the cave system were raised higher than usual, causing the flushing of waters that had no longer residence time in the cave hydrologic system.

SEASONAL VARIATION IN THE LEVEL AND CONCENTRATION OF CARBON DIOXIDE IN THREE "BAD AIR" CAVES IN CALAVERAS COUNTY, CA

Davis G. Cowan, Cave Air Research Project, Box 254545, Sacramento, CA 95865

Bad air (foul air - Brit.) in caves is not an uncommon occurrence in many of the pit caves formed in the near vertically dipping marble of the Calaveras Formation in the Mother Lode area of Northern California. CO_2 concentrations as high as 8% have been recorded at certain times of the year, while at other times, the same cave will exhibit near normal concentrations (<0.5%). Bad air caves are difficult and can be highly dangerous to explore. The purpose of the study was to see if it was possible to predict when the CO_2 concentration would be at a minimum, and consequently, safe to explore.

Initially, data was to be collected in two caves for two years. A third cave was added after the first year due to differential results of data between the first two caves. Time, temperature, relative humidity, and percent CO_2 were recorded at established survey stations on a monthly basis. Percent O_2 was recorded periodically. The concentration of O_2 was lower than what could be accounted for by dilution of the air by the CO_2 . The results of the study were inconclusive for several reasons, but we conclude that it would be difficult to predict the period of minimum CO_2 for a given cave based on data collected from a different cave.

Although the study did not attempt to determine the cause of the variations in concentration or the source of the CO_2 , certain inferences can be made. It appears that the temperature of the air outside the cave may be a key factor in affecting both the elevation and concentration of CO_2 in some caves. The source of the CO_2 may be subterranean as opposed to out-gassing of water supersaturated by passing through surface organic soil. It appears that source of the CO_2 , whether organic or other chemical reaction, may be consuming the O_2 from the cave air.

*MONITORING AND DETECTION OF KEROSENE FROM A
LEAKY UNDERGROUND STORAGE TANK IN A KARST
ENVIRONMENT, TENNESSEE*

Albert E. Ogden, Center for the Management, Utilization, and Protection of Water Resources, Tennessee Technical University, Cookeville, Tennessee 38505

During high water table conditions, kerosene was found on the surface above a kerosene tank at a major industry in Cookeville, TN. Inspection of neighboring industries found two other sites with leaky tanks leaking petroleum products to a sinking stream. The area is underlain by the Mississippian-aged St. Louis Limestone with abundant sinkholes and many large caves. Data from four intact slopes in a southwest direction, similar to surface topography. A dye trace of surface drainage showed water from the sinking stream off-site emerged at an impacted spring in just six hours. The static water level measurements from the wells indicate a northeast direction of ground water flow, opposite to surface drainage. Depth to water averages 30 feet below land surface, but fluctuates over 15 feet between wet and dry seasons.

Contaminated soil and the tanks were removed. The soil was placed in lined and bermed pits and treated by passive volatilization. Soil borings were made by hollow stem augering with split spoon sampling for TPHC to define the extent of the plume. Migration of the kerosene was primarily along gravel-fill beds and along the water line around the building. Three additional monitoring wells sites using the tri-potential resistivity techniques enhance the chances of intersecting fractures and the contaminant. The karstic nature of the rocks will require off-site monitoring of springs around the facility. An interceptor trench and enhanced in-situ biodegradation are planned for remedial action.

*LAVA PSEUDOKARSTS OF MOUNT ST. HELENS: THE
FIRST TEN YEARS AFTER THE 1980 ERUPTIONS*

William R. Halliday and Marcia L. Halliday, 308 Aaron Court, Sterling, VA 22170

The pseudokarst of the Cave Basalt Lava Flow of Mt. St. Helens suffered only minimal direct impact from the 1980 eruptions of Mt. St. Helens. However, the caves and other pseudokarstic forms underwent a variety of impacts depending on their location and exposure to runoffs of varying load and velocity. An entire new pseudokarst developed north of the mountain in a complex of pyroclastics and avalanche debris. It continues to undergo rapid evolution.

*PREVIEW OF THE 6TH INTERNATIONAL SYMPOSIUM
ON VULCANOSPELEOLOGY, HILO, HAWAII,
AUG. 5-9, 1991*

William R. Halliday, 308 Aaron Court, Sterling, VA 22170

The 6th International Symposium on Vulcanospeleology will be held in Hilo, Hawaii in August 1991. It will include two days of formal presentations and discussions plus three days of field excursions to notable caves and related features of Kilauea and Mauna Loa Volcanos. Sessions will include vulcanospeleology of Hawaii,

vulcanospeleology of the Western United States, vulcanospeleology of the world, and a special session combining theoretical vulcanospeleology, biospeleology of lava tube caves, and conservation of lava tube caves. Pre-symposium events on the island of Oahu will include a field excursion to pre-Quaternary lava tube caves of that island. A post-symposium field excursion to the island of Kauai will be of special interest to biospeleologists.

HISTORY

THE CAVE ARTIST'S ARTIST

Russell Gurnee, 231 Irving Avenue, Closter, NJ 07624

Cave Rock Art paintings, drawn by early unknown artists, were copied in situ by artists before the invention of photography. These drawings were sometimes reproduced by other artists for presentation in books and reports. The final representations of the original work appeared in engravings, woodcuts, and aquatints. Cave scenery was often included in the art work (with artistic license) to show the location of the paintings within the cave.

Each artist modified the original in accordance with his skill and sometimes prejudice. Students and researchers used these representations to make conclusions and opinions regarding the original creators of the work.

This paper will show illustrations of well known cave illustrations of the last century and some present photographs showing the paintings as they exist today. The importance of field observation of sites and conditions is essential in understanding the work of these early artists.

THE SECRET BURIAL CAVE OF HAWAII'S KING KAMEHAMEHA I

William R. Halliday, 6530 Cornwall Ct., Nashville, TN 37205

Hawaii's King Kamehameha I unified the islands, in large part, by bloody warfare. But not all of his bitter enemies died in the warfare or were put to death later. For any Hawaiian to desecrate the bones of an enemy was a triumph. In the case of Kamehameha the Great, such desecration would have been the epitome of triumph or despair, depending on one's viewpoint. Thus, Kamehameha's burial rites were conducted with the utmost secrecy, and the site of his burial remains unknown today. Many burial caves are known close to the location of his death, and many have speculated that his bones lie in one of these. Another theory is that his bones were given to the sea. This paper raises the possibility that an underwater lava tube may have been the site of his burial.

THE WHITE LADY OF LA JOLLA

Richard L. Breisch, 4735 Mt. Ashmun Dr., San Diego, CA 92111

The title refers to a California sea cave, a bride, and a book. The book by Rose Hartwick Thorpe was published in 1902. It told the story of honeymooners who were trapped by the tide while exploring sea caves. Supposedly their

bodies were never found. Possibly there were no bodies to be found, since the story may have been the creation of Mrs. Thorpe's fantasy.

THE PACIFIC BASIN SPELEOLOGICAL SURVEY: A FIVE YEAR RETROSPECTIVE

Bruce W. Rogers, 1143 Pine Street, #4, Menlo Park, CA 94025

Chartered in 1985, the Pacific Basin Speleological Survey (PBSS) has embarked upon a project to compile a preliminary listing of the known caves in the island nations of the Pacific Basin. Australian, French, and British work in Melanesia and portions of Polynesia was a matter of record so Micronesia was selected as the focus of the PBSS' working area. Pohn Pei, Kosrae, Truk, and Yap States of the Federated States of Micronesia, Saipan, Tinian, and Rota in the Commonwealth of Mariana Islands, the Territory of Guam, and the Republic of Belau have been visited. Extended expeditions to these areas in 1984, 1986, and 1989 have found a wealth of speleological features to be investigated. Extremely old lava tubes; literally hundreds of limestone solution caves, some horizontal, some vertical, some filled with sea or fresh water, and some with near lethal atmospheres; actively forming reef caves; and volcanic rock shelters are present. The caves harbor a large and varied biota, largely uninvestigated; prehistoric deposits upwards of 3,000 years old; rock art of varying types; and historic deposits from Spanish, German, Japanese, and American periods. Manuscripts for the islands of Pohn Pei, Truk, Yap, and Palau have been completed. Saipan, Rota, and Guam manuscripts are in final compilation.

In addition, the PBSS has taken over the publications in press and preparation of the Golden Gate Grotto, completing a manuscript on sea caves in the San Mateo Coast district in central California. Surveys of sea caves in Golden Gate National Recreation Area and Point Reyes National Seashore, as well as Angel Island State Park, are nearing completion.

INTERNATIONAL EXPLORATION

CAVE EXPLORATION ON ANGUILLA, BRITISH WEST INDIES, INDIANS, AND CONSIDERATIONS BEFORE SHOW CAVE DEVELOPMENT

Jeanne Gurnee, 231 Irving Ave., Closter, NJ 07624

Exploration is the first step necessary when studying a cave in preparation for developing it for public visitation. The government of the island of Anguilla in the British West Indies invited a study of Foundation Cavern in order to analyze its Indian petroglyphs and to recommend ways that the cave might be developed for visitors.

The National speleologist Foundation was responsible for the study; and NSS members Russell H. Gurnee, Pat Stone, Jeanne Gurnee, Bill Stone, and Jack Bruch, together with a team of scientific specialists, performed the work in February 1986 and published the study in 1989.

With the cooperation of the Anguilla Historical and Archaeological Society and experts in Caribbean Indian cultures, the team first identified the area of Indian activity and then proceeded to explore the cave and dive the two pools of fresh water where Indian pots and shards have been found.

The paper gives the results of the study, recommends development procedures, and discusses current attitudes in developing caves containing Indian artifacts on Anguilla, as well as throughout the United States and elsewhere.

EXPLORATION IN THE UPPER CORRIDOR BASIN, COSTA RICA

Norma D. Peacock, 2544 Pinewood St, Jenison, MI 49428
Chuck Hempel, Rd 2 Box 189, Clymer, PA 15728

This presentation will consist of several caves and karst features in the Corridor Basin of Costa Rica and a description of the scientific studies undertaken by the 1990 Expedition.

CAVES OF THE RIO GRANDE RIVER BASIN, BELIZE, CENTRAL AMERICA

R.T. Turner, 4-415 Alfred Building, St. Mary's Hospital, Rochester, MN 55902; G. Ottinger, C. Deer, B. Szukalski

We, and others, have been exploring and mapping the caves of the Rio Grande River Basin. Since 1984, over 35,000 feet of passage have been mapped. The initial explorations focused on Tiger Cave, which has more than 12,500 feet of mostly large, often in excess of 100' x 50' (w/h), dry passage. Our most recent efforts have focused on several river caves in the same area; including Jaguarundi Cave. This cave was located in 1988 by G. Ottinger and R. Turner and mapped in March 1990. The entrance of Jaguarundi Cave is located at the base of a prominent collapse. Large river passage continues both upstream and downstream of the karst window. This cave is unusual for the river caves in that it has an extensive tributary passage which has no active stream in the dry season. As is the case with the other river caves in the area, both the downstream and upstream river passages end in sumps. We believe that the water exiting Jaguarundi Cave enters in succession the Pouch, Rookanga Cave, Kangaroo Cave, and finally the Tiger Cave. Further Exploration is planned to locate the initial insurgence for the system.

JUL MAS NIM, ALTO VERAPAZ, GUATEMALA

Steve Knutson, P.O. Box 572, Boring, OR 97009

In the Central Cuchumatanes Mountains of Guatemala lies the large closed valley of the Riachuelo Yalijux. The main drain of this valley, in the geological past, is the large cave Jul Mas Nim. The exploration and mapping of this, and related caves, has been the objective of National Speleological Society expeditions from 1988 to 1990, after the discovery of the potential of the area in 1987. Work through 1988 made Jul Mas Nim 8.3 km in length and a little over 300 meters in depth.

*CUEVA DEL MANO - THE BOTTOM OF THE WORLD'S
DEEPEST CAVE?*

Carol Vesely, 709 S. Primrose Ave. Apt A, Monrovia, CA 91016

As part of the 1990 Proyecto Papalo expedition, eleven cavers spent two weeks exploring and surveying caves along the south side of the Rio Santo Domingo, Oaxaca, Mexico. A successful dye trace indicated that the major cave in the area, Cueva del Mano, is hydrologically connected to Sistema Cuicateco over 17 kilometers away and 2500 meters higher. This is the deepest dye trace in the world. Over 6 kilometers of well-decorated passage was discovered in Cueva del Mano. More remains to be done in Mano and nearby caves.

*PROYECTO PAPALO '90: THE EXPLORATION OF
SISTEMA CUICATICO*

Bill Farr, 709 S. Primrose Ave. Apt A, Monrovia, CA 91016

Proyecto Papalo is dedicated to the study and exploration of the caves of the Papalo area in the Sierra Juarez of Oaxaca, Mexico. The 1990 expedition pushed Sistema Cuicateco, the main cave in the area, to 1340 meters deep and 20.4 kilometers long. A new entrance, Viento Frio, was connected into the system at -550 meters, adding over a kilometer to the length. In a series of two underground camps located at -1100 meters, the bottom of the cave was extended over 100 meters in depth to a sump. A successful dye trace between Cueva Cheve entrance and the Rio Frio de Santa Ana Resurgence on the Rio Santo Domingo confirmed that the depth potential of Sistema Cuicateco is over 2500 meters.

*UNTOUCHED KARST OF SOUTHERN MEXICO: APOALA
AND EL SUMIDERO DEL RIO GRIJALVA*

Don Coons, RR 3, Cave City, KY 42127

Just north of the city of Tuxtla Gutierrez in the state of Chiapas, the Rio Grijalva cuts an immense canyon through a mountain range of solid limestone. Called El Sumidero, the walls of this 30-kilometer-long gorge rise over 900 meters in sheer cliffs, dropping into the impounded river. Though the canyon is easily accessible by tour boats, any resurgences are now flooded. The surrounding uplands offer a challenge of several hundred square kilometers of haystack and doline karst that must surely drain to the canyon below. The area is preserved by a national park and untouched by cavers the village of Apoala lies four hours north of Oaxaca City in the state of Oaxaca, and is easily accessible by two-wheel drive road. Relations with the Mixtec Indians are unusually cordial, since an American linguist has lived in the area for nearly 20 years. Lying in a secluded canyon, surrounded by 300 meters of massive limestone cliffs, the village water source is a large cave resurgence. The surrounding uplands drain over 200 square kilometers internally through a brecciated limestone caprock into underlying shaft complexes. A brief reconnaissance in January 1990 was done by D. Coons, S. Engler, R. Simmons, and K. Haverly. Every Mixtec

we questioned in the area gave the same reply: Caves? Which one? There are many!

*EXPLORATIONS IN AUSTRIA: THE KOLKBASER-
MONSTERHOLE SYSTEM*

Bill Farr, 709 S. Primrose Ave. Apt A, Monrovia, CA 91016

In the dolomitic Alps near Salzburg, Austria, lies perhaps the greatest concentration of kilometer deep caves in the world. Located atop the Steinernen Meeres plateau across from the world-famous Lamprechtsofen, the Kolkblaser-Monsterhole system in this alpine cave is hampered by difficult access, a limited season, and the very cold (1 degree Celsius) conditions within the cave. Currently 660 meters deep, an August, 1989 expedition pushed the cave to become Austria's eighth longest at over 24 km in length with numerous leads remaining.

EXPLORATION OF CAVES OF ROMANIA

Cristian Lascu, Emil Racovita Institute of Speleology

This talk presents an overview of the most interesting and significant caves of Romania with emphasis on important recent discoveries.

CAVING IN U.S.S.R.

John P. Scheltens, President, National Speleological Society, 303 North River Street, Hot Springs, SD 57747

At the invitation of the Soviet Academy of Sciences, the NSS made its first official Field Trip to the Soviet Union. This multi-image slide presentation recounts this historic adventure which took place in August and September of 1989. This trip includes visiting the large gypsum caves of the Western Ukraine including Optimisticeskaya, the second largest cave in the world. Also included in the presentation are the caves in the beautiful Crimean Mountains along the Black Sea, a river cave filled with fantastic formations; and Marble Cave, a newly discovered cave in the Chimea resembling Carlsbad Caverns.

In many areas, this delegation became the first Americans to ever visit certain parts of the Soviet Union. This presentation offers an initial insight into the caves and cavers of the Soviet Union.

CUEVA DEL TECOLOTE, MEXICO

Peter Sprouse, PO Box 8424, Austin, TX 78713

Since 1980, cavers of the Proyecto Espeleologico Purification have been mapping in Cueva del Tecolote, a large cave system located in the state Tamaulipas, Mexico. A March 1990 expedition succeeded in surveying an additional 3.1 kilometers during a 10-day underground camp. Significant progress was made in the southwest portion of the cave, which trends toward the presumed resurgence 10 kilometers distant. This effort pushed the cave length to 20.8 kilometers, making it currently the fourth longest in Mexico.

*CAVE DIVING IN THE YUCATAN: THE EXPLORATION
OF NOHOCH NAH CHICH*

Ron Winiker, 170 West Cliff Drive #63, Santa Cruz, CA 95060

In November 1987, cave divers Denny Atkinson, Mike Madden, Juan Jose Tucac, and Ron Winiker began exploration of Nohoch Nah Chich, a huge underwater cave system near Tulum in the state of Quintana Roo, Mexico. Burros were used to transport diving gear two kilometers from the road to the large collapse entrance. Heading upstream the divers found that the well-decorated passage did not exceed six meters in depth, eliminating decompression and greatly increasing exploration range. At 450 Meters, the passage was over 100 meters wide with crystal-clear visibility. Over 800 meter of line was laid on the first trip. On a subsequent trip in February 1988, divers laid 1250 meters of new line and discovered an airbell with a circular shaft to the surface. The cave now has over six kilometers of surveyed passage, half of this in the main upstream passage and the remainder in the downstream section and various side passages.

RECENT EXPLORATIONS IN TABASCO AND CHIPAS

Jim Pisarowicz, PO Box 265, Death Valley, CA 92328-2448

In 1989 US and Swiss cavers explored over five kilometers in Sistema Aqua Blanca, a large resurgence cave located near Mascuspana in the state of Tabasco, Mexico. On the same trip, Grutas de Magnificos, a well-decorated cave over two kilometers long, was also discovered.

On a return trip in 1990, flood conditions forced the cavers to retreat from Tabasco to central Chiapas. In this area the limestone is partially capped with sandstone promoting the development of deep pits at the contact zone. Sima de Cedro reaches a depth of 235 meters and contains a 175 meter pit. Sima dos Puentes has a 172 meter pit and a total depth of 292 meters. Cueva Arroyo Grande, the longest cave discovered on the trip, contains a lower segment (4548 meters) and an upper segment (3629 meters) which were physically connected although the connection was not surveyed. In just two weeks, the group mapped a total of 10 kilometers of virgin cave.

THE BEST OF MEXICO

David E. Bunnell, 320 Brook Dr., Boulder Creek, CA 95006

A multi-image dissolve show set to music, this program highlights caves and cave exploration in Mexico within five regions: Oaxaca (Sistemas Cuicateca and Huatla), Purificacion (Cuvas del Tecolote, de la Llorona, and Sistema Purificacion), Xilitla Plateau (Golondrinas, etc.), Cuetzelan (Chichicasapan, Jonotla, ect.), and Baja California (sea caves). Photography by Dave Bunnell, Ron Simmons, Bill Stone, and Peter Bosted.

POZO DE MONTEMAYOR, NUEVO LEON

Joe Ivy, 5310 Roosevelt Ave., Austin, TX 78756-2127

Recent discoveries in this long-know cave in northern Mexico have pushed the depth to 501.25 meters. A new 100-meter pit and two 50-meter pits were found and exploration continues.

VOLCANOSOTANOING IN CHICHONAL

Don Coons, RR 3, Cave City, KY 42127

In 1981 a small, long dormant volcano just south of Villahermosa, Chipas, burst into sudden reactivity. Visible from 200 to 300 kilometers away, its ash spewed in a vertical column to the stratosphere and surrounded the world. In the process, it completely buried three villages and left behind what was arguably one of Mexico's finest pits, 200 meters deep and one kilometer across. Now, nine years later, it is possible to approach the site across several kilometers of blasted ash terrain and rappel down to a 300 meter wide hot tub, heated at one end by geysers and boils. Whether you call it a Sotano or a caldera, a trip to the bottom is a vertical experience of a lifetime.

HUAUTLA 1990

James Smith, PO Box 275, Moxee, WA 98936; William Storage, 7121 Blue Sail Dr., Huntington Beach, CA 92647

For the fifteenth consecutive year, exploration of the Municipio de Huautla de Jimenez region of Mexico revealed major discoveries. A primary focus of this year's expedition was Cueva de Agua Carlota. The cave has been unentered since 1971 when a preliminary exploration and survey was conducted by cavers of McMaster University. The 1990 visit immediately showed Carlota to be one of the area's wettest and most interesting caves, with a surveyed length of 4.4 km and a depth of over 500 meters. A dye trace conducted during the expedition confirmed that a common resurgence exists for Carlota and El Sistema Huautla. Field work revealed new cave entrances in nearby karst areas warranting additional investigation. Several new caves were also explored in the vicinity of the Huautla resurgence.

CERRO RABON

Ernie Carza, 1601 Bridgeport Drive, Los Angles, CA 90026

The Cerro Rabon is a 2100 meter high plateau of rugged karst, located just east of the Huautla area in Oaxaca, Mexico. In 1989, Ernie Garza and Karlin Meyers organized a group of eleven Swiss, British, and American cavers for their fifth trip to this spectacular jungle plateau. The best lead from their previous expedition was Shuanthua, a 350 meter deep pit series with good airflow. On the 1989 expedition, Karlin and several Swiss cavers pushed Shuanthua to -970 meters and still going. The cave contains a huge room with a 140 meter blind pit at one end. The deepest pit in the cave is 165 meters. A return expedition is planned for next year.

*THE ALBA REGIA RESEARCH STATION,
TES PLATEAU, HUNGARY*

Peri Frantz, 16345 Englewood Ave, Los Gatos, CA 95030

In many eastern European countries, caving projects in large, spectacular caves are highly subsidized by the government. These projects have access to equipment, instrumentation, and publication services. Other, less fortunate projects, have none of these advantages and must improvise. The Alba Regia Research Station, on the Tes Plateau of Hungary, is one of these unfunded projects. Although the caves are primarily tight and vertical, there is 300 meter of relief between the sinks on the plateau and springs at its base. A full blown research station, with an amazing collection of scrounged and improvised equipment, supports the cavers studying this lesser known karst. This paper will take a brief look at the caves of the Tes Plateau, and the unique Alba Regia Research Station.

PALEONTOLOGY AND ANTHROPOLOGY

QUATERNARY MAMMALIAN FOSSILS FROM CAVE MOUNTAIN CAVE, WEST VIRGINIA

Fred Grady, 1201 S. Scott #123, Arlington, VA 22204

Nearly 50 species of mammals have been identified from fossil remains in Cave Mountain Cave, Pendleton County, WV. Most of the species identified are indicative of a late Pleistocene age while 3 species of small mammals, 2 of which are extinct, are usually found in older faunas. The fauna is dominated by small rodents, bats, and insectivores. Several species found in Cave Mountain Cave are not members of the historically known West Virginia fauna. Two species from the fauna have become locally extinct apparently due to deforestation in historic time. The faunal remains in Cave Mountain Cave likely accumulated as a result of predation by carnivorous birds, scavenging by woodrats, and natural deaths of bats. The main excavation site was apparently disturbed by saltpeter miners.

CUEVA SAN JOSECITO: A PROGRESS REPORT

Ronald W. Ralph, Texas Parks and Wildlife Dept.; Joaquin Arroyo-Cabrales, Instituto Nacional de Antropología y Historia; Eileen Johnson, Museum of Texas Tech University

Cueva San Josecito, a paleontological locality in southern Nuevo Leon, Mexico, was quarried by the California Institute of Technology between 1935 and 1941 and produced a rich fossil fauna. Four visits in the last two years have brought preliminary vertical and horizontal control to the cave; allowed photographic matching to reestablish grid points; recovered matrix for testing; and stabilized portions of the cave for renewed stratigraphic excavations by a multidisciplinary team of scientists. This work was funded by a research grant from the National Speleological Society (to Ralph, Arroyo-Cabrales, and Johnson), a NSS Ralph W. Stone Graduate Research Award (to Arroyo-Cabrales), a Cave Research Foundation Karst Fellowship (to Arroyo-Cabrales), and a National Geographic Society research

grant (to Johnson). A 6-week field season was conducted in March and April 1990 including excavation, survey, photodocumentation, and laboratory preparation of the bones. The joint U.S. and Mexican venture utilized experienced American and Mexican cavers to supplement the research team.

A GEOMORPHOLOGICAL EXPLANATION FOR SITE LOCATIONS ON THE MCCLOUD RANGER DISTRICT, SHASTA-TRINITY NATIONAL FOREST

Julie Krieger, U.S. Forest service, McCloud Ranger District, PO Box 1620, McCloud CA 96057-1620

Analysis of site locations on the McCloud Ranger District has revealed that there is a very high correlation of sites along lava tube systems, ice caves, and zones of contact between recent lava flows that are barren and forested older flows. Presently these areas are completely devoid of water. Geomorphological studies, however, suggest that these are "fault zone" areas where, during periods of increased precipitation, the trapped underground water would have risen to the surface creating pools, wet meadows, springs and ice. A prime example of this "locating behavior" is a site adjacent to Gelsie's Grotto, a collapsed lava tube system named by local cavers. Excavations at this site have revealed that the importance of water dictates site location, while the primary motivation for seasonal occupation of the area is nearby obsidian sources.

NORTH AMERICA'S LAST "WILD" INDIAN AND THE CAVES OF NORTHERN CALIFORNIA

P. Willey, Anthropology Department, California State University, Chico CA 95929-0400

After wandering alone for several years, Ishi turned himself in at Oroville, California in 1911. He was apparently the last Yahi Indian and the last North American native living a more-or-less traditional life off the reservation and outside direct mainstream Euroamerican contact. He spent most of the rest of his life working for a museum in San Francisco, California; providing information about his traditional native life to anthropologists and museum visitors.

His rich understanding of his environment included a knowledge of the location and uses of the local "caves." These shallow "caves," better described as rockshelters, were used by his group and others as shelter, particularly during inclement weather. A few of the rockshelters in the region have been archaeologically excavated and a wide variety of artifacts recovered. This paper will present an overview of this remarkable man's life and aboriginal cave use in Northern California based on ethnographic and archaeological data.

PHOTOGRAPHY

SHARP PRINTS AND THE FLASH SLAVE DELAY EFFECT

Kenrick Day, Rt. 5 Box 318-19, Harrison AR 72601

It has been discovered that when slaves are used to sync multiple flashbulb type shots, unsharp pictures sometimes result. This is apparently due to the rise time associated with a flashbulb. A picture made using two bulbs in sync may have an equivalent exposure time of 1/15 of a second, too long for optimum hand-held cameras. The effect is generally only noticeable with prints, and grows greater in proportion to the focal length of the lens used. Sample prints will be circulated and various remedies discussed.

WAYS TO AVOID COMMON MISTAKES IN CAVE PHOTOGRAPHY

Ann Bosted, Peter Bosted, 4000 Farm Hill Blvd #310, Redwood City CA 94061

In the past six years we have made many mistakes while taking cave photos around the world. Through the use of slides, we will illustrate many of those mistakes and suggest ways to avoid them. Topics covered will include framing, lighting, the advantages and disadvantages of multiple flash photography, models, assistants, silhouettes, underwater flashes, exposure and F-stops, retouching, film and color balances, equipment, and trick photography.

UTILIZATION OF ALL FOUR BULBS IN A FLASHCUBE

Roger V. Bartholomew, 910 Laurel St, Rome, NY 13440

The regular size flashcube or magicube has a guide number of 34 for ASA 25 film. If all four bulbs are flashed at the same time, a guide number of 68 is possible. Devices to flash all four bulbs made from the flashcube and magicube extenders which were made for the Kodak Instamatic cameras will be explained. If four planar reflectors are used to direct all the flashes in one direction, the guide number will be $r \times 68$ where r is the reflectivity. Removal of the flashcube or magicube shell with the reflector exposes four bare bulbs which can be placed in a folding fan reflector and fired at the same time. Guide numbers for this arrangement will vary with the quality of the reflector.

An efficient arrangement suggested by Rick Day is the quad cube gun which has four flashcube sockets all oriented in the same direction and a guide number of 68 (ASA 25). One to four bulbs can be used with this device. A compact quadcube gun has been constructed by fusing four flashcube sockets salvaged from plastic polaroid cameras.

THE LAVA BEDS NATIONAL MONUMENT PHOTO MONITORING PROJECT

Bill Frantz, Cave Research Foundation, 16345 Englewood Ave., Los Gatos, CA 95032

The purpose of the Lava Beds National Monument photo monitoring project is to develop a set of photos of cave features with enough documentation of how and where

the photograph was made to allow it to be readily rephotographed. Comparing two photographs allows researchers and Park Service personnel to monitor changes in the caves. In addition, where old photographs exist and their site relocated and rephotographed, new photographs will be made to monitor changes that have already occurred.

A short review of the literature on cave photo monitoring followed by a discussion of the techniques used in this project will be presented. Several sample photographs will be shown.

TECHNIQUES FOR UNDERWATER PHOTOGRAPHY

Ron Winiker, 170 West Cliff Dr. #63, Santa Cruz, CA 95060

The techniques presented represent about the seventh generation of ideas that started with a hand held camera with front lighting and have progressed through the use of slaved strobes, magicubes, tripods with ski poles baskets, and filters to correct the excessive blue/green caused by the water. With the aid of Mike Madden, partner in a dive shop in Puerto Aventuras and model Joan Patrick, the current technique places Joan with a slaved strobe to light the area behind her. Mike hides behind a formation and the camera shutter is opened. Mike then fires a strobe to light Joan and fire her strobe. Then using Cyalumes for light, Joan swims out of the picture and Mike commences to paint the rest of the scene with up to 20 flashes. On site processing of the film allows a next day reshoot to perfect the photographs.

SURVEY AND CARTOGRAPHY

TILT ERROR IN HIGH INCLINATION SUUNTO COMPASS SIGHTINGS WITH THE GLASS ROD CYLINDRICAL LENS

Roger V. Bartholomew, 910 Laurel St., Rome, NY 13440

For Suunto compass sightings with large inclination angles a glass rod mounted slightly beyond the Suunto case decreases the angular separation of the Suunto cursor line and the target light and allows easy alignment of the Suunto cursor and the light beam emerging from the glass rod. Lang Brod has cautioned that the compass must be perfectly level to obtain a true compass reading.

A preliminary experiment on an azimuth of 242.0° with a $+44.2^\circ$ inclination angle has shown that 1.0° of tilt causes a 0.85° error in the azimuth reading. In the same experiment, an attempt was made to level the Suunto according to Brod's suggestion: "so that the upper and lower edges of the drum dial are nominally parallel to the upper and lower edges of the rectangular inner window observed through the lens". The result was an error of 1.4° in azimuth and the tilt measured 2.2° .

These results suggest that for greater precision another method of leveling the compass is needed which is independent of the orientation of the Suunto compass drum. The compass drum orientation is affected by compass dip which will cause different errors at different azimuth angles.

*AN EVALUATION OF THE SMARTLEVEL AS A SURVEY
INCLINOMETER*

Roger V. Bartholomew, 910 Laurel st, Rome, NY 13440

The Smartlevel is a digital inclinometer developed for use as a carpenter's level. It measures inclination angles from +90 to -90° to the nearest 0.1° of precision can be selected to the nearest 0.2 or 0.5°. Other nodes include rise over run, percent of slope, or simulated bubble. It has a rugged solid state sensor and a liquid crystal display, sealed inside a weather resistant (not weather proof) polycarbonate nodule. It requires a 9-volt battery. Recalibration is done by placing it on a slope, pressing a button, turning the level around and pressing the button again. The display flips over so you can still read it when it's upside down.

Disadvantages for cave survey include: LCD faces 90° to the line of sight so that it must be tripod-mounted or a Brunton type mirror/pointer arrangement must be used. There is no sample and hold button so that it can be sighted and read at different times.

Mfg: Wedge Innovations, 532 Mercury Dr., Sunnyvale, CA 94086, Cost \$89.95 + \$6.50 posting and handling.

*STANDARDS AND CRITERIA OF THE
NSS CARTOGRAPHIC SALON*

George Veni, 11304 Candle Park, San Antonio, Texas 78249

During the 1989 NSS Cartographic Salon, a new judging method was tried and was favorably received. As a result, a committee formed to fine-tune this new methodology and has since published the results in *Compass and Tape*. The committee's goals were to develop fair standards which would be consistent year to year, and which would serve as a model for cave cartographers on what constitutes a "good" map. Committee members came from various parts of the country to prevent setting standards which represented a particular region's style or biases. An overview of the new methodology and standards shall be presented. Discussion will be encouraged.

UNITED STATES EXPLORATION

*EXPLORATION OF GREENHORN AND MILLERTON
LAKE CAVES, CALIFORNIA'S LARGEST GRANITE
CAVE SYSTEMS*

Bob Richards, 6001 Auburn St #123, Bakersfield, CA 93306

California's Sierra Nevada contains two granite caves which surpass those found anywhere else in the world in terms of size and depth. What sets them apart from most other caves in plutonic rocks are the relatively long distances between entrances and the presence of an active underground stream. Both offer a challenging caving experience involving climbing over waterfalls and traversing potholes.

The Greenhorn System, northeast of Bakersfield, is presently both the longest (2 km) and deepest (152 m). The caves are formed by the fault-controlled flow of Greenhorn Creek through Mesozoic plutonic rock. This creek, which is buried up to 50 m below the valley floor, has been mined

for GOLD since 1854. Though the gold rush was short lived, the mining activity in the caves has been sporadic ever since.

Unlike Greenhorn, the granitoid system at Millerton Lake, northeast of Fresno, is formed along the intersection of a vertical joint and a horizontal zone of weakness of Cretaceous age. Because joints tend to be more stable structures than faults, these caves tend to be much less broken by rockfall than those in Greenhorn. The evidence can be seen in most areas by a flat bedrock ceiling, smoothly sculpted walls, potholes, and other vadose corrasional speleogens. As big sandy Creek was being pirated underground, it literally sand-blasted the passage seen today. The scouring by water-borne sediments has contributed to the passage enlargement of this (1km) system.

*BEYOND THE SECOND DOWNSTREAM SUMP-
SCOTT HOLLOW, WV*

Ron Simmons, PO Box 7351, Charlottesville, VA 22906

In July of 1989 a team of three sump divers camped for a week beyond the second downstream sump in West Virginia. In order to set up the camp, all equipment had to be transported through a 900 foot long, 60 foot deep sump. The camp resulted in the completion of over 12,000 feet of survey to a fifth downstream sump.

GREAT X - A PERSONAL CHALLENGE

Don Coons, RR 3, Cave City, KY 42127

In August of 1986, the survey of the lower half of Great X, Wyoming was completed. Although numerous trips were made in the process of surveying, one stands out. A through trip by the speaker and Pete Shifflet fulfilled our greatest expectations.

POWIE III

Bob Bastasz, PO Box 2417, Livermore, CA 94550

Prince of Wales Island Expedition II took place during July and August of 1989. Over 20 Alaskan and "lower 48" cavers took part in exploration which left Alaska holding the 1st (El Capitan - 598 feet), and 3rd (Snow Pit - 452) deepest surveyed pits in the United States. Exploration of this Arctic Rain Forest had been pioneered by Kevin and Carlene Allred during POWIE I in the summer of 1987. Most of the 1000 square miles of exotic karst, which is in places 2000 meters thick, and receives up to 300 inches per year of precipitation, is yet to be examined. Going cave and pit leads left at the end of POWIE III remain to be checked by the participants of POWIE IV, which should occur during July and August of 1990.

*NEW DISCOVERIES IN THE EASTERN BRANCH OF
LECHUGUILLA CAVE*

Patricia Kambesis, 1026 South Candler St, Decatur, GA 30030-4464

The Eastern Branch of Lechuguilla Cave has relinquished a series of major new discoveries over the past year and a half. Climbing leads have yielded significant amounts

of upper level passage, a major new extension, and a new deep point in the cave. So far over 10 miles of new passage have been explored and surveyed revealing a complex multi-level maze.

In addition, new slides of the High Hopes section of the cave and of cave diving activities will be presented.

NIELSONS WELL, A UTAH RECORD SETTER^[3]

Dave Shurtz, 87 S 400 E, Clearfield, UT 84015

In the fall 1986, two Wasatch Grotto members, Ken Stahley and Jim Micholls, acted upon a tip from an elk hunter to find a deep pit in northern Utah. On August 23, 1986, the cavers located the obscure pit and dropped the impressive 315 foot shaft, only to find a register left by a couple of rock climbers the year before. As it turned out, the climbers had yo-yoed the virgin pit on March 3, 1985 and then created the register and left the cave, without seriously checking the large room they discovered for leads or even naming the cave. Realizing the depth potential of the cave, and the fact that they probably had already discovered the deepest single pit in the west, Ken and Jim felt that they were on the brink of a major discovery.

In May 1987, Ken and Jim invited Mike Beer (the discoverer of Columbine Crawl), to help with the continued exploration of the cave. Recognizing the importance of some skulls found in the larger of the two leads from the Big Room at the bottom of the pit, they invited Rod Horrocks into their project because he was a vertical caver with paleontology experience.

Dave Herron, Dave and Glenn Shurtz, and Clair Call explored the smaller of the two leads; leading to a 10 foot pit, a 42 foot pit, a 45 foot pit, and a 250 foot pit named "Fantasy Well" with several great leads at the bottom.

The cave is currently 647 feet deep, which makes it the third deepest in Utah and the 23rd deepest in the US. Besides the 1,800 ft. of survey, the results of the continued efforts at Nielsons Well have been; what is probably the longest single drop in the west (-315 ft.), the largest room in Utah, and the longest freefall in a Utah cave (250 ft. in Fantasy Well). Because of the cold temperatures (39°F), loose rock, very narrow slots, and deep pits Nielsons Well is a very dangerous cave. Nearly every trip to the cave has produced minor to semi-serious accidents, despite extreme caution by the explorers. Exploration and survey of the sporty cave is continuing, and will undoubtedly produce more significant discoveries.

VIDEO

MAKING OF THE WIND CAVE VIDEO

Bob Montgomery, PO Box 2102, Casper, WY 82602; John Scheltens, 303 North River St., Hot Springs, SD 57747; and Paul Stevens, 5964 Seabright Road, Springfield, VA 22152

The "Wind Cave Video" is the first commercial video produced by the NSS for sale to the general public. NSS members wrote the script, planned the production, served as talent and developed the tape box, contracted with one post-production company for professional video production and post-production, with another company for jacket printing and tape duplication. NSS members documented the filming of the "Wind Cave Video" and produced "Making of the Wind Cave Video". There were a variety of funny moments and lessons learned.

NSS A/V LIBRARY CAMCORDER LOAN PROGRAM

Alex Sproul, 102 Travis Court, Seaford, VA 23696

The NSS A/V Library has a Sony SP-7 8mm video camera and all the associated equipment necessary for you to develop a cave-related video for the A/V Library. You can borrow it to produce a cave video by describing your plans in a written proposal.

DEVELOPING THE USSR CAVING VIDEO

Bob Montgomery, PO Box 2102, Casper, WY 82602

The 1989 NSS Field Trip to the USSR visited the large gypsum caves of the western Ukraine and the alpine caves of the southern Crimean peninsula near the Black Sea. There were numerous challenges associated with making a video of caves in the USSR.

NSS VIDEO SALON

Alex Sproul, 102 Travis Court, Seaford, VA 23696

Each year the NSS conducts a salon of films and videos with the winner shown at the annual convention Photo Salon. A discussion of the judging criteria describes what makes a good cave video.

FILM VS. VIDEO

Joe Hoffman, 13003 SW 7th Court, Fort Lauderdale, FL 33325

How do film and video compare with regards to capabilities, equipment, lighting, cost, ect? Lessons learned while filming "Project Cave Light, 77 Feet Below" and "Cave Story" will be discussed and compared to video.

EQUIPMENT/TECHNIQUES SHOW AND TELL

Bob Montgomery, Moderator, PO Box 2102, Casper, WY 82602

Discussion and demonstration of various video equipment and techniques by members of the audience.

^[3] © 1990 Rodney D. Horrocks, Used by permission.

GUIDE TO AUTHORS

The *NSS Bulletin* is a multidisciplinary journal devoted to speleology, karst geomorphology, and karst hydrology. The *Bulletin* is seeking original, unpublished manuscripts concerning the scientific study of caves or other karst features. Authors need not be associated with the National Speleological Society.

Manuscripts must be in English with an abstract, conclusions, and references. An additional abstract in the author's native language (if other than English) is acceptable. Authors are encouraged to keep in mind that the readership of *The Bulletin* consists of both professional and amateur speleologists.

For general style refer to the present *Bulletin* and the following guides: "Suggestions to Authors" (U.S. Geological Survey), "Style Manual for Biological Journals" (American Institute of Biological Sciences), and "A Manual of Style" (The University of Chicago Press). For assistance in writing an abstract see "A Scrutiny of the Abstract" by K. Landes, *Bulletin of the American Association of Petroleum Geologists*, vol. 50 (1966), p. 1992. Because good figures are an essential part of any paper, authors are encouraged to see what bad figures look like in the editorial on figures by K. Rodolfo in the *Journal of Sedimentary Petrology*, vol. 49 (1979), p. 1053-60.

Each paper will contain a title with the author's name and address. This will be followed by an abstract and the text of the paper. Acknowledgements and references follow the text. References are alphabetical with senior author's last name first, followed by the date of publication, title, publisher, volume, and page numbers. See the current issue of *The Bulletin* for examples.

Authors should submit two copies of their manuscript (in-

clude only copies of the illustrations) to the appropriate specialty editor or the senior editor. The manuscript must be typed, double space on one side of the page. Authors submitting manuscripts longer than 15 typed pages may be asked to shorten them. All measurements will be in *Système Internationale* (metric). Other units will be allowed where necessary if placed in parentheses and following the SI units.

Figures and lettering must be neat and legible. Figure captions should be on a separate sheet of paper and not within the figure. Most figures will be reduced, hence the lettering should be large. Once the paper has been accepted for publication, the original drawings (with corrections where necessary) must be submitted to the editor. Black-and-white photographs must be sharp, high contrast, and printed on glossy paper. Color prints will be printed at authors expense only.

All submitted manuscripts are sent out to two specialists for review. Reviewed manuscripts are then returned to the author for consideration of the referee's remarks and revision (where necessary). Revised manuscripts are returned to the appropriate editor who then recommends acceptance or rejection. Upon acceptance, the author should submit all photographs and original drawings to the editor.

Once the paper has been typeset and laid-out, the senior author will be sent one set of proofs for review. Any corrections other than printer errors will be done at the author's expense. A reprint order form will be sent with the proofs. At this time all authors will be requested to contribute page charges of \$25 per page to help defray the cost of publication. The actual cost to the society is about \$100 per page. Acceptance of manuscripts for publication is not contingent upon payment of page charges.

A new speleological journal has been produced by Institute of Geography of the Czechoslovak Academy of Sciences. The journal is entitled *Studia Carsologica*. Its primary language will be English. Its focus is the publication of articles etc. on the effects of human activity on caves and karst. However, other karst topics will not be rejected out of hand.

Three volumes have already been published and Volume 4 is expected out soon. I have been appointed to the Editorial Board representing North America. If you have appropriate articles, book reviews, or other items, please send them to me for consideration.

George Huppert
Dept. of Geography and Earth Sciences
University of Wisconsin
La Crosse, WI 54601

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Since the economy in Czechoslovakia is not stable as of yet, they have not determined a price for the journal. At this time they are trying to see what the economy does and what the demand is. They are looking for subscribers. Typically, items coming out of eastern Europe have been quite reasonable. To receive the first three volumes and get on the mailing list, write to:

Dr. Otakar Stelcl
Institute of Geography
Czechoslovak Academy of Sciences
662 82 Brno, Mendlovo nam 1
CZECHOSLOVAKIA

THE NSS BULLETIN

Volume 53

June, 1991

Number 1

CONTENTS

ATMOSPHERIC PRESSURE CHANGES AND CAVE AIRFLOW: A REVIEW Warren C. Lewis	1
DISCUSSION AND REPLY	
HISTOPLASMOSIS: A HAZARD TO NEW TROPICAL CAVERS S. A. Craven, Warren C. Lewis	13
PROCEEDINGS OF THE SOCIETY—1988 Norma Peacock	15
PROCEEDINGS OF THE SOCIETY—1989 Norma Peacock	36
PROCEEDINGS OF THE SOCIETY—1990 Norma Peacock	51

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