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Joseph E. Dom and Carol M. Wicks - Morphology of the caves of Missouri. *Journal of Cave and Karst Studies 65*(3): 155-159.

MORPHOLOGY OF THE CAVES OF MISSOURI

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The morphology of solution caves differs from region to region based on the recharge mechanisms and the dominant type of porosity. The pattern of cave passages representative of the entire Salem and Springfield Plateaus and of the Perryville and Hannibal karst areas was determined. The number of closed loops and the tortuosity of the passages were used to statistically determine the morphology of 633 mapped caves in Missouri. The 633 caves were from 17 counties and from each of the karst areas in Missouri. For most caves in the Salem and Springfield Plateaus and the Perryville karst area, as determined by passage length, the pattern of development is branchwork (71.7, 83.4, and 84.4%, respectively) and rudimentary (16.5, 10.3, and 14.8%, respectively). The Hannibal area shows 2 distinct patterns of development. Three caves are network mazes (81.2%) and the remainder are either branchwork (13.1%) and rudimentary (4.9%). The morphologies of the caves from the Salem and Springfield Plateaus and the Hannibal and Perryville karst areas suggest the distribution of caves within Missouri is similar to that found by Palmer (1991) for cave passages worldwide. However, there is higher percentage of rudimentary caves due to extensive stream incision. Given the high percentage of branchwork and rudimentary patterned caves in Missouri, the origin of Missouri's caves was likely driven by point-source recharge that flowed along bedding plane partings.

Based upon the type of recharge and the dominant porosity of the bedrock, Palmer (1991) concluded that there are 5 fundamental cave morphologies that can be identified from field observations or plan view cave maps. Of the 5 fundamental cave morphologies, ~57% are identified as branchwork, 17% as network, 14% as rudimentary single passage, 5% as ramiform/spongework, and 3% as anastomotic (Palmer 1991). Weighted by length, these relative frequencies of major cave patterns in Palmer's investigation sample (~500 caves) match within 1% all known caves in the world >3 km long.

The branchwork pattern of cave morphology is a product of point-source recharge, through sinkholes, flowing through first order conduits that converge to become higher-order conduits down gradient. The branchwork pattern can be a product of either groundwater flow along bedding plane partings or along fractures/joints. The network pattern of cave morphology is the product of either diffuse recharge through an overlying permeable rock or from streams sinking into jointed/fractured rock. The diffuse recharge allows for simultaneous enlargement of many passageways. The anastomotic pattern of cave morphology is the product of sinking streams. However, the anastomotic pattern is the result of preferential groundwater flow along bedding plane partings. Anastomotic caves, as well as some network maze caves, are the product of periodic flooding, causing sudden short-term increases in groundwater flow that inundate all or part of a cave to the ceiling (Palmer 1975). Fractures and partings in the bedrock are subject to extremely steep hydraulic gradients, allowing for rapid formation of maze-like passages (Palmer 1975). The ramiform/spongework pattern of cave morphology is the product of dissolution by acids from a deep-seated source, cooling of thermal waters, or mixing of two waters sources of contrasting chemistry. Rudimentary single-passage caves form as the result of any of the aforementioned methods.

Missouri's nickname is "The Cave State" as it has >5500 catalogued caves, and more are added to the list every year as new caves are discovered. This study applies Palmer's (1991) classification system of morphology to 633 of the mapped caves in Missouri. These 633 caves represent all 4 karst areas within Missouri.

GEOLOGIC SETTING

REGIONAL GEOLOGY

The Ozark Plateaus physiographic province covers an area of >103,600 km² and comprises parts of Missouri, Oklahoma, Arkansas, Kansas, and Illinois (Thornbury 1965). The Ozark Plateaus of Missouri is divided into 4 karst subprovinces: The Salem Plateau, the Springfield Plateau, the Hannibal Karst Area, and the Perryville Karst Area (Fig. 1).

The boundaries of the Salem Plateau are drawn at the limits of the area underlain by the Cambrian and Ordovician carbonate rocks (Fig. 1). The Salem Plateau is an ancient erosional surface composed of thick sequences of sedimentary rocks (Bretz 1965). Fenneman (1938) defined the Springfield Plateau as that "part of the Ozarks which is underlain by rocks of Mississippian age." Bretz (1965) interprets the Springfield Plateau to be an erosional surface comprised of thick sequences of sedimentary rocks. The Hannibal Karst Area is defined as the area underlain by Ordovician, Silurian and Devonian carbonate rocks. These rocks are dissected by streams that flow eastward towards the Mississippi River. The Perryville karst area includes Perry and Cape Girardeau Counties. Strata gently dipping towards the east with dips of

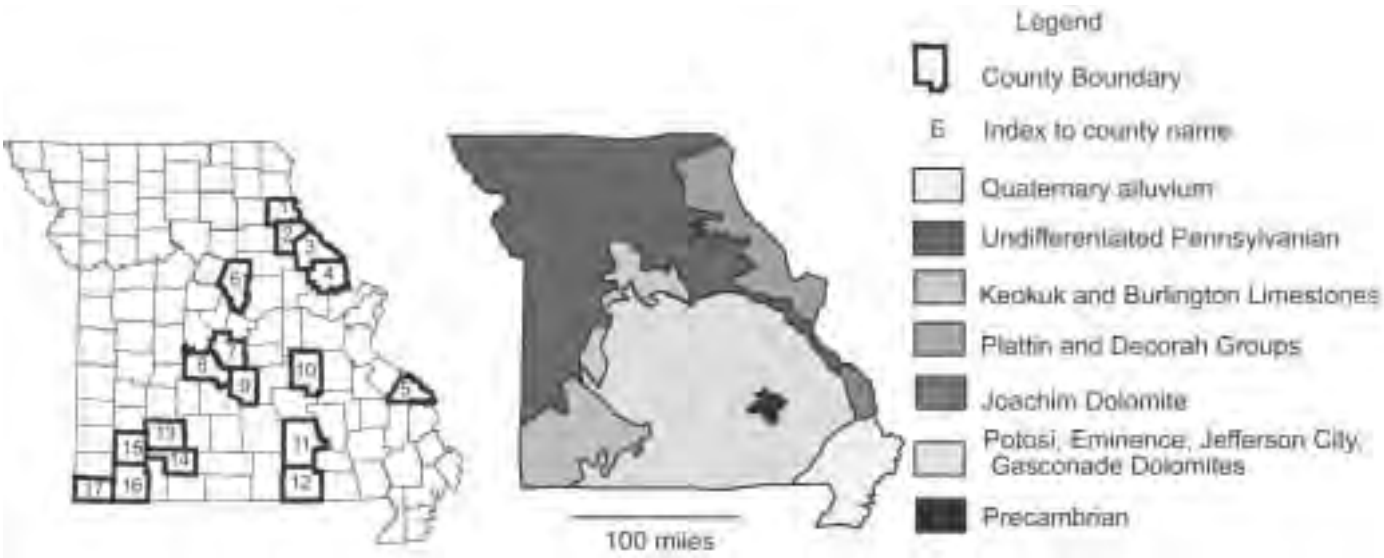

Figure 1: Geographic distribution of selected counties (left panel) and a general geologic map of Missouri (right panel) (Thompson, 1995). The counties are 1 - Marion, 2 - Ralls, 3 - Pike, 4 - Lincoln, 5- Perry, 6 – Boone, 7 – Miller, 8 – Camden, 9 – Pulaski, 10 – Crawford, 11 – Shannon, 12 – Oregon, 13 – Greene, 14 – Christian, 15 – Lawrence, 16 – Barry, and 17 – McDonald.

<19 m/km underlie the area. The rocks of the area are Middle Ordovician or older.

METHODS

More than 5000 cave maps were available for this study from ~70 counties (Table 1). A method was developed to reduce the number of counties selected and then to reduce the number of maps to be analyzed while maintaining representation from each of the 4 subprovinces. The end result was that 633 cave maps from a total of 17 counties were selected as the database for this study. (The Missouri Speleological Survey, Inc., and the Missouri Department of Natural Resources provided the maps to the authors.) The subset of counties was selected by removing all counties along boundaries between 2 or more subprovinces such that only counties that were completely enclosed within one subprovince were used. The final 17 counties were chosen on the basis of the number of cave maps accessible for each county and geographic distribution within the 4 karst subprovinces (Fig. 1). Once the subset of counties were selected, all cave maps within those counties were included in the sample set except for maps for which fewer than 6 orientations could be determined and, in Perry County, cave maps that indicated vertical passages were removed from the sample set.

The metric used to classify the caves into categories was the number of closed loops within a cave and the tortuosity of the cave passages. If a cave exhibited more than one pattern, the cave was classified according to the dominant pattern exhibited.

To distinguish between branchwork passages and anastomotic passages, and between branchwork passages and network passages, number of closed loops was counted and tallied. (Note: Closed loops did not include passages at different levels as nearly all caves in Missouri are horizontal, except in Perry County). If the cave had more than 3 closed loops, it was considered to be predominantly anastomotic or network rather than branchwork. To distinguish between the anastomotic passages and the network passages, the ratio of the length of the cave passage to the straight-line distance between the ends of the passage (tortuosity ratio) was calculated for all caves in this study and for the example of a network pattern cave given in Palmer (1991). The tortuosity ratio for each of the caves was tested against the null hypothesis that they approximate the tortuosity ratio for Palmer's type cave for the network pattern. The statistical test used was a means test for a small sample size with $\alpha = 0.05$. If the null hypothesis was not rejected, the cave was categorized as a network cave. If the null hypothesis was rejected (the tortuosity ratio was significantly different than that calculated for Palmer's example of a network cave), then the cave was categorized as an anastomotic cave. Ramiform (and spongework) passages were determined by the ratio of passage width to passage length exceeding 0.3. Rudimentary caves are single passage caves and a metric was not needed to categorize these caves.

As a check on the metric, the orientation of cave passages was determined with rosette diagrams using a method similar to that used by Deike (1969). Network caves should have a preferred orientation. In addition, if branchwork caves exhibit a preferred passage orientation, then the branchwork caves have a structural control (i.e., joint pattern, presence of faults, etc). The distribution of orientations of each rosette diagram was compared to the uniform distribution (no preferred orientation) using a χ^2 test with $\alpha = 0.05$ (Williams 1972). If a cave exhibited a preferred orientation, then the distribution of ori-

Table 1. The percentages of each cave morphology type for various regions of Missouri and the worldwide average (Palmer 1991).

	Total number of counties	Number in final sample[1]	Total number of caves[2]	Number used[3]
Salem	42	6	1402	327
Springfield	22	6	497	170
Hannibal	9	4	360	39
Perryville	2	1	58	97

[1] Number in final sample is the number of counties that were represented in the final sample.
[2] Total number of caves is the number of mapped caves that were available for use in this study for an entire subprovince.
[3] Number used is the number of cave maps that were analyzed in a study.

Table 2. The percentages of each cave morphology type for various regions of Missouri and the worldwide average (Palmer 1991).

	Anastomotic	Branchwork	Network	Rudimentary	Ramiform[1]	Number[2]	Used in study[3]
World	3.0	57.0	17.0	14	5	not known	500
Salem	11.5	71.7	0.1	16.5	—	1402	327
Springfield	4.7	83.4	1.5	10.3	—	497	170
Hannibal	0.0	13.1	81.2	4.9	—	360	39
Perryville	0.6	84.4	0.0	14.8	—	58	97
Missouri	6.6	67.0	13.4	13.0	—	>5500	633

[1] No ramiform caves were found in Missouri; however numerous examples of galena and sphalerite mines hosted in carbonate bedrock in Missouri conform to Palmer's classification of ramiform caves.
[2] Number of caves is the number of mapped caves that were available for use in this study.
[3] Used in study is the number of cave maps that were analyzed in a study.

entations was not uniform (null hypothesis was not accepted). If a cave did not exhibit a preferred orientation, then the distribution of orientations was uniform (null hypothesis was not rejected).

RESULTS AND DISCUSSION

The results of Palmer (1991) were based on worldwide averages, and certainly there is not an expectation that such a global average would be exhibited in such small areas such as the Salem or Springfield Plateaus. However, qualitative differences between the global percentages and the percentages found in Missouri might provide insight into the karst development of Missouri.

For the Salem and Springfield Plateaus and the Hannibal and Perryville areas, 71.7, 83.4, 13.1, and 84.4%, respectively, of the passages were branchwork pattern (Table 2). The branchwork caves exhibited preferred orientations, thus there appears to be a structural control on passage development. However, this obvious structural control is not easily related to known joint patterns or faulting within the State (Ball & Smith 1903; Barnholtz 1961; McCracken 1971; King 1977; Cole 1991; Davis & Reynolds 1996). For 3 of the areas, the percentage of branchwork caves is higher than the global average of 57%. (This ratio is not necessarily due to a large number of branchwork caves but to having so few network caves.) Previous work by Aley (1978), Halihan *et al.* (1998), Vandike (1985, 1996), and Wicks and Engeln (1997) shows that the dominant recharge of the 4 karst areas is through sinkholes and losing stream reaches. Using Palmer's (1991) classification of cave patterns based upon the type of recharge and dominant porosity, the expected cave pattern would be branchwork.

Only 0.1, 1.5, and 0% (Salem, Springfield, and Perryville, respectively) were network caves, and these caves did indeed exhibit a preferred orientation. This is a much lower percentage than expected by Palmer's work. However, the statewide percent of network caves (13.4%) is close to the global average (17%) due to the high percentage of network caves in the Hannibal area (81.2%; Table 2). The large percentage of network passages is easily explained by the presence of three lengthy caves: Mark Twain, Cameron, and LaBaume Caves. Since these 3 caves were of a different pattern compared to the rest of the state, it is clear that they formed under unique conditions. Mark Twain Cave, Cameron Cave, and LaBaume Cave formed in the Louisiana Limestone, located along a 2-km

stretch of the Mississippi River and each is <1.5 km from the Mississippi River. All 3 of the caves have tall, narrow passages with flat ceilings typical of formation along joint planes (Sasowsky pers. comm. 2002). There are also 2 unmapped caves in the vicinity that have names (Mini Fissure and Mammoth Fissure) indicating an origin similar to Mark Twain, Cameron, and LaBaume Caves. Network caves form by diffuse recharge through a permeable caprock into a jointed/fractured bedrock or because of floodwater injection into jointed/fractured bedrock. Given the proximity of these caves to the Mississippi River, the caves most likely formed due to floodwater injection processes. There is no permeable caprock overlying the cave-forming Louisiana Limestone that would have provided diffuse recharge, allowing for simultaneous passage growth along joint sets. The caves also have fluvial sands and silts, consistent with floodwater injection (Sasowsky pers. comm. 2002).

Anastomotic caves were 11.5, 4.7, 0, and 0.6% of the population for the Salem and Springfield Plateaus and the Hannibal and Perryville areas, respectively. Statewide, the percentage is 6.6%. The global average is 3%. There are a few more anastomotic caves within the Salem than expected. The anastomotic pattern of cave morphology is the product of diffuse recharge through an overlying permeable layer and/or sinking streams that flow along bedding plane partings (Palmer 1991). Given the nearly horizontal bedding within Missouri, flow along bedding plane partings is likely, thus a slight increase in the number of anastomotic caves is expected.

For Salem, Springfield, Hannibal, Perryville, 16.5, 10.3, 4.9, and 14.8%, respectively, of the caves were rudimentary in pattern. The statewide average of 13% matches the global average of 14% (Palmer 1991). However, due to a software limitation (at least 6 orientation vectors were required to produce a rosette diagram), many rudimentary caves were eliminated from the dataset. This artificially lowered the percentage of rudimentary caves and underrepresented the rudimentary caves within our database. Therefore, there could be many more rudimentary caves than we include. Palmer suggests rudimentary caves have many origins. We think that the rudimentary caves in Missouri may be due to surface erosion. The incision of the streams has likely truncated many larger cave systems, leaving behind only short remnants from the much longer cave system. When the remnants are mapped, they appear as short, rudimentary caves. As most of Missouri's karst areas are thought to be ancient erosional surfaces (Bretz 1965), deep stream incision is expected. Without a detailed reconstruction of the paleo-cave systems, it is difficult to determine if the cave map represents a true rudimentary single-passage cave or a remnant of a larger cave system. In some cases, the remnants can be visually extrapolated to determine that they were once one system. For example, in Shannon County, a person can stand in the entrance of Bear Cave #2 and look across the surface valley and see the entrance of Little Bear Cave (Baker *et al.* 1989).

The ramiform and spongework pattern of cave morphology is the product of dissolution by acids from a deep-seated source, the cooling of thermal waters, or mixing of 2 waters of contrasting chemistry (Palmer 1975, 1991). Hydrothermal fluids flowed through the subsurface of Missouri during the Pennsylvanian-Permian and resulted in the ore deposition within the Old Lead Belt, Viburnum trend, and Tri-State regions (Roedder 1977; Leach 1979; Gregg & Shelton 1989; Symons & Sangster 1991). Whereas groundwater flow and deposition of ore in the Viburnum Trend and Old Lead Belt regions were preferentially along old algal reef structures (Gregg & Shelton 1989), in the Tri-State region, the hydrothermal fluids deposited ore in "solution collapse structures" (Brockie *et al.* 1968). For a few mines, there are maps available of the zone of mineralization; these maps appear to be ramiform (and spongework) caves into which the hydrothermal fluids flowed and deposited ore (Brockie *et al.* 1968: p. 415). Because these mines are not caves *per se*, they were not included in the database. However, their formation and occurrence fits the Palmer model.

CONCLUSIONS

We have taken the classification scheme of Palmer (1991), developed a metric, and used the metric to analyze the morphology of the caves of Missouri. We used the metric on caves much shorter than those included in the study by Palmer. Differences between the global percentages of morphology types and the percentages found in Missouri suggest a lack of network caves and a plethora of rudimentary cave within the State. The lack of network caves is likely due to the lack of caprocks, and the plethora of rudimentary caves is likely due to deep stream incision.

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Andreas Pflitsch and Jacek Piasecki - Detection of an airflow system in Niedzwiedzia (Bear) Cave, Kletno, Poland. *Journal of Cave and Karst Studies* 65(3): 160-173.

DETECTION OF AN AIRFLOW SYSTEM IN NIEDZWIEDZIA (BEAR) CAVE, KLETNO, POLAND

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Analyses of radon gas tracer measurements and observation of the variability of thermal structures have long been thought to indicate the presence of weak air currents in Niedzwiedzia (Bear) Cave, Kletno, Poland. However, only after ultrasonic anemometers were installed could different circulation systems of varying origin and the expected air movements be observed by direct measurement. This paper presents: a) the different methods applied in order to determine the weakest air currents both directly and indirectly; b) a summary of hypotheses on the subject; and c) the first results that air indeed moves in so-called static areas and that visitors affect both cave airflow and temperature. First results show that even in so-called static caves or within corresponding parts of cave systems, the term "static" has to be regarded as wrong with respect to the air currents as no situation where no air movements took place could be proven so far within the caves. Moreover, the influence of passing tourist groups on the cave climate could unequivocally be identified and demonstrated.

Both speleometeorology and speleoclimatology differ significantly from their counterparts that deal with airflow under free atmospheric conditions: Weather conditions and climatological shaping at a specific location on the Earth's surface are mainly governed by short to medium-term (regional to global scale) changes, whereas the speleoclimate is largely or entirely dependent on local conditions (Bögli 1978). These, in turn, have an influence on openings and cavities that are interconnected. Typically, conditions in such cave systems are continuously homogenous (e.g., high relative air humidity prevails over long periods of time, temperature variations are very low, and air movements are little or absent). In combination with the total darkness inside, these factors have led to the generation of very special and fragile ecosystems.

It is a common assumption in cave climatology that air movements in caves are the results of the endogenic and exogenic factors described below. After Schuster and Novak (1999), the distinction of endogenous and exogenous factors as a cause of air circulation is made due to thermodynamic differences. For the exogenous factors, the mass transfer is contemporaneous with the transfer of energy between the cave gas phase and the outside atmosphere.

EXOGENIC FACTORS

Air movements are generated by the following processes:

-Differences between air pressure inside the cave and the outer atmosphere, which in turn are the result of the continuously changing pressure systems (Moore & Sullivan 1997).

-Pressure differences generated by the different orientation of openings compared to the actual wind direction. In such situations, the windward side shows higher values of air pressure than the leeward side (Bögli 1978).

-Temperature differences and the resulting pressure differences between the cave and outer air (Bögli 1978; Moore & Sullivan 1997). Bögli (1978) regarded the genesis of cave winds as a consequence of temperature differences between the atmosphere inside and outside the cave as an explanation valid for systems with 2 or more openings at a different height. His example of the Hölloch system shows a height difference of 500 m. The differences in pressure are governed by temperature differences between the air inside and outside the cave. During the winter, the air entering the cave system warms up, becomes lighter, ascends, and escapes through an upper opening. This loss in mass causes a very small amount of lower pressure inside the cave in comparison with the outer air pressure. During the summer, air entering the cave cools down, gains weight, descends, and flows outside through a lower opening. The amount of both effects is mostly very small and depends on the relationship between the cave volume and the number and the diameter of the openings. More recent results from Moestrof Cave, Luxembourg, show interesting relationships between the changes in pressure and differences in air density (air outside and inside the cave), air temperature outside, and the velocity of currents within the cave (Boes *et al*. 1997).

ENDOGENIC FACTORS

For the endogenous factors, no change in mass takes place; instead, transfer of energy is on a mechanical basis in a closed thermodynamic system. Air movements are generated by the following processes:

-Pressure differences inside the cave that are caused by differences of air density, which in turn are the result of temperature differences, humidity, and CO_2-content (Bögli 1978),

-Transfer of power through turbulent flow of water (Cigna 1971; Schuster & Novak 1999),
-Changes in volume caused by changes of water levels in caves (Ford & Cullingford 1976).

From the compilation of influencing factors above, it becomes fairly obvious that air temperature is one of the key factors for the generation of air currents. Temperature differences within the cave and between the cave and outer atmosphere can lead to balancing air currents, with weak air currents that are due to endogenic factors and quite high-velocity currents in the range of m/s due to exogenic effects (Schuster & Novak 1999).

The balancing currents of air into and out of a cave are normally too weak to contribute significantly to the difference of temperature between the cave air and the outside atmosphere. Thus, the temperature inside the cave is mainly governed by rock temperature, which in turn reflects the long-term mean annual air temperature of the outside atmosphere.

Moore and Sullivan (1997) report that daily fluctuations of air temperature outside the cave of an order of 30°C are reduced to an amplitude of <1°C at a depth of 57 cm inside limestone. In contrast, the same authors demonstrate that an annual amplitude of outside air temperature of 30°C is still detectable to a depth of 11 m with a variation of >1°C. Thus, caves of depths >11 m display variations <1°C. Distinct deviations from these values can only be expected where airflow is strongly oriented into the cave.

Furthermore, this shows that cave temperature can be approximately estimated based on the respective latitude and elevation above sea level at which the cave is located (Moore & Sullivan 1997). However, there are even more factors that have an influence on cave temperature, as follows:

Water: Cave rivers and smaller streams have a much higher influence on cave temperature than the weak air currents. The specific heat capacity of air and its lower density cause a much lower heat content of the air in comparison with rocks and water, causing a quick approximation of air and water temperature (Bögli 1978). The heat content of a defined volume of air is 3200x smaller than that for water and 1800x less than that for limestone. Caves that are influenced by cold meltwaters show a lower temperature than expected from the temperature outside, especially during the spring and partly during the whole year (Bögli 1978; Moore & Sullivan 1997).

Geothermal heat flux: This factor is generally regarded to have a minor effect on cave climate. Using a geothermal gradient of 0.03°C/m, an influence on cave climate can be assumed only for very deep caves. In the case of caves that belong to the active endokarst, the effect of geothermal energy can be ignored as the heat is completely masked by surface temperature effects.

Structure: For static caves (i.e., those with only one entrance–"blind"), the position of the entrance in relation to the main cavity can lead to marked differences in cave climate. If the entrance is located below the main cavity, the latter or higher areas within the cave system "collects" the less dense, light air and forms so-called "pockets of warm air". In case of an entrance above the main cavity, cold, dense air descends to lower parts of the cave forming a "pocket of cold air" that stagnates within the "hole", thus creating stable layering.

Aspect: The location of a cave with respect to the aspects of individual slopes should have some influence on the cave temperature, where the thickness of the geologic formation that covers the cave is small. This should then lead to a slight increase of cave temperature when compared to the mean annual air temperature for sunny slopes with southern aspects and slightly lower cave temperatures on northern aspects, where shadow effects are significant. These assumptions could be partly documented during our measurements in Balzarka Cave (Moravian Karst, Czech Republic); however, similar assumptions or data could not be found within the body of cave literature.

Conclusion: In general, only very low wind speeds of the order of a few cm/s can be observed, which do rarely exceed 1 m/s especially in endogenic systems. Occasionally, however, cave winds can reach gale force as, for example, 166.3 km/h in the Turkish Pinargözü Cave (Bögli 1978). These high wind speeds are generated by so-called chimney effects (Moore & Sullivan 1997). Other caves, as for example Wind Cave in South Dakota or the Cave of the Winds in Colorado, are well-known for their winds or sound that is generated when wind is pushed through narrow cavities (Conn 1966).

CLIMATIC CLASSIFICATION OF NATURAL CAVES ACCORDING TO THEIR VENTILATION

With respect to the climatic situation and ventilation, static and dynamic caves are distinguished in the literature. Both terms were introduced by Geiger (1961), using the number of cave entrances only: Caves with only one entrance are thus regarded as static systems, whereas caves with more than one entrance are referred to as dynamic caves. Although Ford and Cullingford (1976) demonstrate that static caves should only have one or no entrance, we think that this classification is not very useful, as wind speeds even in caves with only one entrance can reach high values.

Investigations of dynamically aerated caves with high wind speeds are manifold. The way of aeration of the Salzgrabenhöhle described by Schuster and Novak (1999) is one of the most recent to be mentioned in this context. Compared with Hölloch investigated by Bögli (1978), which has a height difference of 500 m between the uppermost and lowermost openings, Salzgrabenhöhle also has a very large vertical span of 640 m, which in turn causes marked pressure differences that are easy to calculate.

As wind speeds in so-called static caves are mostly low (Schuster & Novak 1999), and below the lower limit of detection of previous measurement instruments, it has to be emphasized here that the complete detection (quantification) of air currents (vertical and horizontal components) is more a

technical problem of measurement. The VDI Guideline (VDI 1988) quotes a reasonable threshold value of 0.6 m/s for the use of rotational anemometers. In general, wind speeds <0.5 m/s are regarded as "situations where wind direction remains undetectable with measurement devices" (Reuter *et al.* 1991: p. 33). For situations that are known as calms, no information about wind speed or direction is available. However, recent studies that used radon gas as a tracer show that even in caves where no system of currents could be proved, a complex system of air currents could be detected though not yet quantified (Hebelka 1998; Przylibsky & Piasecki 1999). Furthermore, recent large-scale climatological investigations of Moestroff Cave, Luxemburg (Boes *et al*. 1997), and various caves of the Moravian Karst, Czech Republic (Hebelka 1998), could detect and quantify even very low wind speeds of < 0.5 m/s in a very detailed way using a hot wire anemometer. The exact detection of wind direction and wind speed is still not possible with this method.

From the results compiled above, so-called "static" caves can be regarded as climatic systems that give insufficient information about a possible system of air currents that might be present within them. This lack of information could be filled in the meantime using sonic anemometers. The use of such measuring devices makes it possible to detect very low air currents down to cm/s, to record even the slightest changes in direction and velocity in intervals of split seconds and the detection of the slightest variations in air temperature, which is very useful in caves, too. The VDI guidelines quotes a lower limit of detection for air temperature of these devices as 2.2 x 10^{-2} °C (VDI 1994). The technology of sonic anemometers has been available since the mid-1960s and has been used specially in micrometeorology. But it is a fairly new instrument in East Europe, especially for cave climatologists.

The use of this thermal technique in addition to the detection of weak air currents allows for a long-term quantification of such events that, until now, could only be achieved using artificial tracers (Pflitsch & Flick 2000).

Our investigations in various cave systems in Germany, Poland, the Czech Republic, and Slovakia (Piasecki & Pflitsch 1999; Pflitsch *et al*. 1999) have shown that it appears to be more useful to classify such caves as dynamic in a climatologic sense, in which the air velocity is easily detectable and where wind speed can reach high values. In those caves, the wind plays an important role and can be regarded as the main forming agent, and air movement as the primary process for the climate of all or part of the whole cave system. Change of the other meteorologic elements, such as air temperature and relative humidity, is also clearly detectable.

Moreover, Piasecki (1996) has shown that it is useful to divide caves into different parts. During long-term investigations in the small system of Niedzwiedzia Cave, Poland, individual areas unequivocally had static climatic conditions, whereas other parts of the cave system had dynamic ones.

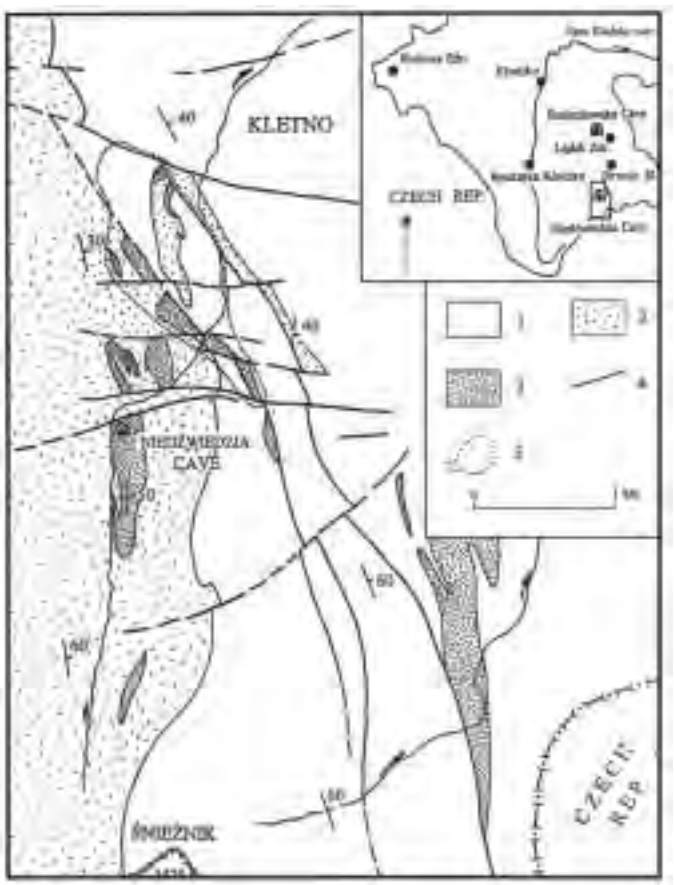

Figure 1. Overview of the Niedzwiedzia (Bear) Cave, Kletno, Poland and the geology of the surrounding area (Przybilski & Piasecki 1998, after Don 1989). Legend: 1 = Gneiss, 2 = Metamorphic Stronie Series, 3 = Marble and other carbonate rocks, 4 = Faults, 5 = Location of former uranium mine.

Thus, we revise the classification of caves into dynamic or static climatic systems, as the old classification is obsolete. The latest measurement results point to the fact that static conditions can only be claimed where little or no air movement can be demonstrated–except for areas close to entrances–and where the spatial and temporal variability of the climatic elements is small. Furthermore, within a system spatial and temporal differentiations must be applied.

INVESTIGATIONS TOWARDS A NEW CLASSIFICATION SYSTEM OF CAVES

THE STUDY AREA

Niedzwiedzia (Bear) Cave, Kletno, is within the Klesnica Valley of the Snieznik Massif in the East Sudetes Mountains at an altitude of 800 m (Fig. 1). The corridors known so far make up 3 levels built in calcite-dolomite and dolomite-marble with a total length of 2500 m–the longest cave system of the Sudetes Mountains. The marble occurs in pockets of unknown thickness, and it is not known if these are isolated pockets or if

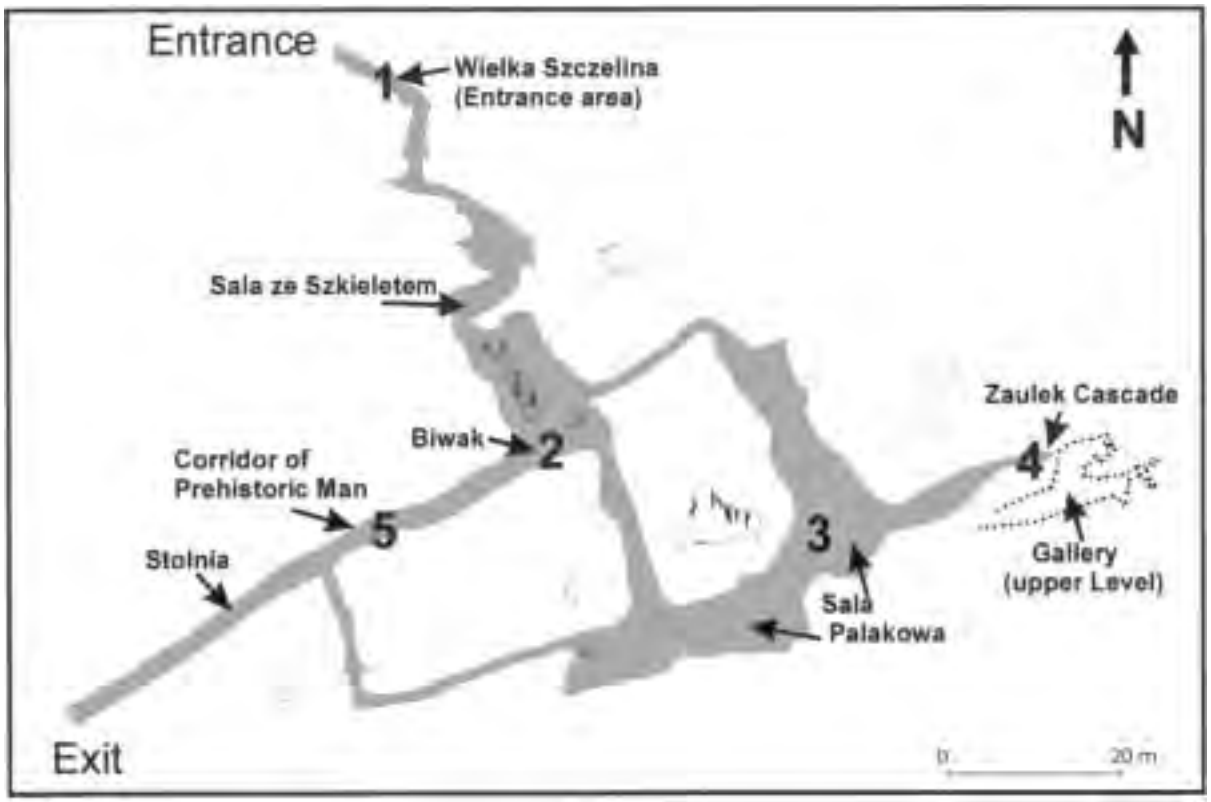

Figure 2. The part of Niedzwiedzia Cave, Kletno, Poland that is open to tourists and the study areas.

they are interconnected with one another. They are embedded in metamorphic formations of the Snieznik, which are mainly gneiss and paragneiss of the Snieznicka, Gieraltowska, and Transitory Series and micaceous schist of the Stronska Series. The massif is characterized by many joints and faults. Just north of the cave, a fault with rectangular tectonic fractures governs the morphology of the cave corridors. Hydrological and hydrochemical investigations, as well as sedimentological analyses in the water corridors, clearly point out that more cavities have to be present.

It is expected that the cave morphology has a special influence on air movements within the cave and that some characteristics of these structures are also important for the origin of the detected airflow. Morphological investigations show that from the early Holocene onward, Niedzwiedzia Cave belonged to a closed cave system, and contact to the surface only existed via ponors (Don 1989). Only as recently as 1966, an opening into the cave, which was until that date obscured by slope material and cave deposits, was cleared by an explosion in a marble quarry. In the following years, entrance and exit passages were created to the cave corridors (Pulina 1989). These are blocked by locked doors and, thus, secured against the influence of the air outside the cave. As the cave is open to tourists 5 days a week, the doors are opened only briefly many times a day.

Climatologic investigations, which were conducted after the discovery of the cave in 1966, first periodically and later in the 1990s on a regular basis, have shown that 3 climatic zones can be distinguished within the cave (Piasecki 1996). The static zone has the largest extent and includes most corridors and halls of the lower and intermediate levels, whereas the dynamic zones and those that can be regarded as transfer areas play a minor role in terms of spatial extent. The characteristics of the climatic components and the extent of the climatic zones are shown in Figures 2 and 3.

METHODOLOGY

In order to detect the cave climate, the following methods were used:

MEASUREMENT OF AIR TEMPERATURE

From 1991 onward, air temperature was measured at one station outside and 5 inside Niedzwiedzia Cave, ~1 m above the floor. Temperature logging was conducted using PT100-sensors (platinum resistance thermometers) with a recording interval of 1 minute and with 10 minute means. In addition, extreme values were recorded. Measurement error is ±0.2°C.

In addition to the automatic measurements, manual measurements were conducted on a regular basis; these used horizontal and vertical profiles at 16 locations within the cave with distances of 0.1, 1.0, and 2.0 m above the floor. The recording device was a DL-15 datalogger of "Thies" (Germany). In order to record the most natural, undisturbed conditions possible, only those data were used that had been recorded 3 hours after the last tourists had left the cave.

RADON MEASUREMENTS

In order to identify permanent air movement, alpha particles that are generated during the decay of radon were

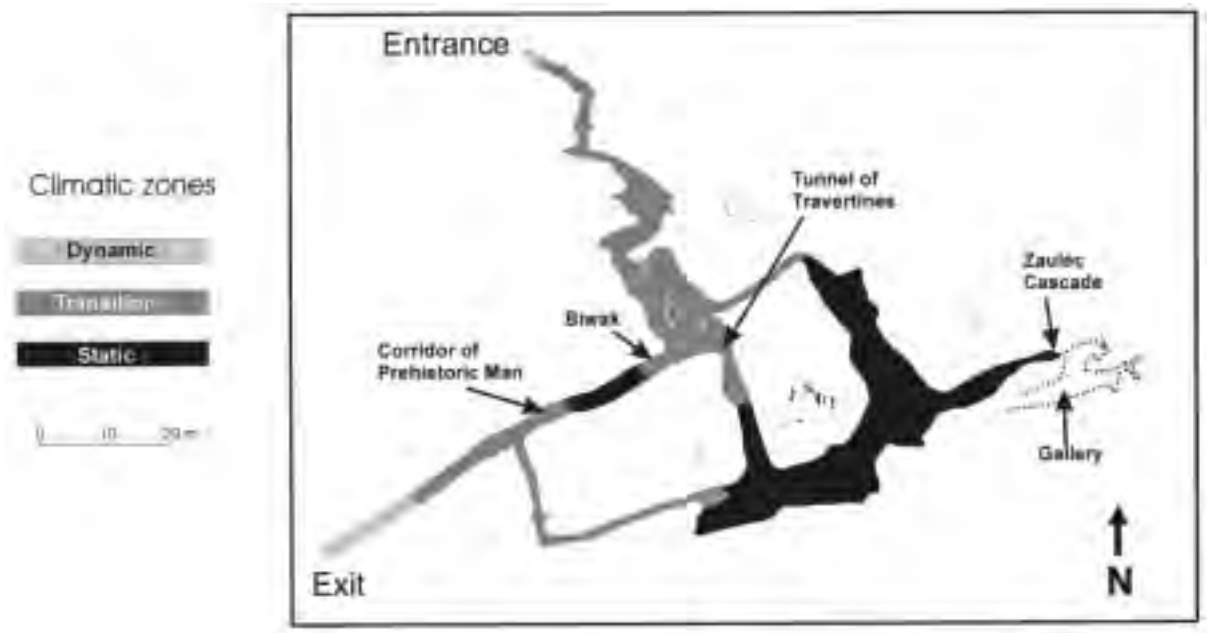

Figure 3. The three climatic zones of Niedzwiedzia Cave and the locations of sonic measurements.

collected passively. The fundamentals underlying this method are based on the following physical and chemical properties of radon:

-Little chemical reactivity and a long half-life enable a reasonable detection of changes in concentration,
-The high density of radon causes an accumulation close to the floor so that gas movements are due to air movements.

In order to identify the mean trace gas concentration, 15 trace gas detectors were installed as 5 vertical profiles with 3 detectors each. Furthermore, one detector was installed in the water of the Travertine Hollows, and sediment samples were taken in order to analyze the background concentration.

For comparison of radon concentration in caves of different morphology and with different numbers of openings, additional measurements were conducted in Radochowska Cave, which is aerated via 6 openings. The period of measurement includes the 2 years 1995 and 1996, and the results can be obtained in detail from Przylibski and Piasecki (1998).

MEASUREMENT OF AIR CURRENTS USING SONIC ANEMOMETERS

Investigations using a 2-D sonic anemometer were conducted in a depression in the Rashomon Gate region, Japan, by Shaw *et al*. (1996). Additional information comes with the use of 3-D sonic anemometers, which also record the vertical component.

Such investigations using 3-D sonic anemometers were conducted from March 1998 onward in Niedzwiedzia Cave (Fig. 4). The first results are presented in the following and related to the temperature and radon gas measurements (Przylibski & Piasecki 1998). The objectives of the investigation are to identify and quantify the system of air currents within the whole cave system and its seasonal variability. The measurements were conducted using METEK sonic anemometers USA-1. The measurement principle of the ultrasonic anemometer is based on the duration of ultrasonic pulses measured in 3 different directions (VDI 1994).

Figure 4. View of an ultrasonic anemometer at the Biwak measurement point.

A sonic anemometer offers measurement opportunities that are very different from mechanical anemometers. By measuring low level winds with a mechanical device, the wind must provide enough power to overcome friction and to accelerate the mass of the moving parts (Locker 1996). On the contrary, a sonic anemometer has the following properties:

-no friction
-no inertia

These features are important for measuring very low wind speeds because of the following advantages:

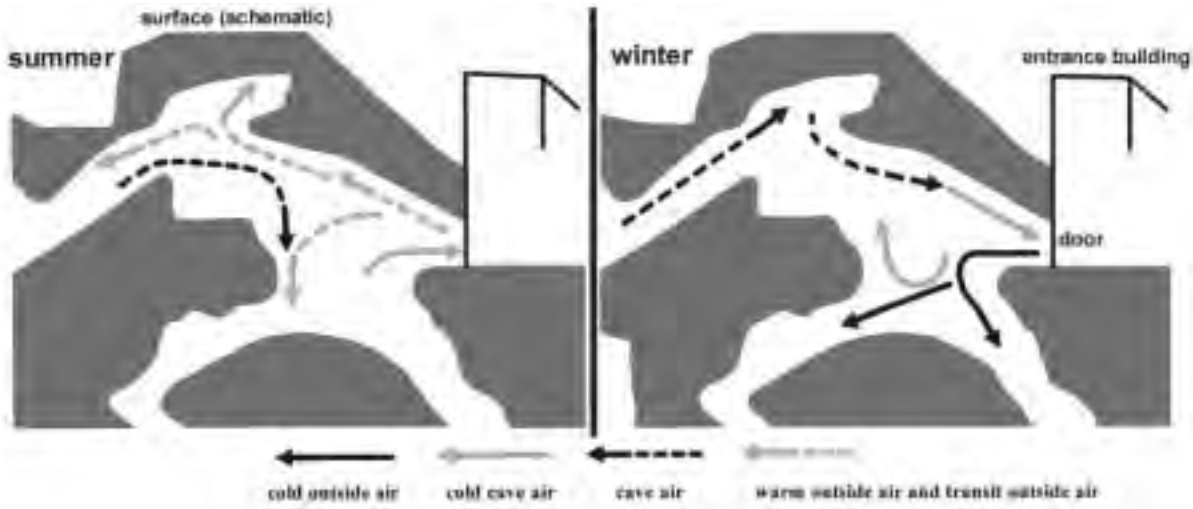

Figure 5. Schematic cross section of the air currents adjacent to the entrance area of Niedzwiedzia Cave.

-no start up phase
-useful results during short measurement intervals, for instance 1 second
-determination of very short fluctuations of wind vectors and temperature

The use of sonic anemometers makes it possible to measure current velocities with speeds of a few cm/s and the registration of finest changes of wind direction and speed in intervals of less than seconds. In addition, it is also possible to prove the finest variations of air temperature. According to the VDI guideline, the lower detection limit as well as the uncertainty of measurement for wind speeds is 0.025 m/s and for temperature 2.2 x 10^{-2} °C (VDI 1994). Based on this guideline only measurements with wind speeds >0.025 m/s are useful information. Below this limit, the information of the wind direction is not useful.

The measurements were conducted over a period of 3-5 weeks at the locations that show "static" climatic conditions; the locations of the sonic anemometers are shown in Figure 2.

Biwak	1 & 2.0 m above floor level ceiling 3 m above floor level
Zaulek Cascades	1.0 & 2.0 m above floor level ceiling 10 m above floor level
Gallery	1 m above floor level ceiling 2 m above floor level
Tunnel of Travertine Hollows	1 m above floor level ceiling 1.5 m above floor level
Corridor of Prehistoric Men	1 and 2.0 m above floor level ceiling 5.5 m above floor level

The selection of the measurement locations was influenced by the results of radon and temperature measurements that had already been conducted and by test measurement campaigns that lasted 1 day. During the analysis of the data, it was decided that the respective wind direction would not be used for analysis with horizontal air movements of ≤3 cm/s. These situations are termed "calms".

RESULTS

Using the methods listed above, 5 areas with characteristic patterns of airflow could be distinguished for the intermediate cave level. The first 2 are located within the zone of dynamic climate and the transition zone between dynamic and static climate, respectively (Figs. 2 & 3). Its climatological shaping is influenced by the air exchange between air inside and outside the cave, the conduction of heat through the ceiling rocks, and the processes of heat exchange between the cave air and surrounding rocks (Piasecki 1996).

On the basis of seasonal changes of air temperature and radon concentrations as well as the measurements of currents using sonic anemometers, the following pattern of airflow could be identified for these areas within the cave:

LOCATION 1

Closely behind the tourist entrance of the cave, different anthropogenic and natural processes lead to marked and far reaching air circulation that has an influence, especially on the air currents and temperature of the lower cave level. During the cold season between November and April, a permanent stream of cold air originating from the entrance (Fig. 5), exists close to the entrance area and leads to the floor of the Wielka Szczelina. This stream of cold air, which is due to small permanent openings, causes a reduction of the mean annual air temperature by ~0.5°C. When entering the cave, this stream of dense, cold air mixes with or completely replaces the air inside the lower level of the cave, which has the highest measured concentration of radon. As a result of this effect, the air of the lower level reaches the upper levels of the cave, which in turn leads to increased radon concentrations in the upper levels. This air then flows into the inner parts of the cave, where it can leave the cave (Fig. 5).

A second airflow, which is again oriented downward, is due to natural processes. Prior to the beginning of the cold period, a layer of warm air hangs directly below the ceiling, with the highest temperatures having been detected during October and November. During the course of the winter,

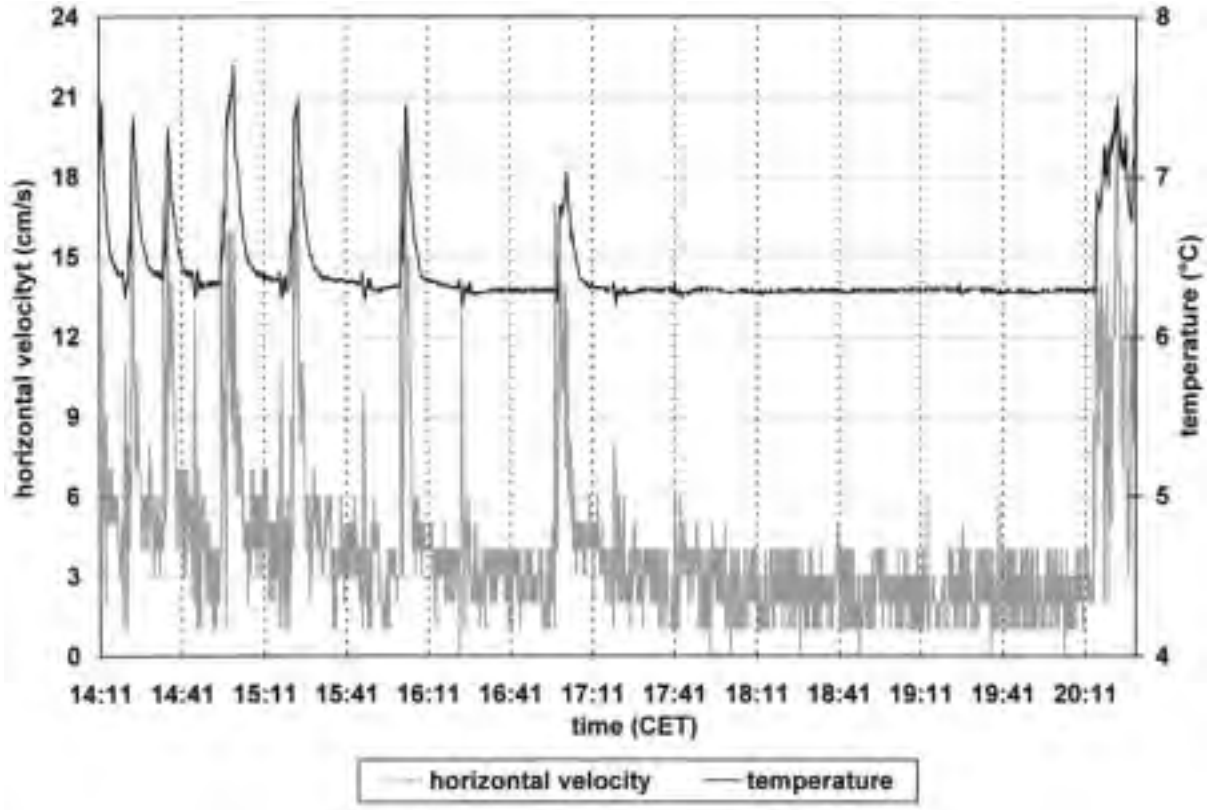

Figure 6. Air temperature and horizontal velocity of air flow in Niedzwiedzia Cave at Biwak, 28th of March 1998 (measured by sonic anemometer, average time: 10 s).

cooling of the rocks leads to a descent of this now cooler air mass. This phenomenon reaches its maximum intensity during the end of the cold period (Piasecki & Pflitsch 1999).

For the warm season from June to September, the mechanisms of air movement cannot yet be completely explained and identified for the area around Wielka Szczelina. The change of air temperature indicates air movement toward the outer cave areas, but this assumption is not supported by high radon concentrations and their little variability. In order to clear this issue, measurements with sonic anemometers are being planned for the future.

LOCATION 2

The second location represents the central or intermediate cave level, respectively. In our hypothesis brought forward at the beginning, we assumed that warming air moved upward from the lower level under the ceiling (Sala Lwa, Sala ze Szkieletem). This hypothesis was supported by temperature measurements that showed increased mean air temperature at Biwak. As static as well as transitional conditions could be proved for this area, the climatic boundaries are not clearly defined here. During consecutive measurements, 2 sonic anemometers were located at the crossing of 2 corridors (Fig. 2).

During the first experimental measurements in March 1998, air currents could be clearly proved. Surprisingly, and contrasting with the long-term temperature measurements, the influence on cave climate of tourist groups that visited the cave could be proved as well. The results presented here show impressively the tourist group influence and how the short-term opening of the doors changes the cave climate.

Figure 6 shows the course of air temperature and wind speed for a period of 6 hours. The average calculated by the sonic anemometer is 10 s. Two different situations are clearly visible: The first part of the period shown here displays a more or less periodic increase and decrease of wind speed, which also shows a clear relation to the air temperature values. After ~17:30 h, these conditions change significantly. The variations of both parameters stop rather abruptly with variations remaining within the measurement error.

The explanation for this pattern is simple: The first part of the figure shows the conditions during the time of the day when tourist groups are being led through the cave and pass the sonic anemometer at a distance of about 5 m. The second part shows the undisturbed period of time.

Beginning with the undisturbed situation, one can see that the air temperature is constantly 6.3°C, with a wind speed between 1-4 cm/s. As the lower limit was set to 3 cm/s (see above), the velocity is largely below the lower limit of detection. In stark contrast to this pattern is the period of time where tourist groups are being led through the cave. Wind speed with values of 3-6 cm/s is largely above the lower limit of detection with peaks of up to 20 cm/s, but again, 2 different patterns are distinguished within this period of time. Firstly, 7 larger increases in wind speed to 15-20 cm/s that last some minutes and secondly, short-term changes with lower values of 9-12 cm/s that are characterized by markedly lower increases in wind speed. This distinction can also be made using air

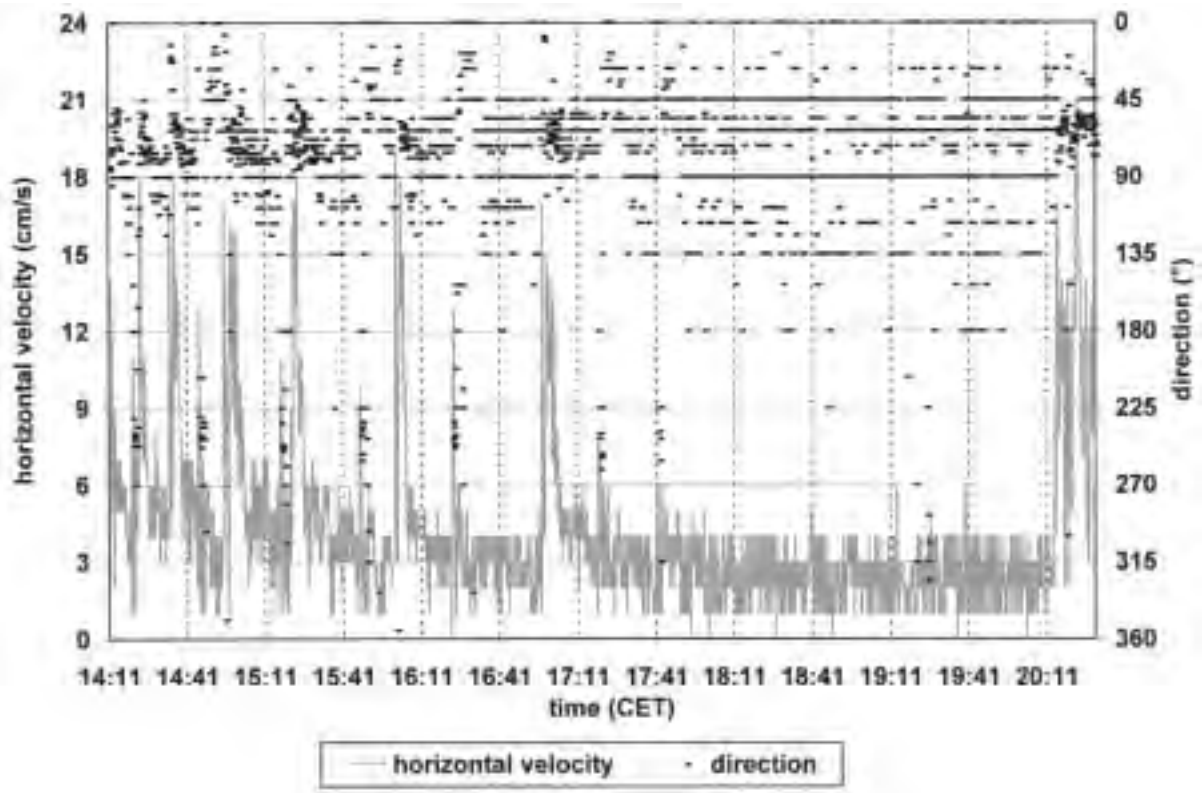

Figure 7. Direction and horizontal velocity of air flow in Niedzwiedzia Cave at Biwak, 28th of March 1998 (measured by sonic anemometer, average time: 10 s).

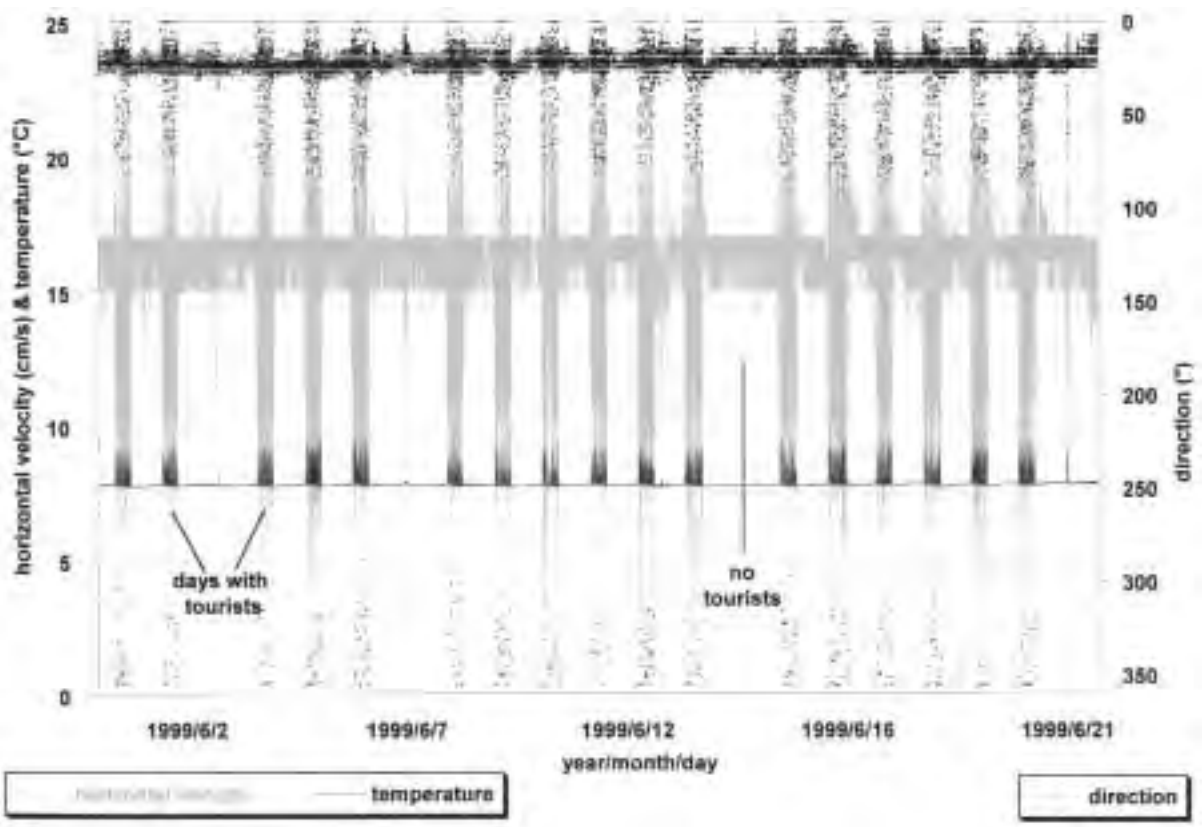

Figure 8. Direction and horizontal velocity of air flow and air temperature in Niedzwiedzia Cave at Biwak, at 2.0 m above ground level, 1st to 21st of June 1999 (measured by sonic anemometer, average time: 1 min).

temperature: The 7 peaks that are clearly identifiable also show marked increases in temperature (by 1.4°C), whereas the short-term changes correspond only to very little variation in air temperature of the order of 0.1°C (although even these small variations can be easily detected due to their characteristic pattern).

Using the information on wind speed as well as the conditions described above can also be seen here (Fig. 7). For

the undisturbed situation, one can see that the background current is predominantly from northeasterly directions but that the direction can change for shorter periods of time to about southeast (again, only wind directions were used where wind speed was >3 cm/s). During those periods of time where wind speed increased, wind direction is from the NE. Contrasting with this pattern, wind direction changes for ~60-90 seconds to SW directions (i.e., toward the respective axis of the corridor with the corresponding smaller peaks). The vertical component shows no change for the short-term changes of the climatic conditions described above apart from an increase in vertical velocity from 1-2 cm/s to 8-11 cm/s during the increase in velocity and air temperature. The temporal distribution of both structures has shown that they are caused by completely different processes. The strong changes are due to the influence of tourists who are standing in front of the instrument, whereas the less strong variations are due to the opening and closing of the entrance doors.

That these phenomena have not resulted from chance on individual days can be seen from Figure 8. The results shown here have been obtained from a measurement location just 2 m away from Location 1. The results stem from measurements conducted over a period of 2 weeks during June 1999 and clearly show that the patterns are highly constant and due to the influence of tourist groups. The first 3 days show a period of time where tourists disturb the current followed by 1 day when the cave was closed, again followed by 6 days with tourist groups being led through the cave, again 1 day off, and another 3 days with tourist groups at the end of this measurement period. Measurements used an averaging time of 1 minute. Although the level of velocity is markedly higher due to seasonal variability (compared to the first example at ~10 cm/s) and although the mean wind direction is oriented northward, the results show similar patterns of disturbance as already described in the first example.

For the nocturnal hours and for the days with no tourist groups inside the cave, a mean velocity of 14-18 cm/s and a constant azimuth of airflow from 15°-30° can be observed. Both represent the situation during undisturbed periods of time at this location, which is characterized by highly constant conditions. Completely varying from this pattern are the days when tourist groups are being led through the cave: wind speed is highly variable with decreases down to ~2 cm/s and increases in velocity up to 27 cm/s. With respect to these observations, wind direction loses its constant characteristic and deviates to easterly directions to ~110° and to westerly directions to 270°, thereby increasing the range of directions from ~15°-200°.

Using the first example as a comparison, it can be seen from Figures 6-8 that during days with tourist activity, in addition to the situation of airflow, significant changes in air temperature can be observed. During the nights and days off, air temperature shows a highly constant course, whereas the presence of tourist groups is, again, characterized by a marked increase in air temperature up to 1.5°C. Corresponding to the situation of airflow, the temperature adjusts to its normal level quite quickly after the influence of the tourists has ceased.

LOCATION 3

The third location includes the Sala Palacowa and areas of corridors close by with strongly developed static, climatic characteristics. Based on the variations in air temperature that now have been observed for many years, it was assumed that only air currents that are weakly developed would be present and that these could, perhaps, be due to heat exchange with the surrounding rocks. Every deviation from the background current would, thus, be related to the influence of tourists and not to any natural causes.

The respective radon measurements showed seasonal alterations in concentration in the vertical profile from Sala Palcoea toward Zaulek Cascade. In the winter, the highest radon concentration was (against our assumptions) measured 2 m above the floor of the hall, and this in turn can be used to conclude that a comparatively high vertical current must be present that prohibits the accumulation of radon close to the floor. For the summer and the transition to autumn and winter, the increase in radon concentration both close to the floor and ceiling seems to be due to 2 seasonally present currents (Przylibski & Piasecki 1998). In order to test these controversial hypotheses, detailed measurements of the airflow are necessary and planned.

LOCATION 4

Both seasonal changes in air temperature and the differences in radon concentration in the Sala Palacowa show the interdependencies of the respective characteristics in the fifth zone, which includes the area of Zaulek Cascade and the adjacent corridor (eastern end of Sala Palacowa). Of special importance for the cave structure are vertical fractures below the hall. Both the corridor that leads downward to the lower level of the cave and the upper corridor of the gallery end blind. The axes of the Sala Palacowa and the Zaulek Cascade cross tectonic fault zones. Using the long-term measurements of the air temperature, characteristic short-term temperature anomalies could be proved (i.e., a temperature inversion that happened irregularly between November and May). Investigation of radon concentrations indicated the variable nature of air movements within the course of one year (Przylibsky & Piasecki 1999).

Using the temperature distribution and the radon concentration, we concluded that a complicated, periodically variable system of airflow had to be present in the Zaulek Cascade and the Galleria. In the Zaulek Cascade, contrary to the normal conditions, inverse temperature profiles could not be observed between 1 and 2 m above ground. This example again (e.g., the temporally altered radon distribution) hints at airflow that is only present periodically between Zaulek Cascade and the gallery directly above it. The origin of this airflow, which we accept here, can be attributed to the heat flux and exchange with the rocks in the ceiling. Furthermore, the

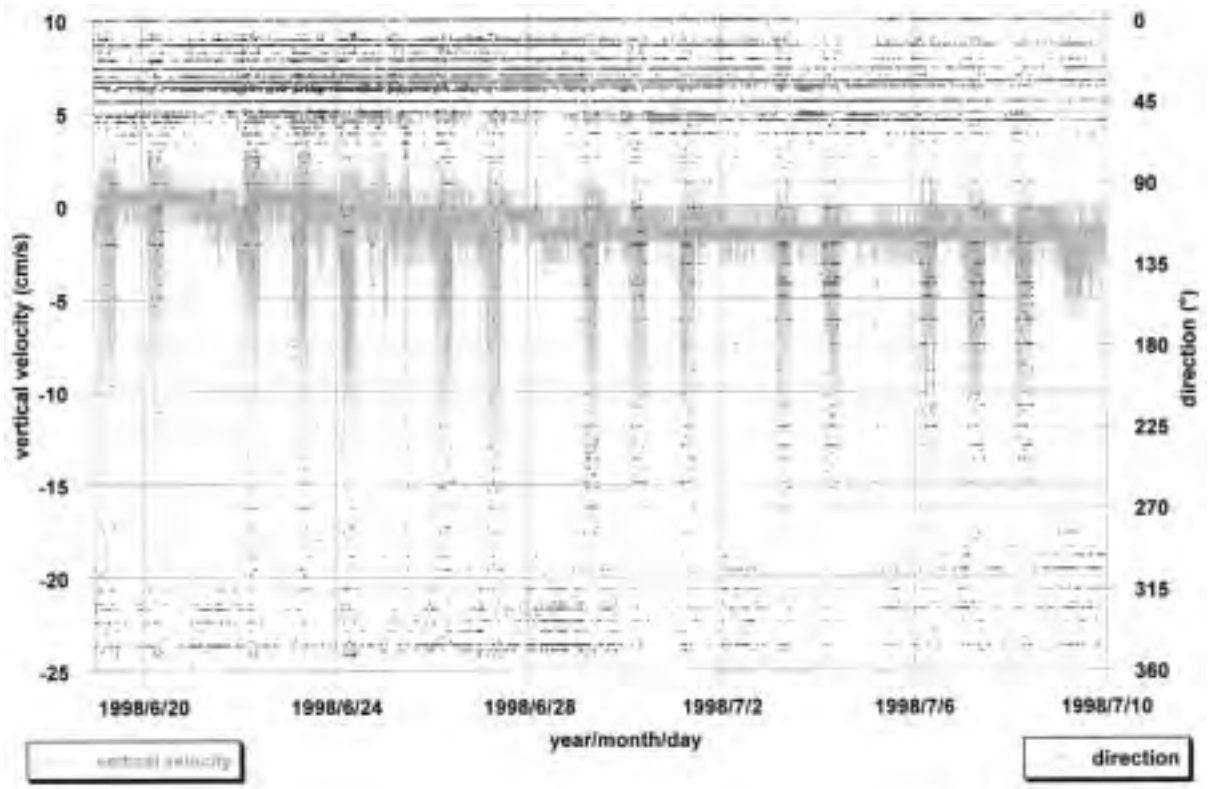

Figure 9. Direction and vertical velocity of air flow in Niedzwiedzia Cave at Zaulek Cascade I, at 2.0 m above ground level, 23rd of June to 14th of July 1998 (measured by sonic anemometer, average time: 1 min).

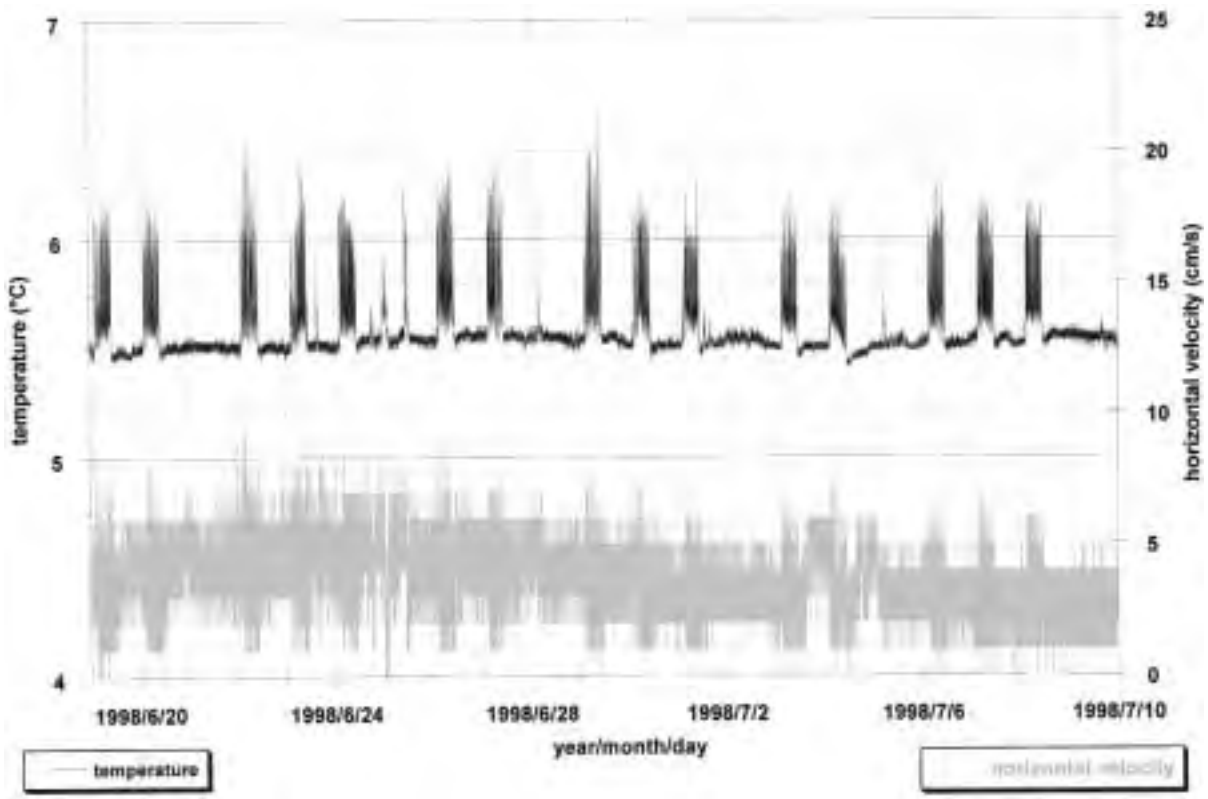

Figure 10. Direction of air flow and air temperature in Niedzwiedzia Cave at Zaulek Cascade I", in 2.0 m above ground level, 23rd of June to 14th of July 1998 (measured by sonic anemometer, average time: 1 min).

air movements appear to be related to the air exchange between different cave levels, which is also periodic (Piasecki 1996).

A downward-oriented current could be observed during short-term measurements in the area around Zaulek Cascade at 2 m above the floor, which was directed toward the axis of the Sala Palacowa (Fig. 9). This current is normally weak (5-10 cm/s) and has a constant nature, but it is heavily disturbed by tourists. Under the influence of tourist groups, turbulent airflow moves with extreme (in relation to the size of the cave)

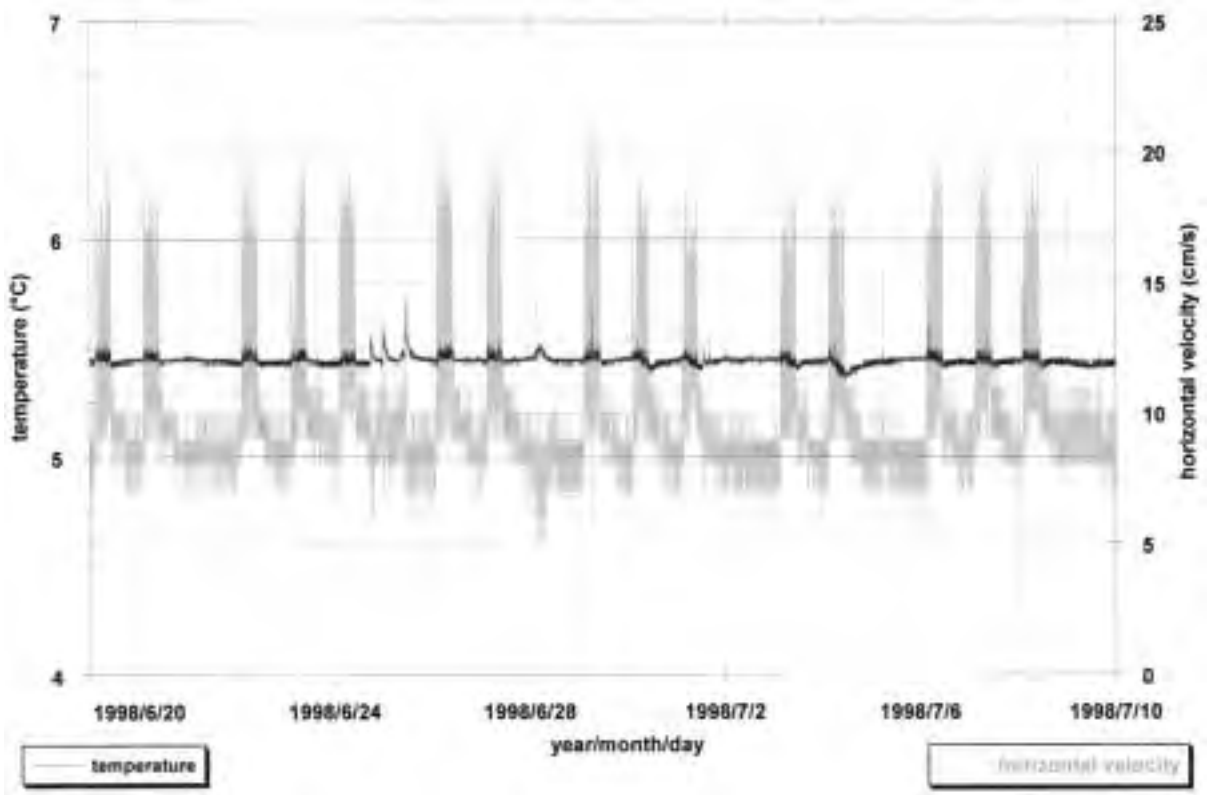

Figure 11. Direction and vertical velocity of air flow in Niedzwiedzia Cave at Zaulek Cascade II, at 0.5 m above ground level, 23rd of June to 14th of July 1998 (measured by sonic anemometer, average time: 1 min).

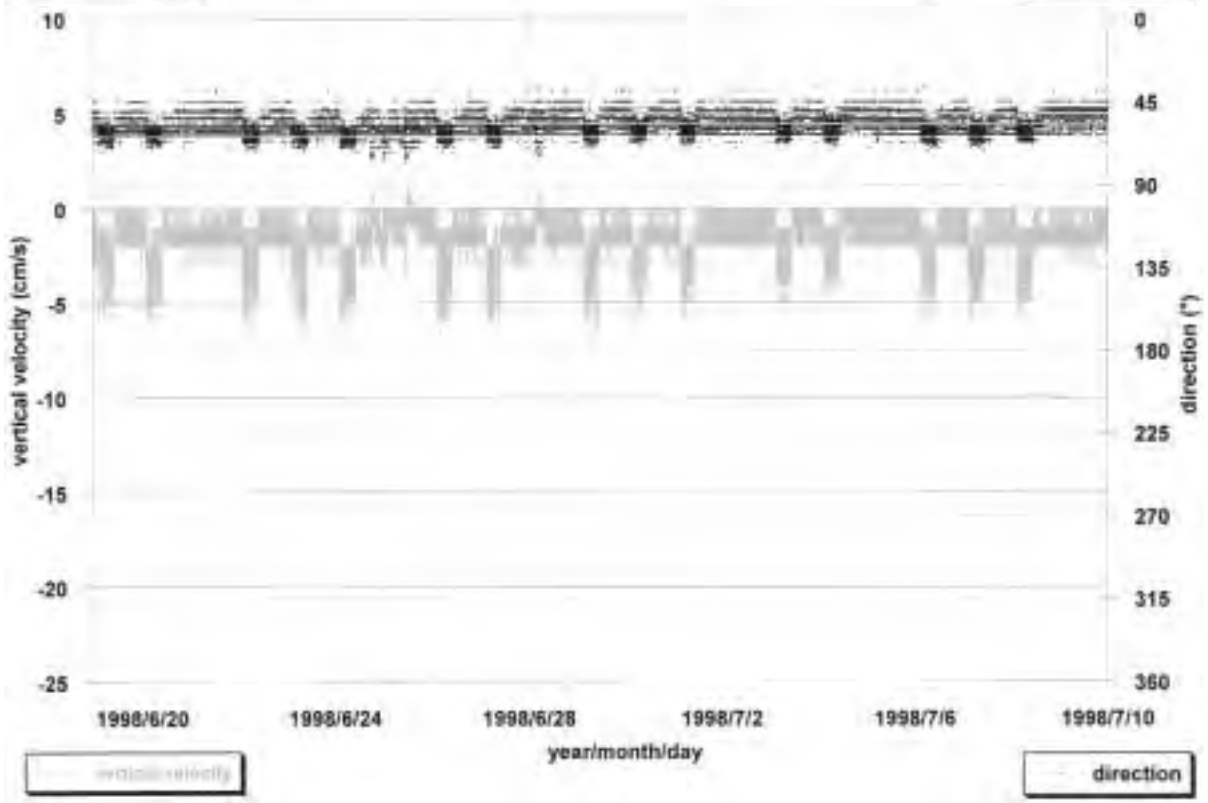

Figure 12. Direction of air flow and air temperature in Niedzwiedzia Cave at Zaulek Cascade II, at 0.5 m above ground level, 23rd of June to 14th of July 1998 (measured by sonic anemometer, average time: 1 min).

downward movements of up to 23 cm/s. The horizontal direction of airflow changes quickly and strongly, moreover we could observe increases in temperature of >1°C (Fig. 10).

Only a few meters behind Zaulek Cascade in the corridor that leads to the upper cave level, very constant airflow with respect to nearly every parameter was recorded at 0.5 m above the floor. The current moved toward Sala Palacowa with a mean velocity of 5-10 cm/s (Fig. 11). Contrasting with other currents (e.g., at Biwak and Zaulek Cascade), this current, which is clearly oriented downward again, remains virtually

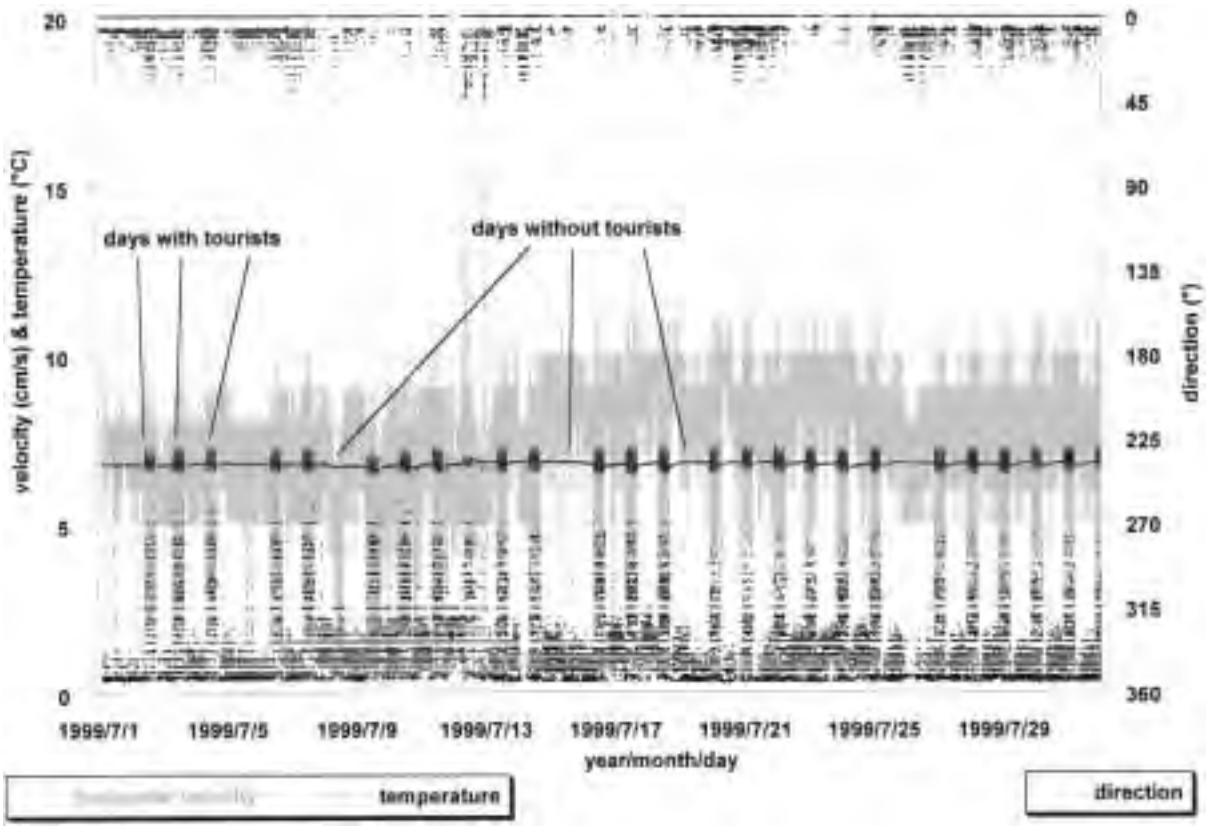

Figure 13. Direction and horizontal velocity of air flow in Niedzwiedzia Cave at Corridor of Prehistoric Man in 2.0 m above ground level, 1st of July to 1st of August (measured by sonic anemometer, average time: 1 min).

unaltered by tourist groups with respect to both air temperature and wind direction. The variability of direction is only of the order of a few degrees, and temperature fluctuations are of ~0.1°C at a maximum.

It is interesting to note that contrasting with this pattern, characteristic increases in the downward component and the horizontal wind speed have been observed during the passage of tourist groups. Here, the vertical component increases from ~3-8 cm/s and the horizontal velocity from 18-23 cm/s or 100-200%. These observations are clear indications that the vertical circulation induced by tourists in the area around Zaulek Cascade reaches up to the gallery of the upper cave level, and that the air masses that cool down there descend into the lower levels using the same corridor. These patterns lead to increased general current activity (Fig. 12). The existence of this pattern as predicted by theory could be verified by measurements of the airflow patterns in the gallery above the Zaulek Cascade.

LOCATION 5

The fifth location includes the exit gallery and part of the Corridor of Prehistoric Man (Fig. 2). Here, the highest air temperatures and radon concentrations were recorded just below the ceiling of the corridor ~10 m above the floor. Both values are clear evidence of permanent air movement toward higher areas of the corridor. In the meantime, the floor of the corridor and the galleries both show changing air currents between cave and outside air on a seasonal time scale (Fig. 12). Although doors and galleries pose a barrier to the airflow and hamper it significantly, the high amplitude of air temperature and its frequent fluctuations clearly show their presence.

The measurements with sonic anemometer conducted continuously since March 1999 have proved the presence of a well-developed and normally constant air current, which is heavily disturbed by tourist groups. In this context, Figures 13 and 14 show a similar situation to that at Biwak. In addition to clear currents, the constant temperature conditions and a well-developed northern direction of currents, the modifications of the velocity of air currents are striking. While the current is between 6-9 cm/s for days where tourists groups do not visit the cave, visitor days reach values between 1 and 11 and, in peak times, up to 17 cm/s (Fig. 13). In addition to the horizontal component of air currents, the vertical one is strongly modified (Fig. 14). For the days without tourist use, an upward air movement of 5-6 cm/s can be seen, whereas the heat produced by tourists gives rise to strong turbulence and, thus, to a perpetual change between upward and downward airflow. It is interesting to note in this context that the vertical component does not switch back to the original situation during the nocturnal quiescence period, but that this only happens during the few days when no tourists are allowed to enter the cave. Using air temperature and currents as indicators for a comparison of days with and without tourists, it becomes obvious that every group of tourists can be identified with these measurements variables (Fig. 15).

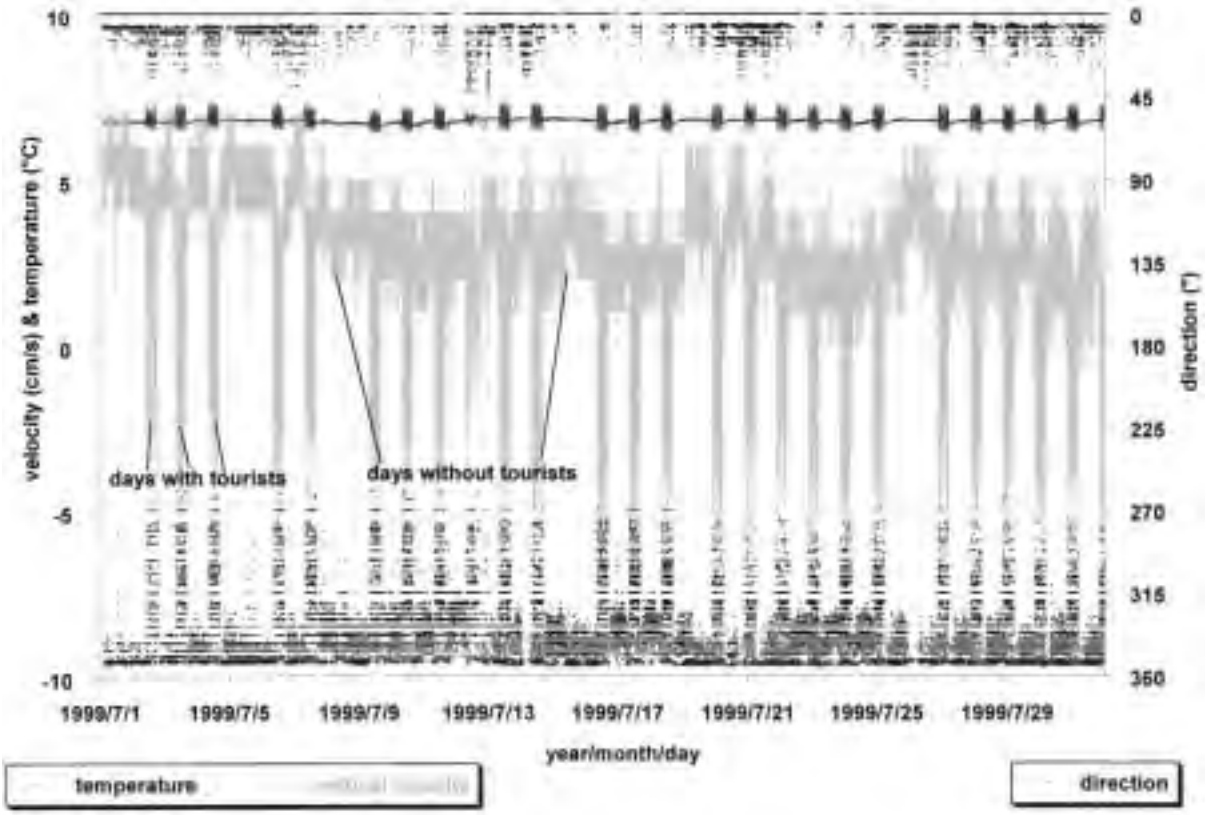

Figure 14. Direction and vertical velocity of air flow in Niedzwiedzia Cave at Corridor of Prehistoric Man at 2.0 m above ground level, 1st of July to 1st of August (measured by sonic anemometer, average time: 1 min).

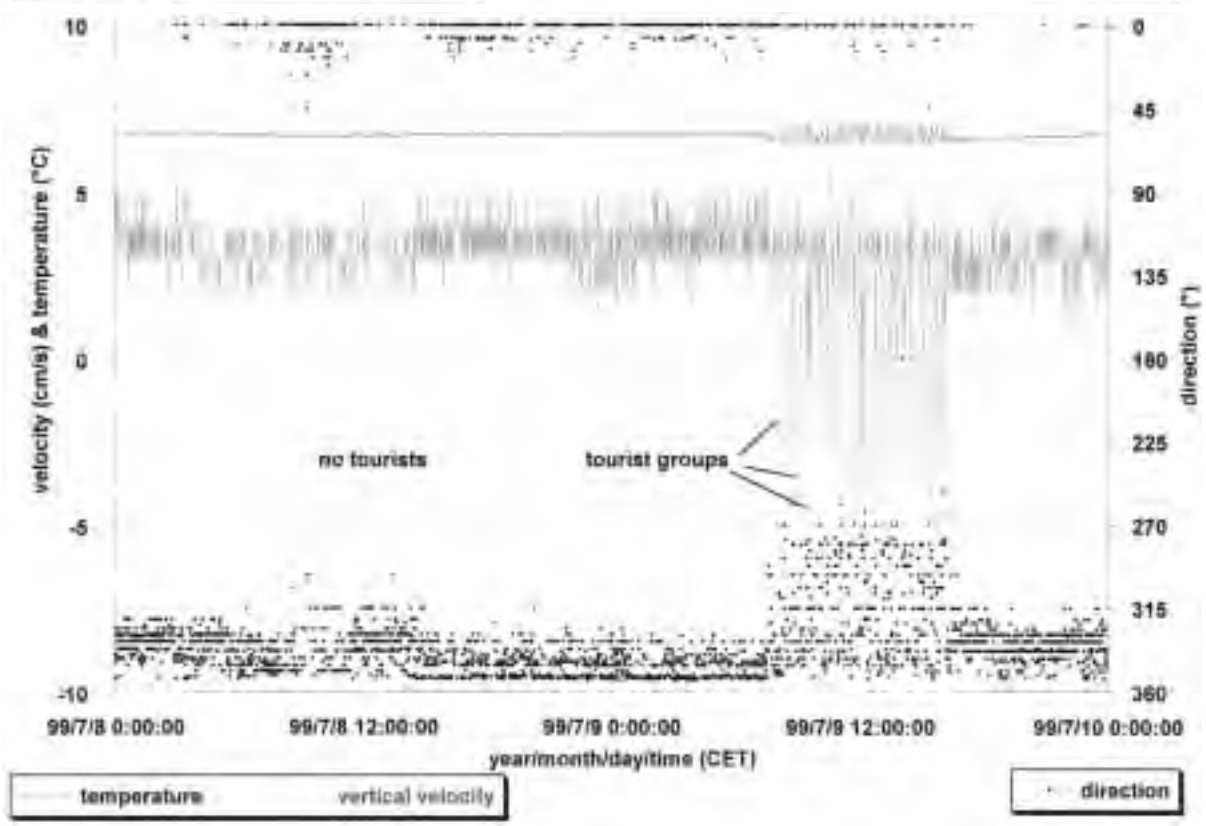

Figure 15. Direction and vertical velocity of air flow in Niedzwiedzia Cave at Corridor of Prehistoric Man at 2.0 m above ground level, 8th to 9th of July (measured by sonic anemometer, average time: 1 min).

SUMMARY

The investigations of variability of air temperature, radon concentration, and current velocity in Niedzwiedzia Cave, Kletno, Poland, that used sonic anemometers, unequivocally proves the existence of a complex system of airflow. The hypotheses made so far can only account to a limited extent for the origin and the flow of air within the selected parts of the cave (static areas). The opportunity of direct measurement of air movement presented here enabled us to verify the results obtained from other methods. Furthermore, in addition to the seasonal differences, we could identify those short-term differences that are due to the influence of tourists. It has also become possible to look at different aspects of the detection and recording of the climate system within the cave. Here, the investigation of long-term (seasonally induced) changes and the evaluation of short-term variability have the same priority. The differentiation and quantification of the causes of these changes (natural and anthropogenic) are of equal importance.

First results show that even in so-called static caves or within corresponding parts of cave systems, the term “static“ has to be regarded as wrong with respect to the air currents. No situation where no air movements took place could be proved so far within caves. This observation is in agreement with the results of measurements that are now being conducted in the Czech Republic and Germany.

Moreover, the influence of passing tourist groups on the cave climate could unequivocally be identified and demonstrated. Depending on the location and distance of the measurement location from the stopping points of these groups, different degrees of alteration of all climatic variables could be shown. The modification of the air temperature and the situation of the air currents are partly short-lived, but long-term alterations also could be observed, and conditions only returned to normal after a quiescence period of at least 1 day. Further investigations are needed here to yield new information about the extent and influences that these modifications have on the cave climate.

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SELECTED ABSTRACTS FROM THE 2003 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN PORTERVILLE, CALIFORNIA[1]

BIOLOGY

MOLECULAR PHYLOGENETICS OF CAVE CRAYFISH IN THE GENUS *ORCONECTES*

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The freshwater crayfish genus *Orconectes* comprises ~90 species, including 6 troglobitic species. The cave-adapted species of *Orconectes* are found along the Cumberland Plateau in Alabama, Kentucky, and Tennessee, in the Interior Lowlands of Kentucky and Indiana, and in the Missouri Ozarks. Phylogenetic examination of 75 species of the genus *Orconectes* shows that cave-adapted members are more closely related to the burrowing genus *Cambarus* than to other stream-dwelling species of *Orconectes*. Additionally, it appears that multiple cave invasions by different surface species of *Cambarus* gave rise to the various cave-adapted species of *Orconectes*. One particular *Cambarus* species, *C. tenebrosus*, is a troglophile that occurs in caves with troglobitic *Orconectes*. *C. tenebrosus* appears to be one of the ancestors to the cave-adapted *Orconectes*. *C. tenebrosus*, which can be found in caves, springs, or stream tributaries, is likely a species complex across its range from Indiana south to Alabama. Our findings support previous hypotheses on the evolution of cave *Orconectes* by a series of separate cave invasions by surface species.

CALIFORNIA CAVE BIOGEOGRAPHY

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Cave life is found in carbonate rocks in the coastal ranges, Mojave Desert, Sierra Nevada, Mother Lode region, Marble Mountains area, and the lava beds of northern California. No troglobites are known from sea caves, but they contain interesting marine life. The Mother Lode region, including Tuolumne and Calaveras counties, is comparatively rich in cave-adapted species on a national scale, including one species of mite, 5 *Banksula* harvestmen, 8 pseudoscorpions, 3 *Stygobromus* amphipods, 2 millipedes, and 4 springtails. Blind carabid beetles have been studied in other parts of the state. California caves are relatively poor in Rhaphidophoridae (camel crickets) and other elements common in other karst regions. Many caves have lost their bat colonies (usually the western big-eared bat) and are threatened by land development.

MISSOURI CAVE BIOGEOGRAPHY AND BIODIVERSITY

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The Missouri Biospeleological Database (MBD) was developed to track and analyze Missouri's rich cave fauna. Six partners pool their data, and we currently have 935 species, 1232 localities (caves and springs), and 8640 locality records. About 973 (17%) of 5800 caves have biological records, but only 408 caves (7%) meet minimum criteria for biological evaluation. There are 68 described troglobites, including 32 aquatic species or "stygobites", 15 phreatobites, and 21 terrestrial troglobites. Another 16 troglobites are undescribed or possibly are troglophiles. We know of 147 troglophiles (14 aquatic), 217 trogloxenes (20 aquatic), and 478 species of uncertain status (41 aquatic).

Karst biogeographic regions include the Springfield and Salem plateaus, Ozark River Basins, Perryville Karst, Hannibal Karst, and isolated areas, such as Caney Mountain. Caves east of the Mississippi River often contain a higher diversity of terrestrial troglobites. Troglobites are known from 367 Missouri sites, but 18 troglobites occur at single sites only. Seven possible new troglobites are from single sites. Missouri shares 46 troglobites with other states.

The "Site endemism" (SE) metric and other metrics were used for ranking and comparing caves for conservation planning. Many species and biologically important caves are being added to the Missouri Natural Heritage Database, and I am now able to produce species range maps in Arcview.

A PRELIMINARY POPULATION STUDY OF THE CAVE CRICKET, *HADENOECUS CUMBERLANDICUS* HUBBELL & NORTON, FROM A CAVE IN CARTER COUNTY, KENTUCKY

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The distribution and movement of adult female cave crickets, *Hadenoecus cumberlandicus*, were evaluated in Coon-in-the-Crack Cave I (THC= 212 m) in Carter Caves State Resort Park, Carter County, Kentucky. Crickets of this parthenogenetic population were studied from February to April 2003. Crickets were individually tagged with grid-style patterns using either coral pink or blue phosphorescent paint. Hind femur length was recorded for each individual unless unavailable. After a short "paint-drying period" crickets were released to within 5 m of where originally observed.

Throughout the course of the study, 2378 *H. cumberlandicus* were processed, 1277 of which were observed only (mostly juveniles). Of the 769 tagged, 332 were recaptured, thus the recapture rate was just over 43%. Only 6 crickets were recaptured more than once (2x). Based on movement data of tagged individuals, crickets were fairly mobile within the cave, demonstrating a mean travel distance of 41 m although the greatest number of crickets moved 10-15 m. The Schumacher-Eschmeyer estimate of the population size during the study period was 5508 individuals. Crickets were most dense near areas of ceiling crevices, enlarged fractures, at intersecting passages, or in "bells." The average femur length for this population of *H. cumberlandicus* was 1.89 cm (SD ± 0.23), with a range of 0.9-2.4 cm. Assuming femur length is related to age, the population appears to consist of 3 cohorts. With nearly half the population juveniles, it is likely that the population density is continuing to increase. Numerous crickets autotomized one or both of their hind legs when handled, thus imposing potentially significant restrictions on their movement patterns and distances displaced. Loss of a hind leg(s) likely influenced their ability to exit the cave and to forage in the forest litter. While a night examination of epigean habitats directly above the cave passages was conducted on 17 April, no crickets were observed. This, perhaps, was due to the cool temperatures of the season.

GENETIC STRUCTURE AND HISTORICAL BIOGEOGRAPHY OF STYGOBITE POPULATIONS AS THEY RELATE TO DEVELOPMENT OF HYDROLOGIC SYSTEMS: A CASE STUDY IN THE EDWARDS AQUIFER OF TEXAS & NORTHERN MEXICO

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Gene genealogies are increasingly used to examine patterns of relatedness of populations of stygobites from different cave systems. Recent studies indicate that hydrology, rather than morphology, is dictating these patterns in a variety of organisms examined, including isopods, amphipods and fish. However, hydrology is typically examined only secondarily to explain relatedness, and virtually no studies exist that test the congruence of an *a priori* hydrologic hypothesis with a biological hypothesis. In addition, due to the recent abundance of genetic data and phylogenetic trees, there are newly available techniques to test tree congruence in a biogeographic framework (taking vicariance, dispersal, extinction, and other area-organism phenomena into

[1] The *Journal of Cave and Karst Studies* was unable to publish many of this year's abstracts because the files we received from the Convention's Sessions Committee were incomplete or otherwise unusable. In some cases, we were able to obtain the original abstracts and publish them, but it is quite likely that some otherwise important and qualified abstracts were not published this year or mistakes were included in some published abstracts. We regret the inconvenience this may cause some presenters. (The standards for publication of abstracts were published in v. 59, n. 1, p. 61 issue of the *Journal*.)

account). I am using these tree-matching techniques to test the congruence of a hydrological hypothesis (development of the Edwards Aquifer) with a biological hypothesis (gene trees of 2 aquatic isopods, Cirolanidae: *Cirolanides* and Asellidae: *Lirceolus*). Though analyses are incomplete, the general pattern shows congruence for recent nodes (closely related cave systems) and lack of congruence for historic nodes (cave systems in different segments of the aquifer). A likely explanation for this pattern is that the hydrologic trees are not completely accurate in their representation of the hydrogeologic development of the aquifer. This method shows great promise for studies of modern hydrologic relations, particularly in situations where traditional techniques such as dye tracing fail, as well as historic hydrologic relations that are less studied but are relevant for conservation considerations, such as contaminant transport.

CAN THE BLIND SEE? STUDIES OF VISUAL PIGMENTS IN STYGOBITIC CRUSTACEANS

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One of the most commonly cited examples of troglomorphy is eye loss. However, previous studies of cave-adapted crayfish indicate that while the structural components of the eye degenerate, the visual pigments responsible for light capture remain functional. To determine if this observed functionality is unique to crayfish or a widespread phenomenon, the evolution of the visual pigment gene (opsin) was investigated in several additional hypogean crustacean species, including the shrimp *Antromysis cubanica* (Mysidae, Mysidacea) and the freshwater anomuran crabs *Aegla cavernicola* and *A. leptochela* (Aeglidae, Decapoda).

The *Aegla* cavernicoles exhibit differing degrees of eye degeneration and the most closely related surface species have been determined as *A. strinatii* and *A. marginata*, respectively. Sequenced opsin genes from both cave adapted shrimp and crabs do not show any evidence of loss of function (i.e., no stop codon accumulation or significant sequence differences).

In comparisons of the opsin gene between surface and cave pairs of *Aegla*, the opsin sequences of *A. cavernicola* and *A. strinatti* were identical. In *A. leptochela*, 2 forms of the opsin gene were detected, with the calculated divergences from *A. marginatii* as 0.14% and 9.7%. Although the closest surface relative has not yet been determined, the divergence of *A. cubanica* from the most closely related crustacean opsin is 2.1%.

These results indicate that in cave adapted crustaceans, the conservation of function in the opsin gene is widespread. Further studies will be aimed at determining when and where the opsin gene is expressed in crustaceans.

THE BIOGEOGRAPHY OF THE SUBTERRANEAN INVERTEBRATE FAUNA OF WEST VIRGINIA

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Species richness in a series of adjoining caves in Greenbrier County, West Virginia, was investigated in order to i) estimate biodiversity for this area, ii) determine whether cave size is related to the number of species, and iii) determine how many caves need to be sampled to achieve an accurate estimate of biodiversity. Eighteen subterranean invertebrate species were collected from 65 caves within a 25 km² area. Cave length was correlated with number of species. Few caves were needed to collect many of the species; 7 caves were needed to collect 95% of the species. By sampling only the largest 7 caves, 89% of the species were captured. However, the species accumulation curve did not reach an asymptote and estimations based on species rarity show that half of the species were not collected at all. Therefore, the patterns observed are approached with caution and more data and sampling are needed.

OXYGEN CONSUMPTION/BODY MASS RELATIONSHIPS OF *GAMMARUS ACHERONDYTES* & *G. TROGLOPHILUS* (AMPHIPODA) IN AN ILLINOIS CAVE

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Cave stream faunas typically occur in low densities, with species adapted to low levels of available nutrients. Contamination of cave streams with increased nutrients from surface runoff allows stygophilic species to become more dominant in the stream community, potentially displacing stygobitic species that have lower metabolic rates. In Illinois Caverns, as in several other caves in Illinois' Salem Plateau, *Gammarus troglophilus*, a stygophilic amphipod, co-occurs with the federally endangered *G. acherondytes*, a stygobite. It has been suggested that *G. troglophilus* is displacing or out-competing *G. acherondytes* as a result of nutrient enrichment. To test the hypothesis that *G. troglophilus* has a higher metabolic rate than *G. acherondytes*, we measured the seasonal basal metabolic rates of both species in the laboratory. Slopes of the rate of oxygen consumption versus amphipod body mass differed. The relationship for *G. troglophilus* was steeper than for *G. acherondytes*, indicating that the larger *G. troglophilus* have a higher mass-specific respiration rate than *G. acherondytes*. *Gammarus troglophilus* may have a further competitive advantage because of their larger adult body size, which may facilitate greater reproductive capacity than for *G. acherondytes*. Reversing the current trend of habitat degradation will require a concerted effort on the surface to mitigate land use practices responsible for degradation of cave stream water quality.

CONSERVATION AND MANAGEMENT

BAT COUNTS AND THE FEDERAL DATA QUALITY ACT: *PLECOTUS TOWNSENDII* MATERNITY COLONIES IN AND NEAR MOWICH CAVE, OREGON 1983-2002

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The Federal Data Quality Act was enacted in 2000 to ensure quality of data in federal actions. Bat counts and estimates of maternity colonies of *P. townsendii* at Mowich Cave, Oregon (obtained through 2 FOIA requests) are analyzed in the context of this law. The initial US Forest Service report form for the observation in "Summer 1983" specified an estimate of "40 bats (20 young?)". The subsequently documented birth rate for this bat at Mowich Cave is just under 100% per female per year. Thus, the seasonal 1983 population evidently was about 21 females and 19 young. However, the cited figure and date soon began to diverge from the original to as much as "50+ bats (7-2-84)". Such mis-statements reversed the projected population trend and provided inappropriate support for the controversial gating of this cave in 1992.

A somewhat similar misconstrual was published after 1999 exit counts: Those for July 26 and August 18, respectively, were 23 and 45 "big bats"; the latter clearly reflected 22 newly volants, as expected in August. A report distributed by the Umpqua National Forest (backdated to June 1999), however, attributed this August 1999 increase to re-closure of the gate's inset portal in July 1999. The 2001 season counts were less than half the 1983 baseline, the 2002 data strongly suggest that most of the maternity colony temporarily moved elsewhere to avoid the gate, and no data at all have been supplied for the 2000 maternity season. The Mowich Cave experience indicates that other statements about bat count data for Pacific Northwest caves should be revisited.

THE NATIONAL CAVE AND KARST RESEARCH INSTITUTE: DEFINING ITS ROLE IN CAVE AND KARST MANAGEMENT

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The National Cave and Karst Research Institute's enabling legislation directs it to pursue 6 objectives: 1) further the science of speleology; 2) centralize & standardize speleological information; 3) foster interdisciplinary cooperation in cave and karst research programs; 4) promote public education; 5) promote national and international cooperation in protecting the environment for the benefit of cave & karst landforms; 6) promote & develop environmentally sound & sustainable resource management practices.

All of these mandates relate to the management of caves, but lack a strategy for implementation. Developing such a strategy in consultation with the broad cave and karst community currently constitutes a major focus for the Institute.

While housed within the National Park Service during its current "establishment" phase, the Institute is growing into a broad coalition of government and non-government partners who will address issues affecting all cave and karst resources worldwide. Cave-specific programs and positions within the federal land management agencies mainly focus on issues impacting resources within their stewardship, whereas the Institute will provide a broad umbrella for all groups and individuals working to protect and manage these fragile and challenging terrains.

CAVE AND KARST INVENTORY OF WIND CAVE NATIONAL PARK

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Wind Cave National Park contains over 20 known caves and a variety of karst features including blowholes, sinkholes, shelters, and sinking streams. Wind Cave is the park's primary resource, and, historically, all inventory, survey, and cave management efforts have focused on Wind Cave itself. The other caves and karst features have received limited attention.

At 28,000 acres, the park contains large areas that have never been investigated for caves or karst features. Knowing what caves and karst features exist is vital to their protection and to overall park management. Many of the caves contain paleontological and archeological resources, and one cave is known to be a maternity roost for a sensitive bat species. While 19 of the known caves have been surveyed, none have been thoroughly inventoried. Decisions regarding wildfire management, prescribed fire, backcountry visitor usage, non-native plant control, and maintenance activities could be influenced by information on the park's cave and karst resources.

CAVE RESOURCE INVENTORIES–GOALS AND METHODS: REFLECTIONS ON VIRGIN AND LECHUGUILLA CAVES

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Cave resource inventories are intended to help determine the relationship between resources found and their locations. It is important that inventories: 1) be easily implemented in the field; 2) provide consistent results when practiced by different specialists; 3) not promote the inclusion of wrong data; 4) provide versatile tools for present & future data analysis; 5) not require the identification of features in the field that should be identified in the lab.

Rather, cave inventories should rely on readily made observations and agreed-to visual characteristics with non-impacting field-testing techniques.

The success of any inventory scheme depends on the structure of initial questions. If we ask "where are particular things found?", we are dealing in the "R-Mode". Under each variable we record the stations at which the feature occurs. If we ask "what is found at a particular site?", we are dealing in the "Q-Mode" and different variables are recorded under each locale. Q-Mode data management should be strongly preferred because geologic, chemical, and other variables may be entered as scalar values reflecting abundance, magnitude or significance (e.g., none-extreme, 0-5), etc., and this mode is more easily field-checked.

Additionally, Q-Mode analysis allows recognition of various factors, which account for different amounts and styles of variation in the data sets. These factors may be mapped to help managers recognize areas of potential interest, to ascertain the relationship of factors to bedrock geology, hydrology, etc., and to aid in resource management.

CONSERVATION AND RESTORATION FORUM

A LANDMARK CAVE RESTORATION PROJECT IN WIND CAVE, SD

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Major trail construction work in Wind Cave began in the late 1800s. Additional trail work was done in the 1930s by the CCC and then in the 1950s by the National Park Service. Impacts created by these developments were partially restored during the 1980s and 1990s by volunteers at restoration projects and camps. The first phase of a full-scale cave restoration project was conducted during the winter of 2002-2003 along the Natural Entrance Tour Route. In preparation for this project, the extent and nature of all restoration projects along the developed tour routes were documented, and digital maps were created to assist in directing restoration activities. During the 6-month project, 36 tons of trail construction debris was removed from 0.59 km of that tour route. Before and after photos document the project. All historical artifacts discovered were documented, removed from the cave, and added to the museum collection.

This project refined the cave restoration techniques used in Wind Cave and led to development of better systems to document restoration work, estimate total tonnage of debris collected from along tour routes, and defined the process for completing restoration in the remainder of the developed cave. During the project, what we believe to be the first Cultural Landscape Survey in an NPS cave was conducted by a team of specialists who evaluated the developed portions of Wind Cave. They attempted to determine what the cultural landscapes in the cave are, define the landscapes to be protected, and provide guidance on protection measures.

REDEVELOPMENT OF MUSHPOT CAVE, LAVA BEDS NATIONAL MONUMENT

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Mushpot Cave is a developed cave at the Visitor Center facilities of Lava Beds National Monument. Mushpot receives ~35,000 visitors/yr. The cave has an asphalt pathway with >86 separate light fixtures designed to enhance safe movement and to highlight speleothem features. Significant problems involving the management of Mushpot Cave were identified in 1987 and recommendations for possible solutions were accepted on cave lighting, cave restoration, safety, and cave interpretation.

The Mushpot redevelopment project will provide a better visitor experience by improving the lighting of lava tube features while retaining the interpretive displays already present in the cave. Visitor safety will be enhanced by adding access and emergency lighting, as well as an even, non-slip trail. The cave environment will be protected by removing the asphalt trail and replacing it with a curbed concrete trail that will allow easier removal of lint. Algae growth will be limited by more focused lighting and motion sensors that will provide on-demand lighting.

NPS cave-lighting consultant Rod Horrocks worked with the Lava Beds staff to develop a new lighting system design for Mushpot using a 12-V system similar to those at Mitchell Caverns and Timpanogos Cave. Project work began in April with the removal of the asphalt pathway by the Monument's maintenance crew. The expected completion date is early to mid August 2003.

CULTURAL RESOURCES IN CAVES SYMPOSIUM: IDENTIFICATION, RESEARCH, AND CONSERVATION

CULTURAL RESOURCES IN THE CAVES OF MAURITIUS: AN ARCHAEOLOGICAL & ANTHROPOLOGICAL APPROACH

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The paper summarizes cultural use of lava and karst caves, rock shelters, and overhangs in the islands of Mauritius and Rodrigues in the Indian Ocean. It begins with the different categories studied, emphasizing those that show evidence of human use or occupation. Particular attention is paid to use of caves by slaves who fled plantation oppression between 1642 and 1835, the period of enslavement in Mauritius. The research traces use of lava caves and mountaintop rock shelters by the slaves, discussing micro-settlement patterns, defense strategies, diet, and cultural nuances inferred from artifact and ecofact remains. The archaeological record is matched with the historical record for the region or period in question. We also note recent practices including black magic and sorcery evident in some long lava tunnels. Other uses of caves, including irrigation and as water sources, general recreation, drug abuse, and cold storage are also noted.

IDENTIFICATION & LONG-TERM MANAGEMENT OF CULTURAL RESOURCES IN MAMMOTH CAVE

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Mammoth Cave contains a complex archaeological record of prehistoric exploration and mining, 19th Century nitre mining, and modification for visitor access. Historic portions of the cave also have a rich biotic potential, and the National Park Service would like to enhance the cave environment for various cave-using species. The Park Service attempts to preserve cultural resources in the cave while accommodating tens of thousands of visitors, fielding scientific expeditions, and modifying the environment to promote natural biological processes. A long-term NPS/Earthwatch inventory of cultural resources in Mammoth Cave provides baseline data to monitor impact to the resources from various activities.

Preliminary insights about potential impacts from ongoing use of the cave suggest that policing visitor activity and limiting access to sensitive resources can control most direct visitor impacts. Construction of visitor amenities (trails, lights) has a much greater direct impact, but can be mitigated through archaeological investigations prior to modification, and by avoiding fragile remains. Scientific expeditions, while limited in number, potentially have greater direct impacts because they are unsupervised and scientists may not be cognizant of their own impacts.

Scientific expeditions should be limited to problem-oriented research programs with sensitivity to the full range of vulnerable resources. Structural modification to the cave (airflow, encouraging animal access) has indirect impacts on cultural resources, for which the long-term effects are unknown. Monitoring the cave environment should begin before and continue after modifications are implemented.

SPRINGHOUSES & ROOT CELLARS: HISTORIC FOLK USES OF AMERICAN CAVES

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The historic vernacular uses of caves in the United States include obtaining water from the environment, and storing food and liquids within it. Many caves were subsistence and domestic water sources. Evidence for this activity includes the presence of springhouses, dams, small settling structures, and piping. Caves were similarly utilized as adjuncts to domestic economies to store perishable food items. Moisture-tolerant items like eggs, milk, and cheese were preserved in wetter caves and cave springs, while drier caves or passages served as root cellars for the storage of potatoes, sweet potatoes and other items. Liquids such as cider, whiskey, and wine were also stored underground. Evidence for these uses includes cleared or partitioned spaces, wooden boxes, stone and wooden platforms or shelves, ceramic and glass containers, and doors to protect the foodstuffs from theft.

These folk practices emerged by the end of the 18th Century and continued until the middle of the 20 Century, when the arrival of electricity in rural karst areas led to their gradual demise. Common in the eastern and central U.S., these uses are also known from western caves. Vernacular environmental interactions are seldom mentioned in written sources, but oral history and geographic nomenclature can yield additional insights into these activities. Often though, material culture in caves is the only extant source. The physical evidence is, thus, important and deserving of preservation. Although little studied and underappreciated, folk uses of American caves demonstrate flexible and persistent utilitarian strains in the environmental history of caves.

CULTURAL RESOURCES IN VIRGINIA CAVES

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The cultural resources of Virginia caves include both prehistoric and historic contexts. Important clues to prehistoric use are torch materials and stoke patterns. Distinctive prehistoric lighting materials include cane in the more southerly latitudes, and hickory bark. Prehistoric dark-zone cultural contexts include burial, ceremonial (mud glyph and pictograph), exploration, hunting (hibernating bear), lithic, and mineral extraction. The destruction of Native American cave burial sites continues from a historic pastime to what we now know as a cultural crime. Some caves were used as long-term shelters: For example, a Russell County cave contains a 10,000-yr record of use as a habitation from the Early Archaic to Late Woodland Period.

Historic cultural contexts include evidence of cave use for archival records and self expression (inscriptions on walls), commercialization, dancing and making music, food storage (dairy and root cellar type), mineral extraction and mining (clay, onyx, & saltpetre), moonshine production, paleontological excavation (Edward Drinker Cope's workings in 1867), and water resources. Anecdotal uses include homicide evidence disposal, munitions storage (Civil War), dark-zone shelter (hiding from marauding Native Americans), and weapons disposal (Civil War).

In Virginia, prehistoric and historic cultural resources are protected from destruction or theft by the Cave Protection Act. As cavers we can best serve these cultural resources by reporting observations to appropriate researchers and cultural crimes to law enforcement authorities. Without our stewardship, the future is bleak for these resources.

PREHISTORY? WHAT PREHISTORY? ROCK CLIMBING, ROCK ART, & THE ROAD 18 CAVES

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Between 1993 and 2002, extensive cultural resource documentation was undertaken at several Central Oregon lava tube caves developed for use as rock climbing recreation areas by local climbers. User surveys, cave mapping projects, and computer enhancement of faint prehistoric pictographs were successfully utilized to obtain enforcement of federal protection statutes at these archaeological sites. Preservation efforts at the Road 18 Caves were actively opposed by regional climbing-related businesses and national climbing advocacy organizations. Facing a decline in available funds for archaeological site preservation and recreation management, Forest Service and Bureau of Land Management offices sought and ultimately achieved a balanced management approach in the context of problematic local recreation politics.

Documentation is merely the first step in a successful conservation project. Presentation format and timing are crucial factors in the development of cave management tools to be utilized by federal agencies.

IMAGES IN DARKNESS: AN OVERVIEW OF PREHISTORIC CAVE ART IN THE SOUTHEAST

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Over the past several decades, 40 dark-zone prehistoric cave art sites have been identified in the eastern woodlands region of North America. These archaeological sites span four thousand years of prehistory and were produced by a sequence of cultures beginning with Archaic-period hunter/foragers and ending with Mississippian maize agricultural chiefdoms. We examine the environmental and cultural contexts of these sites, seeking common characteristics that allow archaeologists to predict their location and thereby manage them. Site location is considered in light of bedrock geomorphology, elevation, availability of critical resources like water, and endokarst formation and structure.

CIVIL WAR INSCRIPTIONS IN CAVES

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Caves were utilized during the Civil War to an extent never before seen in the United States. Consequently, graffiti were generated in numerous caves throughout the limestone regions of the Confederacy and Border States. Some caves were used as hiding places by guerillas, robbers, refugees, Union army recruiters, and escaped prisoners of war, or as sites to secrete supplies or valuables. Many other caves were mined for saltpeter by either the Confederate Nitre Bureau or by individual contractors, and dozens of caves were toured for recreational purposes by military personnel of both sides. The study of graffiti is very important in correlating caves with specific Confederate government or contractor saltpeter mining operations. Soldier names, already found in 31 caves, may exist in nearly double that number. Civil War cave scratchings, when placed in context with traditional sources, enhance knowledge about the Confederate Mining Bureau and supplement data given in regimental or other histories, diaries, memoirs, or official reports. Cave writings often reflect information recorded nowhere else. Therefore, they should be considered documents in their own right and worthy of preservation.

PRESERVATION OF PREHISTORIC FOOTPRINTS IN JAGUAR CAVE, TENNESSEE

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Approximately 4500 years ago, a group of prehistoric cavers negotiated a complicated cave and discovered a passage nearly 2 hours' journey from the cave's entrance. They walked toward the back of the dead-end passage, turned around and exited the way they entered, leaving footprints and torch material behind them. These are among the earliest evidence of cave exploration in the Midsouth.

Nearly 300 relatively complete footprints remained in moist mud and wet sands when the passage was rediscovered ~25 yr ago. This fragility makes the prints' preservation remarkable but vulnerable to destruction.

The modification of the prints began even as they were being made. As prehistoric cavers followed the members of their own group, they were literally walking in the footsteps of their predecessors, modifying and altering the prints as they left their own. Following the prehistoric human activities, natural processes affected the prints. When the footprints were rediscovered late last century, their destruction accelerated; modern cavers trod over the prehistoric prints. They were also altered during efforts to document the prints archaeologically, especially when a few prints were cast.

The gating of the cave several years ago offers hope that the prints will be better protected now than during the previous several decades and their

destruction slowed. By understanding the modifications, steps can be taken to protect these rare and fragile remains and we can continue to marvel at the material evidence of prehistoric cave exploration.

EXPLORATION: CALIFORNIA CAVES & CAVING

THE HISTORY OF THE EXPLORATION OF CALIFORNIA'S SHOW CAVES

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The discovery of gold near Sutter Creek in 1848 triggered the famous Gold Rush which brought ~100,000 hopefuls to the Golden State. Within 12 years they had panned, sluiced, dug and blasted $550 million worth of gold from The Mother Lode area. In the process, many caves were found. Prospectors discovered California Cavern and Bower Cave in 1850, Moaning Cavern in 1851, Black Chasm in 1854, Masonic Cave in 1857, Natural Bridges in 1872, and Mercer Caverns in 1885.

The huge influx of immigrants clashed with Native American Indians, especially in Northern California, resulting in more discoveries. Kok-Chee-Shup-Chee or Natural Bridge Cave was found in 1852, Plutos was found in 1863, Lava Beds opened up in 1873, Lake Shasta Caverns in 1877, and Subway Cave around 1884.

In Southern California, Mitchell Caverns was found by silver miners in the 1860s and Boyden Cavern was found in about 1888 by loggers. These discoveries were documented by prolific Victorian writers, the most famous of which was John Muir who visited Bower, Cave City, Plutos, and Lava Beds. Most caves that are now show caves were commercialized in the 20th Century, many during The Great Depression.

EXPLORATION OF LILBURN CAVE

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In 1980, the Cave Research Foundation undertook a re-survey of Lilburn Cave, which at the time had a surveyed length of 12.6 km. The new survey revealed additional detail in many of the known areas, as well as entirely new sections, such as Southern Comfort, the 1 by 10 Complex, the Outback, the Opera House, Canyonlands, Area of Low Hanging Fruit, Hog Heaven, and many others. Systematic exploration was aided by the development of a detailed set of quadrangle maps of this 3-dimensional maze cave, whose surveyed length now exceeds 32 km.

TAKE IT FOR GRANITE: A SPORTING NEW GRANITE CAVE SYSTEM

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The Sierra Nevada is home to many caves formed in granite, many of them unsurveyed and largely unknown to cavers. TIFG is a high-elevation, multi-entrance cave in a drainage of the Dardanelles, a large lava-capped plateau in the Carson-Iceberg Wilderness. Piracy of a surface stream into its bed has produced a large canyon passage broken by 4 waterfalls requiring rope to descend. A lower section with a steep gradient is all climbable. Corrasional speleogens, potholes, waterfalls, and chutes characterize the passage. A survey is underway but has been hampered by the short season in which this cave can be visited.

IXL CAVE RETROSPECTIVE–FIFTY YEARS OF USE & ABUSE

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In late 1953, William Miles and caver friends of the IXL Club found cold air blowing from a grapefruit-sized opening in marble west of Santa Cruz, CA, and dug open IXL Cave. Initial exploration and excavation by the conservation-minded youths revealed ~155 m of passage, much of it crawlways. At year's end in 1966, NSS cavers digging for a second entrance revealed, instead, a pit complex dropping nearly 30 m.

Mapping has shown the cave is ~610 m long. The cave was once famous for its heavily decorated as well as size-challenging passages. However, being near a vacation-oriented seacoast town and adjacent to a University of California campus, the cave was, and still is, heavily visited by local youths as a "rite of passage". In addition, in early 1954 two newspaper articles reported the cave's discovery, and a subsequent rescue of portly "Sunday afternoon" cavers several months later unduly publicized the cave on a regional level.

As a result, the cave suffered significant damage from vandalism and carelessness. By the late 1970s, vandalism was directed at removing "magical crystals." By the mid-1980s the cave was gutted of its formerly outstanding decorations. In 1997, the cave was obtained as an addition to Wilder Ranch California State Park and efforts at management are being undertaken. Recently, photographs taken within a few weeks of its discovery were located. These allow comparison of the former beauty of IXL Cave with its present condition. Once again, the lack of responsible ownership and lack of a management plan have essentially destroyed a once beautiful cave.

BENEATH THE DESERT: CAVES OF THE MOJAVE & THE MOJAVE CAVE PROJECT

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The Mojave Desert is a vast expanse encompassing roughly 40,000 km^2, including much of southeastern California and portions of Nevada, Utah, and Arizona. Though not normally associated with caves and karst, California's Mojave includes major carbonate areas and some of the better-known caves in the state, including Cave of the Winding Stair, Mitchell Caverns, Kokoweef Cave, and others. The California Mojave also includes a wide variety of cave types with significant pseudokarst, granite, and lava caves. The Mojave National Preserve was established in 1994. In 2001, the Mojave Cave Survey (MCS), an informal project of the Southern California Grotto, was established to assist in the inventory and survey of caves within the preserve and surrounding areas. Recent work by the MCS has included compilation of historical data and the discovery and mapping of several limestone caves as well as numerous pseudokarst caves.

EXPLORATION: CAVE DIVING

THE QUINTANA ROO SPELEOLOGICAL SURVEY: RECENT ADVANCES IN UNDERWATER CAVE EXPLORATION IN QUINTANA ROO, MEXICO

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The Quintana Roo Speleological Survey (QRSS) supports conservation, safe exploration and survey documentation of the underwater caves in Quintana Roo, Mexico. The present study area incorporates 300 km^2 in eastern Quintana Roo, including 91 independent underwater caves (431 km of surveyed underwater passage). Over 100 collaborators have contributed raw survey data to the database, establishing one of the largest archives of underwater survey data in the world. A database of 230 GPS locations for underwater karst formations, and 74 km of land survey provide surface control points for an emerging regional analysis of cave relationships. Computer software converts raw cave survey data into georeferenced coordinates. Additional software manages GPS data, while calibrating topographic maps and aerial photographs.

EXPLORATION: CAVE RESCUE

A METHOD FOR TURNING A LOADED ROPE INTO A 3:1 HAUL SYSTEM

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The 3:1 system is considered one of the basic systems for rescue. Unfortunately, it can only be rigged when it is not under load. Most cavers do not carry an extra piece of rope for a haul system, so are in a quandary when an individual gets stuck on rope and needs to be hauled up. Use of a "long tail" progress capture device (PCD) allows the rescuer to transfer the weight of the loaded rope off the main anchor knot. The rope can then be re-rigged into a 3:1 haul system with its own PCD. The physical properties of the long tail PCD allow the load to be naturally transferred to the 3:1 PCD after the rescuers make the first haul. As this method uses minimal equipment and manpower, it has an excellent application for self rescue.

EXPLORATION: COMMUNICATIONS & ELECTRONICS

THRU-THE-EARTH 2-WAY VOICE COMMUNICATION WITH CAVE DIVERS

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Commercial acoustic voice communications equipment, used by divers to talk to the surface, can be easily converted into thru-the-earth radios. For this project, 2 units manufactured by Ocean Technology Systems were converted, then used for diver-to-surface voice communications in underwater Florida caves. These 32.768 kHz USB units had ~2 Watts output. This frequency was suitable for the water-saturated limestone with its conductivity of ~.02 S/m.

The conversion involved replacing the acoustic transducers with antennas and filter/matching networks. The surface antenna was a 1-m² resonant vertical loop matched to the STX-100 surface unit. The diver's antenna was a 7.6 m "earth current" trailing wire antenna. The wire impedance was ~80 Ohms in typical Florida Springs with s = .028 S/m. This was matched to the SSB-2010 diver unit, which used a full-face mask containing a microphone, earphones, and a PTT switch.

Both antennas had simple LC filters for improved RF interference rejection. This equipment was used to maintain continuous 2-way voice communication while divers explored 3 different systems at depths to 60 m. Separate 3496 Hz gear was used for tracking. At Hart Springs, divers were directed under surface features while they reported depths and their track was marked on the surface. The surface track was surveyed in 3 dimensions, in effect mapping the cave from the surface. This simple voice link has many applications.

EXPLORATION: INTERNATIONAL EXPLORATION

RECENT EXPLORATIONS IN CUEVA DEL TECOLOTE, TAMAULIPAS, MEXICO

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Cueva del Tecolote is a major cave system located within the Proyecto Espeleologico Purificacion karst study area. Explorations since 1999 have pushed the total length of the cave over 40 km. The 1999 expedition discovered significant passages in the Jellybean Junction area of the cave and a major new route between the Gargoyle Gallery and the Chihue Freeway. The 2001 Expedition added the 7 of 9 Borehole and the March 2003 expedition added almost 4 km of new survey in many areas of the cave. ArcPAD GIS software was used on a handheld computer (in cave) to manage the >100 leads for the 2003 expedition. Many leads remain to be pushed in the cave and there is a renewed interest in pushing other caves in the area.

PROYECTO CERRO RABÓN 2003

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

Systematic speleological research on a bi-annual basis began in 1985. This heavily karstified uplift of limestone has since yielded hundreds of kilometers of caves. The Kijahe Xontjoa system has been pushed to a depth of –1223 m, well below one of its speculated resurgences, the Nacimiento del Río Uruapan. An unexplored region to the south named the upper Uruapan Valley is thought to be part of the catchment area for the Río Uruapan. Its rather large high flow rate of 20m³/sec may be an indication of a large and deep cave system.

In February 2003, a team of 12 cavers from America, led by Cerro Rabón veteran Mike Frazier, ventured into the upper Uruapan Valley to search for insurgences to the Río Uruapan. One cave was mapped from previous year's reconnaissance and the team retreated with valuable knowledge to assist further expeditions into the area.

EXPLORATION IN SUPPORT OF WORLD HERITAGE STATUS FOR CAVES IN WESTERN EUROPE

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Several recent proposals to the UNESCO World Heritage Commission include some of the most significant caves of southern France and the karst area of the Swiss Jura. Several sites are proposed as a single group due to their unique speleothems and spectacular mineralization despite being scattered over a distance of several hundred kilometers. The Sheatenflu site is listed as a proposed international biosphere preserve. The World Heritage designation offers the cavers a powerful tool for preservation and protection of these sites, but has considerable requirements, including the mapping or re-mapping of known cave passages, exploration and documentation of entire zones of cave development, and scientific study and documentation of each site. The exploration in both some well-known and tourist caves as well in as previously "secret" caves has been productive, and is well underway with participants from several countries. The projects are generally well supported by cavers, but are not without controversy.

THE 2003 ATACAMA HALITE KARST EXPEDITION, NORTHERN CHILE

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The Cordillera de la Sal lies at 2800 m msl in the foothills of the Andes. This 130+ km long series of ridges is composed of a series of siltstones, gypsum, and halites, which has been folded and faulted. The salt terrain has been carved into a bizarre landscape with prominent hoodoos. A brief reconnaissance trip in 2002 indicated the presence of unusual caves in the salt beds that warranted a focused effort at mapping and study. The 2003 project team included 6 cavers to focus on the exploration and mapping of caves and to determine the general potential for cave development in the salt karst. Dozens of entrances and 6 main caves were located in the halite beds near San Pedro de Atacama, an oasis town at the edge of the world's driest desert. In the Valle de la Luna area, the conditions of relatively pure halite units and rare rainfall allowed the development of impressive caves. These caves contain some spectacular secondary mineral deposits and passages range from relatively large to crawls, squeezes, and climbs. The density of caves and extent of karst indicates potential for more exploration. The caves are fairly similar to carbonate rock caves, but the walls are transparent and quite edible!

SIMA PUMACOCHA, PERU

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The lack of long or deep caves in the world's highest mountain ranges led some cavers to believe that high-elevation karsts are incapable of significant cave development. But cavers from Canada, Britain and Peru challenged this assumption in Sima Pumacocha, a newly-discovered cave located high in the Andes of central Peru. Explorations in 2001and 2002 pushed and mapped this vertical cave down dry shafts and waterfalls to a sump at -638 m, making Sima Pumacocha the deepest cave in South America. With an entrance elevation of 4375 m msl, it may be the highest significant cave in the world.

CUEVA CHARCO: 3RD DEEPEST CAVE IN MEXICO

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Cueva Charco is located in the state of Oaxaca, in southern Mexico. The cave was first looked at by cavers in 1989, and exhibited potential as a pathway into the downstream portion of Sistema Cheve. However, further exploration showed that the cave parallels the projected trend of Cheve, but drops at a steeper angle towards the groundwater level. A team of cavers set 2 underground camps in 2003 to reach the end of the cave. After kilometers of narrow, tortuous passage, the cavers encountered 300 m of borehole, and then a terminal sump. One significant side lead was pushed almost 400 m before the passage became too tight to follow. With all the data tallied, Cueva Charco is 1278 m deep and 6.71 km long.

MILLIONS OF CAVE PEARLS & OTHER CAVING ADVENTURES IN TABASCO, MEXICO

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Further explorations in Tabasco, Mexico, have uncovered additional caves near Teapa and Arcadio Zentilla in the Sierra Madrigal, Palo Quemado on Cerro Blanco, and in the Sierra Poana. Notable among recent discoveries is Gruta de las Canicas, containing perhaps the largest concentration of cave pearls yet discovered in a single cave (estimated to be between 20-200 million cave pearls), the large passages of Solidad, and the high elevation caves near Palo Quemado. Mexican cavers from Villahermosa continue their explorations of Agua Blanca in the Municipio de Macuspana.

2002-2003 JOINT RESEARCH EXPEDITIONS TO THE MARIANA ISLANDS: AGUIJAN, ROTA, & TINIAN

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A joint research program between Mississippi State University and the Water and Environmental Research Institute of the Western Pacific conducted 3 expeditions to the Mariana Islands between June 2002 and June 2003. The

expeditions focused on the islands of Aguijan, Rota, and Tinian with individuals from Guam, Japan, Mississippi, and Texas participating. Fieldwork has yielded various cave types, including: flank margin, banana hole, fissure, pit, recharge, and discharge.

The Summer 2002 expedition (12 June 2002 - 4 July 2002) was a reconnaissance of Rota and Tinian by 7 individuals who established relationships with local governments and communities, while locating primary regions of cave development. The Winter 2002 expedition (10 December 2002 - 8 January 2003), which was primarily conducted by a 2-man team, focused on features of Tinian and Aguijan yielding 5188 m of survey. The Summer 2003 expedition (3 May 2003 - 17 June 2003) involved 11 members who continued surveys on Tinian and Aguijan and began surveys on Rota.

Logistical strategies varied with the islands investigated and the time of year: Coastal surveys were strongly controlled by sea conditions and tidal fluctuations, inland surveys relied heavily upon local guides due to dense vegetation, and access to the uninhabited island of Aguijan required the support of local government bodies. Additionally, these islands contain an extensive archeological record, including prehistoric Chamorro sites and historic WWII sites. Numerous cave and karst features show evidence of Japanese occupation during WWII, including military modification, artifacts, and occasional unexploded ordnance.

2003 Sistema Cheve expedition

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A 10-week expedition was fielded to Cueva Cheve (Oaxaca, Mexico) in the spring of 2003 in an effort to extend the bottom of the cave (previously -1386 m deep, 22 m underwater in the "terminal" sump). Efforts in 2003 focused on a return to the sump using rebreathers and a series of bolt climbs into the high canyon leading to the sump. A route around the underwater restriction that halted the 1991 reconnaissance dive at the Cheve sump was discovered and the sump was passed within 140 m at shallow depth. A significant stream canyon extension was discovered beyond which rapidly dropped in depth before a second sump was reached at -1472 m. A 4-person dive team ferried gear to the second sump and a 2-person recon team passed the 280-m-long underwater tunnel, surfacing in a 15-m-diameter borehole. Unfortunately, the tunnel was blocked by a breakdown collapse just 50 m further, at a point 9.3 km from the nearest entrance and a depth of -1484 m. Two km of new tunnels were discovered in 2003, including 700 m mapped in high level leads above the Wet Dreams canyon.

The Mayan Maze of Actun Kaua

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Actun Kaua is located under the town of Kaua in Yucatan, Mexico. In 1972, David McKenzie became the first caver to enter the cave. He found it an incredibly complex maze and, with James Reddell, mapped ~6.8 km of passage by 1975. The survey languished for over 2 decades with little new accomplished. In December 2001, January 2002, and January 2003, the project was reactivated, adding 3.8 km of survey into what may be perhaps the densest concentration of passages recorded in the world at ~1 km/100 m². It is often difficult to say where the series of closely spaced cave passages ends and broad rooms filled with bedrock pillars begin. Many cave walls are covered with primitive clay drawings. Some areas have been significantly enlarged by mining the clay for unknown purposes, probably during pre-Columbian times. Many questions remain about the cave's full extent, the reason for its radically different development compared to most other caves, including those within 3-5 km, and if the part currently known is only a branch of a far more extensive complex.

Caves Of India continue to surprise: December 2002 US Expedition to Meghalaya

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During December of 2002, 10 American cavers spent 3 weeks in the northeastern state of Meghalaya, India, for the purpose of cave exploration. This was the first caving expedition organized by Americans in India. The team was working closely with several Indian cavers and one caver from the UK. Ten caves were explored in the West Khasi Hills on the Iaw-Paw Plateau near Nongnah (the Langrin area). The peculiar feature of these caves is their formation in calcareous sandstones. The longest cave examined, Krem Maw Tynhiang, was explored and surveyed to 3167 m in length with no end in sight. Total survey of the 10 caves yielded 6600 m. The caves are also fascinating due to their unique fauna characterized by an abundance of bats (including horseshoe bat), hand-sized spiders (*Hetrapoda robusta*) and cave-dwelling snakes, tentatively identified as genus *Elaphe*. Additionally, 2 blind pits in rather pure limestone were investigated in Wahlong, East Khasi Hills (the Shella area) with depths estimated at 20 & 60 m. In conjunction with cave survey, GPS, photographic, and geologic data were collected during our visit. Certain aspects of our work are available for viewing at:

http://www.deepcaves.net/India02/india02.htm.

In summary, Meghalayan karst once again has proven to offer extraordinary diversity for speleological endeavors.

Exploration: Survey & cartography

Update on 3D mapping of a portion of Laurel Caverns, Pennsylvania

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In June 2002 a portion of Laurel Caverns, PA, was scanned with a DeltaSphere-3000 device built by 3rdTech, Inc. in Chapel Hill, NC. It is a scanning, time-of-flight laser rangefinder that takes up to 20,000 measurements/sec. The laser is directed around the environment with mirrors and motors, capturing 360° panoramas that have a 150° vertical span at a resolution of about 13 samples per degree (in each direction). The laser measures distances to the first surface it hits, up to about 15 m away, with an accuracy of ~8 mm. To overcome occlusions or shadows, range scans are taken from multiple locations. Sufficient overlap between scans allows them to be aligned with one another during post-processing.

For each range scan, there is also a color panorama acquired with a Kodak Professional Digital Camera. A wide-angle lens is used, providing sufficient color imagery at a resolution that is close to that of the range scan. Average time for a scan is ~30'. To complete the work, we spent 6.5 hrs scanning from 9 locations.

Post-processing has involved several steps. The color images are fused together with the range data, coloring each range sample. We use the Polyworks software tools from Innovmetric coupled with some of our own custom tools.

Compass/inclinometer using laser pointer for cave surveying

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A new device has been developed that incorporates a small laser to make compass and inclinometer use easier. The laser is used as a pointer, not as a distance measurement device. The device is a 2-piece folding unit with a laser pointer and inclinometer on the front piece and the compass on the back piece.

To use the compass, the rear half of the device is approximately leveled with the back at the "from" station, and the front half tilted so that the laser points as the "to" point. The vertical plane containing the survey points also contains the line of laser light and the axis of the compass. The compass is read in the usual manner. A telescoping extension is useful when the "from" station is on the ceiling of a passage. To read inclination, the hinge of the device is held on the "from" survey station, and the laser is pointed at the "to" survey station. The inclinometer is read in the normal manner. Two types of inclinometers were tested, an electronic version and a mechanical version. Both can be used without looking at them, and hold their readings once they are set.

The device is ~15 cm long when folded and ~5 cm in "diameter". The device has been used in cave surveys and has performed well. The device has been tested around a 4-sided loop, and backward and forward loops have closed with ~1° of average error horizontally and 0.3° vertically.

Cartography of Lilburn Cave

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Lilburn is a 32-km-long, 3-D maze cave that presents interesting cartography challenges. This has led to the development of a multi-level quadrangle system. Approximately 90 quadrangle maps are needed to cover the entire cave. For convenience in reproduction and in-cave use, the text and level of detail are sized for 11" by 17" format, but can also be used in 8.5" by 11" format. Up to 4 vertical slices are made for each plan view. The slices are selected on a station-by-station basis for the best clarity, rather than strictly by ele-

vation. A special code for each station is used by a custom plot program to decide which level(s) a given station is to be plotted on. Typically, 3-5 stations of overlap are used at level transitions. Each transition is given a number, and prefixed by "U" or "D" to tell the reader whether to look "up" or "down" a level for the corresponding number. A program was written on a Mac to make the line plot and borders given the code for a given quadrangle. The cave passage and details are drawn in Canvas or Illustrator. This makes it much easier to make changes than using pen and ink. Additional maps to visualize the overall cave have been made with custom software, including stereo 35-mm slide pairs.

REGIONAL STUDIES FOR UNDERWATER CAVES IN QUINTANA ROO, MEXICO

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Underwater cave survey techniques integrated with the Global Positioning System (GPS) disclose underground drainage configurations and cave relationships in eastern Quintana Roo, Mexico. The present study area incorporates 6300 km². Garmin II+ and Garmin V GPS receivers, calibrated for civilian applications, verified entrance coordinates at independent underwater cave systems. With Selective Availability disabled, a 12-channel receiver reports a 3-9 m Estimated Position Error at coordinate collection locations. Correlating distant cave systems by conventional land surveys in the indigenous jungle environment is problematic; those surveys exceeding 1.5 km encourage GPS applications. A database of 230 GPS locations for underwater karst formations, and 74 km of land survey provide surface control points for the regional analysis.

Safety and environmental issues require underwater cave explorers to amend traditional cave surveying methods. A permanent guideline, knotted at fixed intervals, is positioned in new passage during initial exploration. Survey data are collected on the exit utilizing a depth gauge and compass, while knotted segments of the guideline are tallied between survey stations. Eleven underwater caves in Quintana Roo are surveyed by more accurate methods. Taped survey lengths, compass backsights, and measuring passage attributes are means used to create these maps.

THE EFFECTS OF LAVA ON COMPASS READINGS

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Cavers mapping lava tubes know well that compass readings are not always what they should be. This is, many times, incorrectly attributed to the attraction of the magnetized compass needle to magnetic material (magnetite) contained in lava. However, the main causes of unwanted needle deflections are due to distortion of the magnetic field because: 1) a property of magnetic material called susceptibility and; 2) magnetization of magnetite from lightning strikes.

Knowing how these effects arise and their characteristics may aid the mapper in achieving better readings. Fore- and back-sights cannot correct for readings caused by distortion of the earth's magnetic field.

DJVU MAP ENCODING FOR DISPLAY ON THE WEB

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Using DJVU encoding has given the Raders Valley Project the ability to communicate visually to project participants using highly zoomable, crisp, small file size images of current working maps. Further information such as "zoom startup" and embedded hyperlinks in the image further the usefulness of this technology. To begin the process, cave project participants must download a small browser plug-in that will allow the embedded images to be loaded via their web browser. Then maps both working and complete can either be scanned or opened in the DJVU editor and encoded for display on the web. Using the zoom tools in the browser, the project participant can now zoom in to specific areas with very little loss of detail to focus on areas of interest within the survey. This technology opens the door to sharing maps with incredible detail and a small file size via the web.

MORPHING DIGITAL WORKING SKETCHES TO LINE/WALL PLOTS USING MANIFOLD 5.5

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Registering and morphing a rough digital working sketch to a line plot only accomplishes part of the complex process needed to accurately trace a final digital cave map. To fully accomplish a digitally "traceable" bottom layer requires that the passage walls from section to section match up and further that the left and right points at each station are registered and morphed along with the sketch to the line plot points. I have developed such a workflow process using Manifold 5.5. First, working sketches are scanned and then opened in Manifold. A separate lineplot image with tics for left/right is then opened in the same project and control points placed on both images at spots corresponding to survey stations, left/right points and wall segment joining points. Using a geo-registering method that Manifold calls "Affine", the rough sketch is then morphed onto the line plot and the assembly begins piece by piece. The final result is a fully aligned and digitally traceable cave map layer. Experience has shown that proper order in placing the control points results in consistent and highly accurate results.

EXPLORATION: US EXPLORATION

WIND CAVE: 100 MILES AND BEYOND

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The survey of Wind Cave (Wind Cave National Park, SD) grew from 150.8 to 171.2 km in 2001 and 2002. This moved the cave from 8th to 6th on the world's longest caves list. Achievement of the 161-km mark happened in August 2001. Exploration was accomplished by Park personnel as well as volunteers, including cavers from Colorado's Wind Cave Project. Trip leaders focused on a variety of areas in the cave. Exploration occurred in the Club Room, Colorado Grotto, Halfmile Hall, Historic, North, and Southern Comfort sections. The pace of exploration has been impressive: 12.1 and 8.3 km were mapped in 2001 and 2002, respectively.

Cavers pushed the edges of the map and these efforts met with some success. Overall, however, the known boundaries of the cave changed little. Many of the 20.4 km discovered were in the interior of the map. An example is the Kneebone area, originally discovered in 2000. This area has yielded >3.6 km of passage and filled in a significant void in the map. Numerous smaller discoveries included geologic features, historic artifacts, water inlets, and a near-connection with the surface. The keys to success have been systematic checking of leads. Many miles remain to be explored, and it is difficult to predict where they will be found.

EXPLORATION OF THE KIPUKA KANOHINA CAVE SYSTEM, HAWAII CO, HAWAII

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South Point on the Big Island of Hawaii is aptly named, because it forms the southernmost point of land in the United States. A prehistoric pahoehoe lava flow named the Kipuka Kanohina is just a few miles north of this windswept peninsula. Exploration and survey within this geologic unit has revealed one of the longest and most complex basalt cave systems known to the world. To date, 25.52 km of survey has been accumulated. More than 40 open leads remain to be explored.

EXPLORING EASTERN KENTUCKY'S COAL TRACE CAVE

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Coal Trace Cave was found by Art Petit in the late 1990s in Wayne County, KY. The cave lies above a spring that flushes coal (presumably from nearby strip mines) during large floods. Coal Trace features large passages, a prominent stream, strong airflow, and very tight breakdown chokes. An effort to survey the cave led to the discovery of the Catron Chamber (named for the landowner), which at its largest is 52 m wide and 27 m tall. Although this section of the cave was touted as the largest cave room in Kentucky in numerous newspaper articles around the country in 2000 and 2001, the area is really a large borehole. Currently the cave has been surveyed to a length of 2.4 km, several very good leads remain, and a connection to nearby Barefoot Saltpetre Cave is possible.

EXPLORATION IN CARROLL CAVE, MISSOURI

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Carroll Cave has been closed by the landowner for over 15 years. With >19 km of surveyed passage and at least 100 known but unsurveyed side passages, Carroll Cave is one of Missouri's most significant caves. In December 1999, an attempt to dig into the cave through a nearby sinkhole was abandoned after 5 years of work due to safety concerns. In November 2000, a 23-cm well shaft was drilled from the surface into the cave. Mostly with the help of explosives, this shaft was expanded to 91 cm., reopening the cave in July 2002.

HYDROGEOLOGIC INVESTIGATION OF THE CARROLL CAVE AREA, CAMDEN COUNTY, MISSOURI

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A multidisciplinary approach is currently being used to characterize the Carroll Cave System. Mapping of surface karst and geologic and hydrologic studies in Carroll is helping direct current exploration and surveying efforts. The examination of rock samples and 9 thin-sections from the new entrance borehole of Carroll places the majority of cave in the lower Ordovician Gasconade Formation. Cavern development has been strongly influenced by structural deformation of strata. Groundwater flow follows dip of geologic structure in the Upper Thunder River and Carroll River passageways, but trends along strike of geologic structure in the lower Thunder River passage. Analysis of groundwater samples taken from various locations in the cave indicate a change in dissolved mineral saturations that may help explain the cave's development. Inorganic water quality of the cave is excellent. Flow and chemical analysis of groundwater points to extensive, unentered portions of cave. Overburden and sinkhole location maps are used to infer possible boundaries and extensions of the cave system. A surface temperature survey and characterization of a sinkhole collapse has led to an interpretation of a significant extension of the cave towards Barnett Hollow ~2000 m west of Carroll passageways. Several sinkhole valleys filled with alluvial gravels, that may support recharge to Toronto Springs, have been identified. The validation of computer geologic mapping is currently ongoing with 30 sinkholes out of hundreds field-located and photographed.

EXPLORING HYPERTHERMAL CAVES IN KILAUEA CALDERA, HAWAIII

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Under National Park Service permit, members of the Hawaii Speleological Survey have been locating, exploring, mapping, and inventorying caves in Kilauea Caldera since 1989. Almost 200 lava rise, lava tube, hollow tumulus and other caves have been identified in the 1919 "Postal Rift" Lava Flow. Many are hyperthermal; a few even exceed the 70°C maximum of our digital read-out thermometers. Limiting factors in exploration are temperature, humidity (steam) and subsurface winds, and fumes. Fumes are a problem only in 2 very small caves adjoining a fumarole field; elsewhere the fumes have a pleasant taste and seem to be benign. Hot and cool swirls and currents of air change quickly with changes in surficial wind direction and velocity. Thus, one-minute escape routes are maintained at all times. Thermostratification commonly is marked, with crawling necessary in some caves. Different individuals have slightly different tolerances to hyperthermia in the presence of 100% relative humidity. Empirically developed guidelines for exposures up to 52°C provide a small margin of safety for young, healthy cavers. Steam temperatures vary considerably, and the mere presence of steam no longer is considered a limitation. Personal sublingual thermometers reveal whether extensive rest and replacement of fluids and electrolytes are needed after exiting.

RECENT EXPLORATION IN LECHUGUILLA CAVE

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Lechuguilla Cave was reopened for exploration after a new airlocked entrance was completed in mid-2001. Cavers focused on cleaning up old surveys that had loops with poor closure or did not have reverse shots to catch blunders originally. Re-examination of crawls, climbs, pits, breakdown, and boneyard holes that were passed up or missed by earlier surveyors yielded new passage. Results of recent expeditions have extended the cave length to >175 km of total passage.

DIGGING & THE CAVES OF RADERS VALLEY

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A single well known blowhole was the area's major indicator that something great lay below, but until recently not much else was known about the caves, geology, and hydrology of this magnificent dry valley in West Virginia. Now through various means of digging and micro-shaving/muzzmining many caves including Caves.com Cave, Zicafoose Blowhole, Deels Hole, Bobcat Blowhole, Middle Earth and Freelanders Well are in the process of uncovering and revealing the incredible beauty of some of this area. The project has become a model for using technology to communicate and visually represent data online so project members can quickly determine where to continue exploration both above and below ground. Exploration above ground has been accelerated by the use of a GIS system called Manifold 5.5, which has been adapted to "register" rough working sketches to the actual line and wall plots and to georegister relevant DEM's, aerial photographs, and topo maps for online display.

CAVING IN THE MAMMOTH AREA OF YELLOWSTONE NATIONAL PARK, WY

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Several caves, including McCartneys Cave, Jeweled Cave, Devils Kitchen and AJs Chasm were explored and mapped during an expedition to Yellowstone National Park's Mammoth Hot Springs area in November 1999. Several of the caves were very warm (50+°C) and toxic levels of CO_2 necessitated the use of SCBAs to explore beyond some of the caves' entrances. Caves were noted to have formed in laminated, hydrothermal travertine; and microbial activity was recorded in hydrothermal pools in the caves.

JEWEL CAVE EXPLORATION

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Jewel Cave's barometric airflow has been a valuable tool for discovering new passages. In late 1991, a strong breeze encouraged the excavation of The Stopper, leading to the discovery of nearly 48 km in just 6 years–including larger rooms and passages than any previously known. Today, this breakthrough is less than halfway to the end of the cave.

For 30 years, exploration trips had always been done in a single long day. But with trip times approaching 20 hrs and round trip distances nearing 16 km, it became necessary to establish a single permanent camp in 1997 to facilitate continued exploration of the farthest reaches. Since then, 4-day trips–limited only by the amount of urine that can be carried out–have become common.

Strong breezes led to a second breakthrough later in 1997, and it is beyond The End that most of the cave is expected to be found. The cave currently has >208 km of mapped passages, and innumerable open leads.

GEOGRAPHIC INFORMATION SYSTEMS & DIGITAL MAPPING

ARCPAD GIS MOBILE SOFTWARE IN CUEVA DEL TECOLOTE, TAMAULIPAS, MEXICO

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The March 2003 expedition to Cueva del Tecolote cave system in the Proyecto Espeleologico Purificacion karst study area made extensive use of ArcPAD GIS software. The expedition had 23 cavers in 7 survey teams to send to over 100 possible leads. The GIS project consisted of the existing cave survey as a layer imported from WALLS cave surveying software, a layer of all other known caves in the area, a scanned version of the topographic map, scanned survey notes, and a shapefile of all the leads for the expedition. Leads were symbolized as point features and linked to the corresponding survey note scans. All of the data were loaded onto an iPAQ handheld computer for the expedition. A special "wetbag" designed for use with computers was used to eliminate humidity and water damage to the unit. The iPAQ was used for six days at Camp I and also on long survey trips to different areas of the cave.

Using ArcPAD on this expedition was a big success. Teams with little to no familiarity with a given area of the cave could simply choose a lead on the handheld, and retrieve the survey notes for the area. Leads were color coded based on the type and quality of lead, allowing survey teams to be as productive as possible. Having the handheld computer in the cave also provided programs such as Word and Excel for writing trip summaries and correcting math errors while in Camp I.

ASSESSING PERENNIAL DRAINAGE DENSITY IN THE HIGHLY KARSTIFIED TURNHOLE BEND BASIN, KENTUCKY

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Drainage density is the summed length of all streams in a basin divided by the basin area. It is a measure of average length of streams per unit drainage area and describes the spacing of the drainageways.

Initially, 4 methods were developed to estimate perennial drainage density within the highly karstified Turnhole Bend Basin, KY, resulting in values ranging from 0.24 km/km² to 1.13 km/km². Since mapped cave streams repre-

sent only a fraction of the total underground streams within the study area, the actual values are likely much higher. With each method, by increasing detail, higher perennial drainage density values resulted. Therefore, efforts were taken to devise a model that would reflect a reasonable upper drainage density value.

Using ArcInfo 8.3 and Visual Basic.net, an idealized karst drainage model was developed. Using a square drainage basin, a drain point along the basin's perimeter is randomly selected. A number of sinkhole drains (x) are randomly located in the basin. Repeatedly running the model, a least-distance stream network yields a pattern consistent with the formula.

Anhert & Williams (1998) counted an average of 74 sinkholes/km² for the Turnhole Bend Basin Sinkhole Plain. Applying the provisional equation, perennial drainage density is 6.83 km/km². Though this value is derived from an idealized model, quantitative measures of subterranean stream networks hold potential as powerful analytical tools in the understanding of karst.

INEXPENSIVE LINEAMENT ANALYSIS FOR DISCOVERING INGRESS NEXUS (ILADIN)

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An inexpensive technique has been developed that increases the probability of finding cave entrances in undeveloped karst and pseudokarst terrain. The first trial of this technique was done in Sequoia National Park in late 2002. A small solution cave previously unrecorded by the National Park Cave Survey was found in the area (~465 m²) ILADIN predicted would have a high probability of containing cave entrances. Three choked solution passages, one with moderate airflow emanating from it, were also found in ILADIN highlighted areas. ILADIN's second trial, in an area known to form sandstone pseudokarst caves, also yielded a series of promising cave entrances.

WALLS 2D: REALISTIC DRAWING & MORPHING OF CAVE WALLS & PASSAGE DETAILS & ITS APPLICATION TO GIS

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Walls is a Windows-based program designed to help cave surveyors organize their data and prepare maps. Such programs typically adjust the data to compensate for inevitable errors, but Walls provides tools to identify gross errors in specific survey traverses. While some programs also draw rough approximations of cave walls based on measured distances from survey stations, Walls 2D is a new component that makes Walls the first program to realistically draw cave passages and details. Scalable Vector Graphics file formats allow the use of commercial drawing programs to create fully illustrated maps that Walls can adjust as the cave survey evolves, eliminating the need to fully or partially redraw maps. Sketches are morphed in appropriate ways, depending on their type of information, to reflect changes in the surrounding survey due to corrections and least-squares adjustments.

Certain Walls files can be exported to ArcView and ArcMap for GIS analysis and merged with track-logs and waypoints from Garmin GPS receivers to create complete, detailed georeferenced datasets. The Walls 2D output maps can potentially lead to automated and accurate calculation of cave areas, cave area to bedrock ratios, and analysis of certain hydrogeologic parameters.

USING A GEODATABASE NETWORK TO DETERMINE BEST TRAVEL ROUTES THROUGH JEWEL CAVE

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The cave survey lines and stations shapefiles generated by CaveTools were imported to an ESRI ArcGIS feature dataset, and a geometric network was created in order to find best travel routes through Jewel Cave. The path taken from the elevator entrance to Camp Duh was determined to be 7.0 km, and from the elevator to the end of current survey is 10 km. Restrictions can be placed on the trace in order to avoid certain delicate speleothems or tight constrictions, and the resulting path can be exported as a new GIS layer. This could be a useful tool for cave rescue, as the most desirable path in a rescue situation is not always the shortest. The network is currently limited by the completeness of the cave survey, passage dimension data, and feature inventory, and will be improved upon as more data are collected and entered.

KARST OCCURRENCE & SINKHOLE GIS COVERAGES FOR KENTUCKY

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Growing interest and need for better karst maps for Kentucky has prompted the development of digital karst data. The Kentucky Geological Survey (through a published 30'x60' karst groundwater basin map series in cooperation with the Kentucky Division of Water) and the Kentucky Speleological Survey (through a digital karst feature database) have independently collected and archived karst data for the past several years. Present publications based upon these data and improved by current digital geologic mapping techniques at the Kentucky Geological Survey include a Karst Occurrence map of Kentucky (depicting regions with potential for karst development) and a digital sinkhole coverage for Kentucky (consisting of karst-related topographic depression polygons). These maps are an important foundation for further work and can provide an important resource for those working in karst prone areas.

GEOLOGY & GEOGRAPHY

BIT DROPS (DRILLED VOIDS) AS A MEASURE OF KARST

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Karst is typically defined based upon the presence of sinkholes, caves, and conduit springs. In areas where glaciation has occurred, however, till and other deposits may bury the surface, leaving little evidence of karst. The carbonate aquifer behavior may retain characteristics of karst (conduit, or quick flow) or may be so occluded by sediments that conduit flow does not occur. In order to develop strategies to protect groundwater quality, it is important to know which type of behavior is present.

A band of Devonian and Silurian limestone underlies central Ohio. In several areas, a subtle karst is seen at the surface and rapid groundwater flow is known to occur. In an attempt to discern the presence of subsurface karst, we evaluated bit drops (voids encountered during the drilling of water wells) for 9 counties, 7 of which were considered to have established karst. The data source was the Ohio Dept. of Natural Resources, which provides on-line access to records of 725,000 water wells in the state. In the 9 county area, 75,336 wells were evaluated for voids, and then located by township. For some of the townships not having traditional karst features, significant voids were nevertheless found at depth. A ratio expressing the number of wells with discontinuities to the total number of wells found higher values for some counties with little surface karst. This suggests that rapid groundwater flow can occur in these areas, and that they should probably be considered as "karst" for purposes of groundwater quality protection.

EXTRATERRESTRIAL CAVE-FORMING MECHANISMS

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Earth caves form in many ways ranging from solutional processes to melting/resolidification. Numerous cave types derive from a relatively limited number of geologic and physical processes identified over time by speleologists. Using this foundation, the physics of speleogenetic processes can be extrapolated to other bodies in the Solar System. This type of thought experiment is essential to bolster advocacy of caves as important scientific targets for missions to other planets and moons. Results of such informed speculation are utilizable by mission planners. It can also sensitize non-speleological scientists to possible cave occurrences on extraterrestrial objects.

Planetary mission images show visually detectable lava tubes on Mars, the Moon, Venus, and possibly Io. Other inconspicuous cave types often have no or only subtle surface indicators. Geophysical techniques can elucidate subsurface structure from orbital, aerial, or lander platforms. All methods have advantages and limitations viewed in light of particular missions.

Rocky and icy bodies can experience internal and external energy sources resulting in cracking, surface material shifting, melting, and resolidification. For example, on bodies without liquid water, other solvents (e.g., liquid ammonia, nitrogen, or ethane) may create unique speleogenesis. Subliming water/CO_2 ices on Mars may cause unique voids. Comet perihelion passage may produce vaporization caves.

Many have developed cave classifications. We use the dominant physical process: 1) solutional, 2) erosional, 3) tectonic (including crater impact), and

4) phase transition. Within these categories, we fit known speleogenetic mechanisms while accommodating possible unique extraterrestrial caves (e.g., cryovolcanic icetubes, Martian ground-ice sapping voids, and others).

GENESIS & SEDIMENTATION OF WINDY MOUTH CAVE, WEST VIRGINIA

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Windy Mouth Cave is an 11-kmlong abandoned spring conduit formed within the Hillsdale and Sinks Grove Limestone adjacent to the Greenbrier River. The cave contains complex clastic (fluvial) sediments, which were sampled throughout the cave from gravel bars, floor deposits in domes, and main trunk passages. Particle size distributions revealed 2 end members: a high percentage of gravel, lacking mud and sand, or a high percentage of mud, with no gravel or sand. Four of the 16 samples were intermediate between the two. Chert dominated the samples, with the gravel size fractions averaging 75%. Quartz (as determined by XRD) dominated the clay fraction lithology. Grain shape percentage among size fractions >2.00 mm and >1.00 mm both contained high amounts of sub-rounded to sub-angular grains. Sediments found in the cave are locally derived from rocks of the Greenbrier Group and Maccrady Shale.

Sinkhole inputs from the surface feed different branches of the cave. Most sinkholes have very limited catchment in the present environment, and are underfit in relation to the paleodischarges recorded in the sediments within the conduits. Chaotic gravel deposits indicate periods of intense, probably pipefull, water flow. Fine-grained deposits relate to low flow conditions caused either by lack of recharge or obstruction of the conduit outlet. An ill-defined magnetic reversal found in sediments near the Waterfall Room suggests an age of >760,000 years for deposition of those materials. This is consistent with the height of the cave above present-day base level (30 m).

A HIDDEN SPELEOTHEM: ELONGATED CONCRETIONS IN COLORADO CAVE SANDS

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While digging out ancient sediment chokes to extend 4 partially filled caves in Colorado (Cave of the Winds, Sandite Cave, and Cave of the Swirling Mists in Williams Canyon; Lost Mascot Cave in the Fulford district), cavers have unearthed hidden deposits of elongated concretions of calcified sand (informally called "sandites" by the diggers), embedded in otherwise unconsolidated sand. These are of circular to flattened cross-section, sometimes curving gently or splitting into parallel forks, and may have either rounded or pointed ends. They are up to ~60 cm long and from 6 mm to 5 cm or more wide. Many are isolated and unattached; others are prong-like extensions of larger, irregular calcified masses. In most locations, they parallel the axis of the filled passage in a slanting to subhorizontal attitude, and may cut across bedding layers. They probably grew when the sand in filled sumps was locally saturated with calcite-rich water, but not necessarily below the regional water table. Similar growths have been reported in Australian caves, but not, to our knowledge, in other American ones. Deposits of comparable elongated concretions have also been found in non-cave sands and sandstones in the U.S. and Italy. The calcite-deposition mechanism is undetermined, but the cave examples seem to confirm one conclusion published by researchers of the non-cave concretions: The long axes tend to be aligned along the groundwater flow direction.

HYDROGEOLOGY OF SPENCER MOUNTAIN: LICK BRANCH KARST INVESTIGATION

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Karst hydrogeology investigations continue around Spencer Mountain in Van Buren County, Tennessee. The court-ordered settlement regarding treated effluent from the City of Spencer's wastewater treatment plant required a karst investigation of the Lick Branch to Pennywinkle Spring drainage basin. A temporary discharge of treated effluent is allowed into the Pennywinkle drainage while a pipeline is built to the Caney Fork River. The purpose of the karst study is to determine the potential for treated effluent to reach water supply wells and sensitive cave ecosystems.

The Tennessee Dept. of Environment and Conservation requested that the U.S. EPA Science and Ecosystem Support Division lead the study. Members of the National Speleological Society provided volunteer assistance, and K2 GeoEnvironmental provided specialized analytical services.

A June 2002 dye study used field and laboratory fluorometry analyses of water and passive receptors. Base flow conditions existed at the start and end of the study with 3.94 cm rainfall 12 hrs following initial dye injection. The study confirms that water in Lick Branch flows underground through Lick Branch Cave. The water resurges on the Hartselle Formation, flows over a waterfall, and sinks in the Monteagle Limestone. The water resurges again at Pennywinkle Spring in a distributary spring fashion. Sampling and analysis of area water supply wells did not confirm the presence of dye in any drinking water system. Dye mass recovery at Pennywinkle Spring was 97.5%. Another dye trace showed that Lost Cove (a karst valley) water flows through the Monteagle Limestone to Pennywinkle Spring.

CONSEQUENCES OF LOW PH, CAVE-WALL CONDENSATION & BIOFILM DEVELOPMENT TO SULFURIC ACID SPELEOGENESIS

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Volatilization and oxidation of H_2S to sulfuric acid on cave-wall surfaces causes aggressive carbonate rock dissolution and replacement by gypsum during sulfuric acid speleogenesis. Reddish-brown crusts cover the gypsum in Lower Kane Cave (Wyoming,). The crusts are composed principally of C, O, and Si, with abundant microorganisms and euhedral quartz microcrystals. Condensation droplets hang from cave-wall surfaces and average droplet pH was 1.7, ranging from pH 1.25 on crust to 2.92 on gypsum. Droplets on crust had contact angles >90° (avg. 121.6°), indicating hydrophobicity. Droplets with pH < 2 were undersaturated with respect to gypsum, while droplets with pH > 2 were in equilibrium. Condensate solutions on gypsum will approach pH 2, but typically not exceed it, due to buffering by the bisulfate-sulfate weak acid/base pair (pK = 1.92) combined with the gypsum-sulfate. Droplets on crusts had pH values below the critical HSO_4^-:SO_4^{2-} pK as a result of crust hydrophobicity and acid-producing bacteria. Therefore, armoring of the cave walls by gypsum and biofilms fundamentally impacts how a cave enlarges during sulfuric acid speleogenesis. Microbial colonization of the low pH, moist gypsum habitat forms an organic film that eventually becomes impermeable. Condensation becomes separated and out of equilibrium with respect to the underlying gypsum, precluding diffusion of sulfuric acid through the gypsum to the underlying limestone, limiting or shutting-off sulfuric acid dissolution completely. Only when fresh limestone is exposed will subaerial speleogenesis be reinitiated, and the replacement-colonization cycle start again.

PALEOSOLS & PALEOKARST: A KEY TO PALEOCLIMATE INTERPRETATION IN CARBONATE ISLANDS

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Bahamian paleosols carry a paleoclimatic signal. Paleosol development is dependent on: climate, vegetation, soil organisms, parent material, topography, and time. The Bahamian parent material is Late Quaternary carbonates, and soil developed is therefore linked to epikarst processes. Not only should the paleosol carry a paleoclimatic signal, but the nature of the paleosol/paleokarst contact should also reflect climate: *e.g.*, wetter conditions creating a more complex paleokarst surface that is infilled with more highly weathered paleosol material. Vegetation and soil organisms are a function of climate; the parent material is uniform, so the remaining variables are topography and time. Topography can be factored out by taking sample transects from hills though valleys. Paleomagnetic analysis (secular variation) of the paleosol and geochronology of the parent material can address the time factor. Bahamian carbonates are ~100% $CaCO_3$, and the insoluble components of the soils are not residual, but are eolian additives as Saharan dust; so the starting materials are known. Bahamian paleosols in some outcrops are developed on a planar, unkarstified carbonate surface, suggesting arid conditions, while others form over a well-developed epikarst surface with significant relief, suggesting wet conditions. Forming soils can fill epikarst voids and harden. Carbonate dissolution removes the weaker parent rock, leaving hardened paleosols, and soil-filled pipes as positive residual structures, inverting topography. Soil infiltra-

tion can infill caves and resist surface destruction; such fills in Cueva del Aleman, Isla de Mona, are at least 1.6 Ma old.

WATER TRACING USING FLUORESCENT DYES TO DELINEATE GROUNDWATER FLOW PATHS IN LEE COUNTY, VIRGINIA

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Two groundwater traces using fluorescent dyes were performed in Lee County, VA. The first trace was to determine the hydrologic relationship between 2 caves near the Cedars Natural Area Preserve. Both caves contain populations of the federally listed endangered Lee County Cave Isopod, *Lirceus usdagalun*. The study was part of an investigation by the Virginia Dept. of Conservation and Recreation in support of the U.S. Fish & Wildlife Service recovery plan for *Lirceus usdagalun*. Background fluorescence levels were established at various sampling sites; charcoal samplers were replaced in the stream in Thompson Cedar Cave and at sampling points in nearby springs. Eight ounces of eosine dye were injected into the stream in an unnamed cave 500 m from Thompson Cedar Cave. Ozark Underground Laboratory analyzed the charcoal samplers. Charcoal samplers from Thompson Cedar Cave contained eosine dye, thus demonstrating a hydrologic connection between the 2 caves.

The second dye trace sought to determine the relationship of an actively subsiding sinkhole with nearby springs and wells. Analysis of background charcoal samplers by the investigator using a luminescence spectrometer found no detectable levels of rhodamine WT in sampled springs. During a significant rain event, one pound of rhodamine WT tracer dye was injected into the intermittent stream flowing into the sinkhole. Post-injection analysis of charcoal samplers found dye on one charcoal sampler, thus demonstrating a hydrologic connection between the sinkhole and Jones-Flannary Spring, which is located 200 m south of the sink-point. No connection with other sampled springs or wells was demonstrated.

SEDIMENTATION & POROSITY ENHANCEMENT IN A BREACHED FLANK MARGIN CAVE

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San Salvador Island, Bahamas, provides a unique location to study modern sedimentation processes on carbonate platforms. The time span of visible geology is highly compressed to the middle Pleistocene through Holocene (< 500 ka). Altar Cave, formed within an oxygen isotope substage 5e eolianite (~125 ka) of the Grotto Beach Formation, is a classic example of a flank margin cave exposed during hillslope retreat. The nature of Altar Cave (restricted entrance, simplistic morphology, and easy access) allowed association of cave features with current environmental conditions and made a sedimentation study easier to perform. Sediment profiles from trenches at 3 locations show that deposits formed in conjunction with a Holocene strand plain present today between the cave and the present beach. ^{14}C dates show these deposits to be Holocene. Dates from sediment and bedrock from the back of the cave, and XRD and geochemical analyses show the surficial sediment to be recent and that leaching has altered the cave floor bedrock. Petrology of the floor rock has provided the first evidence of autogenic sedimentation in the form of dissolution residuum, most likely drifting downward from the roof, accumulating during void development. Petrographic analyses show that this leaching has resulted in increased bedrock porosity below the soil profile, and introduced organics have contaminated the late Pleistocene bedrock with young carbon, producing a ^{14}C age of 28 ka. These results demonstrate a potential method of porosity enhancement in young carbonates. These porosity-enhanced zones may have implications on understanding recharge to the fresh-water lens on carbonate islands.

THE USE OF ELECTRICAL GEOPHYSICAL METHODS TO DEFINE GROUNDWATER FLOW PATH IMPACTS IN A KARST AQUIFER

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Pollution and alteration of surface and subsurface hydrology increasingly threaten karst areas. In order to protect these fragile and dynamic watersheds, efficient diagnostic methods must be adapted for use in complex karst settings. The use of surface geophysical techniques to delineate possible flow paths of clean water in karst aquifers is a new application of existing technology. This study examines stream loss in a small tributary of the Youghiogheny River known as Hoyes Run in Garrett County, MD. The stream bounds the pit of the Deep Creek limestone quarry, operated by Keystone Lime Company. During low flow, the stream abruptly terminates in a swallet, leaving ~100 m of dry streambed. Multiple resistivity profiles using the SuperSting™ R8 System were generated along the zone of loss and compared with results of ground penetrating radar and electromagnetic conductivity profiles in the same location. A dye trace using Fluorescein™ confirmed the flow path of water from the stream into the quarry. Cavities detected in the study were evaluated based on resistivity signal as to their contents (air or sediment filled) to determine which ones might be involved in groundwater transport. The study suggests that surface geophysics coupled with hydrologic and geologic analysis can locate possible flow paths for groundwater in a karst aquifer, even in the absence of obvious karst surface expression. Borehole confirmation is slated before remediation measures are executed.

HYDROGEOLOGIC METHODS USED TO PREDICT CAVERN DEVELOPMENT: RADERS VALLEY, GREENBRIER COUNTY, WEST VIRGINIA

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Conventional hydrogeologic mapping techniques have been combined with several analytical methodologies to predict cavern development in Raders Valley, Greenbrier County, WV. The area is dominated topographically by Brushy Ridge anticline and Muddy Creek syncline, which bound this open karst valley. Numerous karst features give clues to cave development in the valley. A model for cavern development was created based on observing cavern development in other areas of Greenbrier County. The hypothesis was that 4 hydrogeologic conditions should be met to develop a large cave in the area: 1) The Hillsdale Limestone-McCrady (shale) Formation contact would need to be exposed to surface runoff; 2) A large area of surface runoff should go underground at the contact (sink); 3) The limestone would need to be fractured where the runoff is captured; 4) Captured surface water would need to flow unobstructed along a fracture or fault to form the cave.

Surface geologic mapping was used to locate the Hillsdale Limestone-McCrady Formation contact and faults. Topographic maps were used to locate sinkholes and determine inflow locations to the cave system. Map calculus techniques were used to locate areas of fractured limestone and faults. Dye traces were compared with other nearby cave-spring dye traces to indicate whether groundwater flow was obstructed. An integrated interpretation was made to predict the location of the cave system on the west side of Raders Valley between Tolers Sinkhole and the Lower Spring. Field walking resulted in finding Middle Earth Cave near the predicted location.

AMERICA'S NATIONAL CAVE & KARST RESEARCH INSTITUTE 2003: THE GEARING-UP PHASE

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America's National Cave and Karst Research Institute, established by the U.S. Congress, began its "gearing up phase" in December 2002 following a 2.5 year development stage led by Interim Director, Zelda Chapman Bailey. Permanent director Louise Hose has established the Institute office in Carlsbad, New Mexico. The Director's current efforts include initial operational setup, recruiting staff positions, and working with partners to design a permanent building and form a long-term vision.

The Institute operates under a mandate to at least match its current federal funding with non-federal sources. We currently operate under a funding match from the state of New Mexico, which supports collaborative efforts by NM Bureau of Geology–Carlsbad Office hydrogeologist Lewis Land and NM Institute of Mines and Technology (NMT) geomicrobiologist Penny Boston. Land's recent investigations of variations in groundwater discharge from gypsum sinkholes at Bottomless Lakes State Park, NM, has resulted in presentations and a paper to be published this fall in an Oklahoma Geological Survey Circular. NMT created a Cave and Karst Studies Program to provide strong intellectual and educational foundations for the Institute and wider speleological community. Several new Cave and Karst graduate students to be admitted in Fall 2003 under Boston's direction will strengthen NMT's new but aggressive cave and karst research mission.

THE NATIONAL CAVE & KARST RESEARCH INSTITUTE:
HOW WILL IT ADDRESS ITS SCIENCE MANDATE?

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The U.S. Congress directed the National Cave and Karst Research Institute to pursue 6 objectives, including 3 scientific pursuits: 1) further the science of speleology; 2) centralize and standardize speleological information; 3) foster interdisciplinary cooperation in cave and karst research programs. The enabling legislation directed the National Park Service (NPS) to establish and "jointly administer" the Institute with a public or private agency, organization, or institution. This language, along with a requirement for >50% non-federal cost-sharing, suggests an unfamiliar undertaking for the NPS. The legislation provides ample opportunity for the karst science community to address 2 critical questions about the Institute's science mandate: 1. How will it be achieved? 2. How should the Institute structure itself to achieve it? The Institute's science agenda must be determined before settling on an organizational structure. Current suggestions range from a clearinghouse for grants supporting others efforts to developing full-fledge research facilities and staff at multiple locations.

The NPS "jointly administers" lands with other federal agencies and leads the Cooperative Ecosystem Studies Units Network, examples of multiple, public and private partners doing research. However, both models depend almost entirely on federal funding. A single university (e.g., Los Alamos NL) or corporation (e.g., Sandia NL) operates many federally funded national laboratories under contract. Non-profit corporations commonly administer institutes that need to raise non-federal funds (e.g., Woods Hole). The Institute encourages all karst scientists to join in considering the appropriate science-related activities and most effective organizational structure for the Institute.

ON THE DEFINITION OF CAVERN BREAKDOWN: A REVIEW OF THE CHANGING CONCEPTIONS OF BREAKDOWN

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Published accounts of cavern breakdown often have equivocated between (1) the use of breakdown as a noun signifying collapsed bedrock fragments, and (2) the use of breakdown as a verb signifying the breaking and falling of bedrock from cave ceilings and walls. A focus on breakdown and breakdown features naturally leads to detailed descriptions of breakdown morphology and passage features generated by the production of breakdown. A focus on collapse processes leads to an emphasis on geologic triggering mechanisms and collapse mechanics, especially if the investigator is concerned with cave stability and safety. The 2 approaches are not mutually exclusive. However, an emphasis on the collapse processes to the exclusion of detailed descriptions of actual, recognizable collapsed bedrock fragments has led to an impoverished conception of cavern breakdown, one that fails to appreciate the richness of breakdown occurrences. One has only to peruse the definitions of breakdown offered in recent lexicons of cave and karst terminology, or offered in putative reviews of breakdown morphology, to appreciate that the time has come for a reassessment of our conception of cavern breakdown. The reassessment should result in a definition that includes a greater variety of phenomena and features, and is applicable to a variety of types of caves, including those formed in carbonates, gypsum, halite, quartzite, sandstone, and lava.

GENESIS & CHARACTERISTICS OF TUMBLING ROCK CAVE, A VALLEY WALL CONDUIT IN JACKSON COUNTY, ALABAMA

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Tumbling Rock Cave is a valley-wall conduit developed along the Cumberland Plateau Escarpment of northeast AL. The cave functions as a drain for Round Cove, a closed depression at the head of Mud Creek Valley. The creek sinks in the floor of the valley, reappears in the cave where it sinks again, and then resurges at a spring near the entrance. The conduit is sub-parallel to, and within, the eastern valley wall, suggesting an origin through stress-relief fracturing. The system is sinuous in plan view, but the orientation of specific segments is controlled by joints, or joint swarms.

Field investigations included cave hydrology and morphology, geochemistry of deposits, and paleomagnetism of clastic sediments to understand the genesis and function of the conduit. Clastic fluvial sediments are found throughout the cave. These range in size from clay to gravel. Eight oriented samples were collected for paleomagnetic analysis. Six showed normal polarity, suggesting deposition within the present chron. Two samples, taken from a brown clay deposit ~10 m above present stream level, were magnetically reversed. This indicates a minimum age of 780 ka for the growth of this conduit. Conduit growth initiated phreatically and became vadose some time prior to 780 ka. As the cave developed, new levels were formed, and shafts developed concurrently. Escarpment retreat processes presently dominate over valley lowering, possibly due to stratigraphic control of the underlying St. Louis Limestone.

THE CARBONATE ISLAND KARST MODEL AS APPLIED TO ROTA (LUTA), TINIAN, & AGUIJAN ISLANDS, COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

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The main components of the Carbonate Island Karst Model (CIKM) are: 1) enhanced dissolution as a result of fresh water/salt water mixing; 2) glacio-eustatic movement of the fresh-water lens; 3) the influence of local tectonics; 4) eogenetic karst, i.e. karst developed in carbonate rock that has not been buried below the range of meteoric diagenesis; and 5) the model has 4 classifications of carbonate islands; Simple Carbonate (no non-carbonate rocks above sea level), Carbonate-Cover (non-carbonate rocks above sea level but not exposed) , Composite (carbonate and non-carbonate rocks exposed) , and Complex (inter-fingering of non-carbonate rocks and/or faulting).

Recently, Tinian, Aguijan, and Rota (Luta) in the Mariana Arc were investigated relative to the CIKM. Based on the fieldwork, Tinian is classified as a Composite Island within the CIKM. However, by applying different CIKM classifications to different physiographic regions of Tinian, the Northern Lowland and Median Valley are Simple, the Southeastern Ridge and Central Plateau are Carbonate-Cover, and the North-Central Highland is Composite. Aguijan, a small island just southwest of Tinian, is classified as Simple because it has no non-carbonate rocks exposed, and no evidence of non-carbonate rocks interacting with the lens inside the island. Rota, with large amounts of non-carbonate rock exposed at the Sabana and Talakaya areas, is classified as a Composite Island within the CIKM; however, the Taipingot Peninsula, which is connected to Rota only by a narrow isthmus and has no exposure of non-carbonate rock, could be classified separately as a Simple Carbonate island.

APPLYING STATISTICAL ANALYSIS TO CAVE MAPS TO INFER CONTROLS ON CONDUIT DEVELOPMENT IN THE EDWARDS AQUIFER OF CENTRAL & SOUTH TEXAS

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As one aspect of a multifaceted approach to a better understanding of flow in karst aquifers, hydrogeologic controls of cave morphology in the Edwards aquifer of central and south Texas were studied. Extensional faulting and fracturing of the Balcones Fault Zone influenced extensive karst development in the Cretaceous Edwards Group limestones. Cave maps from the Texas Speleological Survey archives were digitized using ScionImage Beta Release 4 to collect statistical information on the overall trends of caves. Cave trends were compared to structure defined by mapped faults and gradient to determine the significant controls on flow as reflected in cave elongation. Modern local hydrologic gradient was approximated by assuming it is parallel to topography and measured from DEMs from the Texas Natural Resource Information System.

Structural controls proved to be the main contributor of the morphologies of caves in this region with 23% of 129 caves studied showing strong elongation parallel to the mapped faults. Another 20% of caves were strongly elongated but not parallel to faults or gradient; these were inferred to be developed along local fracture trends. Caves that showed elongation parallel to both structure and gradient comprised 8% of the caves studied. Only 5% of the caves studied were determined to be parallel only to the modern local hydrologic gradient as defined by topography. The remaining 44% of caves could not contribute information toward understanding the phreatic flow system because they are either dominantly vertical caves formed by vadose processes or are weakly elongated phreatic caves.

RECHARGE AREA DELINEATIONS IN THE SALEM PLATEAU, ILLINOIS

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Detailed groundwater tracing in the Salem Plateau of southwestern Illinois was conducted from 1996 to 2001. Over 100 dye introductions were made during these investigations. The karst area formed on the St. Louis Limestone in the Salem Plateau physiographic province of Illinois covers ~427 km²; ~120 km² are within recharge areas delineated in these investigations. The study area averages ~29 sinkholes/ km² and is autogenic with nearly 100% internal drainage. Studies of groundwater flow in the region have been promoted by those interested in protecting groundwater resources on which rural residents are dependent, and to provide data to support efforts protective of the federally listed Illinois Cave Amphipod (*Gammarus acherondytes*) and its associated biological community. The investigations revealed misunderstandings about the size and interconnectedness of groundwater systems in the region. It also provided an opportunity for coordination with cave bioinventories and a better understanding of cave fauna distribution. Locating potential dye introduction points led to the discovery of many additional caves, several containing species of concern. Six groundwater systems providing habitat for *G. acherondytes* were delineated along with 5 adjacent groundwater systems that recharge delineations were incidental to the investigations. The investigations led to the confirmation that some new locations of *G. acherondytes* represent new populations. Some recharge area delineation has been developed for 4 other groundwater systems. The time of first arrival of dyes and mean groundwater gradients were calculated for each trace.

SEASONAL CHANGES IN SPRING WATER QUALITY IN RUTHERFORD COUNTY, TENNESSEE

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Ten successful ground water traces were conducted to 7 springs in Rutherford County, TN. Four of the springs were sampled at week intervals from August 2002 to May 2003. Sampling of 3 additional springs then began in February 2003. The pH of all springs remained fairly constant throughout the sampling period. All springs showed low ammonia and BOD_5 levels. Although the COD levels were also low, they were greater than BOD_5 levels in all instances. This suggests either the presence of nonbiodegradeable organics or reduced metals. The results also show that COD levels in the urban-drained springs are higher than rural-drained springs. COD levels could also be correlated with rain events. The highest levels typically occurred during periods of no rain. Dissolved oxygen levels for all springs were lowest during September dry conditions (≤5.0 mg/L) and highest after spring rain events. This is expected due to cooling temperatures. DO levels in the urban springs remained below 6 mg/L throughout the sampling period with the lowest level being 2.1 mg/L. Nitrate, phosphate, and sulfate levels were well below health limits but, in general, showed a gradual rise in late spring and early summer. All of the springs showed significant changes in conductivity with storm events. Also, temperature changes of about 5ºC were observed between the cold and hot season. This demonstrates open conduit conditions between the sinking streams and springs. As a result, contaminants that enter the karst drainage systems receive little or no filtration before emerging at the springs.

ANNUAL BANDING IN SMALL COLUMNAR STALAGMITES

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Most stalagmites show banding. The frequency of banding in stalagmites is of much interest because they may preserve data on seasonal changes that take place in caves. We are finding well-preserved banding in small columnar stalagmites as couplets of clear and dark (inclusion-rich) layers. These bands are easily observed in typical thin sections. The average thickness of these bands (couplets) matches the uranium series-determined growth rates for the stalagmites, showing that the bands are annual depositions of calcite. Where the banding is continual and not interrupted by growth hiatuses, the band record provides an annual resolution of growth history. The growth history, whether it is represented as growth hiatuses, mineral changes, or an annually resolved history of growth, is likely tied to climate change. The banding record has potential to yield a calibrated annually resolved climate record.

THE EGEMEIER MODEL MEETS HOT AIR: A VADOSE CONVECTIVE AIR-CIRCULATION MODEL FOR THE DEVELOPMENT OF BONEYARD, CEILING PENDANTS, LOFTS, BLIND POCKETS, VENTS, RIMS & SCALLOPS

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Boneyard and associated passage morphologies have traditionally been interpreted as phreatic features. Egemeier suggested that these latter features might result in places from wallrock dissolution by H_2S, dissolved in vadose films, oxidizing to H_2SO_4. But this did not explain why these morphologies developed. A model is proposed whereby convectively driven circulation may develop these morphologies even without H_2S. Atmospheric convection within caves is commonly driven by variations in air density related to depth, temperature, and humidity. Warm, humid air rises and cools. Where it reaches the dew point, continued upward flow results in condensation on exposed surfaces, etching them. This Rayleigh-Benard convection may take place in pores larger than a few decimeters. Irregular recesses in the pre-drainage dissolutional surfaces may be sites of greater heat-flow and consequent cooling, and condensation. They may be selectively deepened, leaving protruding areas to experience progressively less condensation and dissolution. This may result in the development of blind pockets, lofts, domes, pendants, arches, and in places, *en echelon* flow scallops. Where the sinking limb of one convective cell is near the rising limb of another, evaporation gradients result, in which initially acidic condensates are drawn through the intervening bedrock, dissolving some. This may eventually connect the two cells, allowing subsequent barometric pumping of the cave atmosphere. An integrated, connected system of boneyard may result, preserving a sense of the geothermal gradient as a series of vents, dissolved on one side and with a rim of precipitates (popcorn) developed in places on the other.

GUADALUPIAN SPELEOGENESIS REINTERPRETED: NEW MODELS FOR OLD HOLES

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A speleogenetic model, which assumes gypsum blocks, crusts and associated minerals, and dominant passage morphologies are late predrainage features, and relies on post-Basin and Range oxidation of H_2S rising from distal hydrocarbon sources is currently popular. However: most gypsum and associated minerals are probably vadose; passage morphologies commonly reflect significant vadose modification; H_2S transport as small bubbles is unlikely in undersaturated water; no evidence of rapid transport is recognized; alternative sources of isotopically light sulfur exist; regional structure favors other gas migration pathways; available dates for cave-lining calcite spar predate the Basin and Range.

An alternative model is proposed: The principal generation of caves initially formed by brine/fresh water mixing following Laramide uplift, unaffected by sulfide oxidation. Continued development resulted in reduced brines filling caves below the water table. H_2S degassed, resulting in reducing atmospheres in caves with limited entrances, and circulated repeatedly by Rayleigh-Benard convection, corroding wall-rock in parts of the rising limbs of cells and precipitating "popcorn" in parts of the descending limbs. Corrosion produced boneyard, domes, arches, rims, etc. Later, as stratigraphic cover thinned and entrances formed, H_2S oxidized to H_2SO_4, etched the wallrock and allowed sulfate minerals to form evaporitically. Condensates separated from bedrock by a gypsum rind may become quite acidic, allowing the local precipitation of acidophilic minerals, including alunite and halloysite, which dates thus indicate a minimum age of draining. Basin and Range uplift and climatic drying opened and dried old caves, while reactivated mixing and degassing continue speleogenesis at lower depths.

CAVING ON THE SAN ANDREAS FAULT: TALUS CAVES IN PINNACLES NATIONAL MONUMENT, CALIFORNIA

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Moderately long talus caves have formed in Pinnacles National Monument, located 180 km south of San Francisco, CA. The Pinnacles are located in the western half of a 23-Ma Miocene volcano torn in half by the San Andreas Fault. The fault has rifted the halved volcano northward nearly 325 km from the Lancaster area, northeast of Los Angeles, to near Hollister in central California. The rhyolitic volcanic rocks lie on a basement of Permian(?) metamorphosed clastic and carbonate sedimentary rocks intruded by Upper

Cretaceous granitic rocks. Three relatively large (1754, 229, and 176 m long) talus caves have developed by both stream erosion along vertical joints subparallel to the adjacent San Andreas Fault (SAF) and cyclopean boulders toppled by large magnitude (M >7) earthquakes along the SAF. Cave passages range from lofty stream canyons to between-boulder squeezes. Seasonal streams and periodic El Niño floods rearrange cave sedimentary fills, opening and blocking cave passages. Decorations of cristobalite, gypsum, birnessite, ice, and amberat are present. Townsend's Big-eared bats roost and hibernate in different parts of one cave and have staged a minor population boom following closure of the cave following El Niño damage in 1997. Scores of adjacent smaller caves and shelters have formed by tafoni development.

A PRELIMINARY MINERALOGY OF TALUS CAVES IN PINNACLES NATIONAL MONUMENT, PAICINES, CALIFORNIA

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Moderately long talus caves have formed in Pinnacles National Monument, located 180 km south of San Francisco, CA. Because of the unusual setting, the caves essentially lack "normal" carbonate speleothems. Limited amounts of clear to milky-white colored cristobalite coralloids; biogenic cristobalite diatom moonmilk; gypsum as powdery white crusts and yellow moonmilk, altered by biogenic processes; seasonal ice speleothems; thin, blue-black biogenic deposits of birnessite; and dull to lustrous brown-colored deposits of amberat are present as decorations. The gypsum and cristobalite have formed by evaporation of solutions rich in dissolved silica derived from unstable volcanic ash. The ice forms during the cold winter months from groundwater seepage. The birnessite and cristobalite moonmilk have formed by biogeologic processes in damp passages. The amberat has formed from woodrat (*Neotoma* sp.) droppings.

QUANTITATIVE FOOTPRINT OF FLANK MARGIN CAVES

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Flank margin caves are hypogenic features resulting from mixing dissolution between freshwater and sea water, and develop with no human-sized openings to the surface. Their morphology is globular chambers that are horizontally broad, and vertically restricted, elongated parallel to the edge of the freshwater lens in which they form. At the back of the main chambers, there are often smaller chambers and small tubes that end abruptly in solid bedrock. This configuration is very different from typical epigenic caves, which are coupled to surface water flow patterns.

This preliminary study examined the "footprint," or quantitative configuration, of flank margin caves. Existing cave maps were analyzed in Autocad to determine cave perimeter and area. Ratios were calculated to determine the correlation between the area and perimeter of the voids in various island settings, taking into account interior residual bedrock pillars. The data reveal that as flank margin caves become larger, they link together laterally along the edge of the lens such that their morphology shifts from circular and sub-oval voids to elongated ovals, a pattern perpendicular to their water flow path. In contrast, epigenic caves grow with an elongation directed parallel to their water flow path.

AQUEOUS GEOCHEMICAL STUDY OF TUFA CREEK, SHANNON COUNTY, MISSOURI

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Carbon dioxide off-gassing due to agitation as Tufa Creek gradually falls 25 m in elevation over a 583-m stream reach is the principal mechanism for calcite deposition along this fen-fed stream. Water chemistry results support this conclusion. The stream water warmed from 14-19°C. The pH increased from 7.02 to 7.96 standard units. Specific conductivity decreased from 0.570 to 0.488 millimhos/cm. Alkalinity decreased from 368-321 mg/L. Dissolved calcium decreased from 157-117 mg/L. Magnesium decreased only marginally from 156-148 mg/L. Total hardness (calcium and magnesium) decreased from 313 to 265 mg/L. Chloride remained statistically unchanged from 7.6 to 7.5 ppm. Sulfate decreased from 5.7 to 4.7 ppm. Calcite saturation increased from -0.03 to 0.85. PCO_2 equilibrated from -1.51 to -2.56, but did not achieve atmospheric (-3.5) before entering the river. Biological mediation perturbs water quality data at a sedge-muck section of the forested fen. Tufa formation correlates with elevation drop. Comparing Tufa Creek data to nearby Ebb and Flow Spring and Thompson Creek reveals that sufficient stream mineralization and optimal stream geometry are needed for freshwater calcite deposition. Tufa deposition rates along Tufa Creek are less than those predicted by the Plummer-Wigley-Parkhurst rate law. We speculate this is due to inhibiting effects of dissolved Mg^{2+} or rate changes effected due to periodic gravel scour on the stream.

SUBTERRANEAN SOIL DEVELOPMENT

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Low density, soil-like material lines the walls, floors and ceilings of some caves. In Lechuguilla and Spider Caves in New Mexico, this material is particularly well developed, but similar material has recently been described in Jewel Cave, SD. The deposits are diverse in composition with variable amounts of clay and Al-oxide minerals and all are rich in Mn- and/or Fe-oxides. The mineralogy and microbiology of these deposits bear striking resemblance to terrestrial soils in which iron, aluminum and manganese oxides accumulate.

Lithiophorite, nordstrandite (and gibbsite), goethite, kaolinite, and illite have been identified by XRD, and abundant nanocrystalline Fe-oxides were found by TEM examination, similar to minerals found in laterite soils. Likewise, todorokite and birnessite, often observed in soil nodules, are also present in these cave deposits. A diverse microbial community has been identified in these deposits by 16S rDNA sequence analysis, and includes microorganisms whose closest relatives are manganese- and iron-oxidizing bacteria and nitrogen-fixing bacteria.

The similarities in mineral and microbial species composition to that in soils suggest that these cave deposits may undergo a process similar to terrestrial soil development. Both chemical and microbial processes probably influence the formation of these cave deposits. Chemical weathering from the condensation of weak carbonic acid in the cave atmosphere may contribute to the dissolution of the bedrock carbonate, but microbial breakdown of bedrock probably plays a more significant role, as the microorganisms themselves may release organic acids. The residual weathered products, rich in secondary minerals and organic matter, are essentially subterranean soils.

EOGENETIC KARST DEVELOPMENT IN THE MARIANA ISLANDS: AGUIJAN, ROTA, & TINIAN

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The islands of the Mariana Arc are tectonically active and composed of Eocene volcanic rocks mantled by Tertiary and Pleistocene carbonates that form an eogenetic karst landscape (i.e., formed on limestones that have not undergone deep-burial diagenesis). Fieldwork on Aguijan, Rota, and Tinian has revealed distinct cave patterns controlled primarily by the position of the fresh-water lens as predicted by the Carbonate Island Karst Model (CIKM), including flank margin (FM) caves and banana holes, and cave morphologies modified primarily by joints, faults, and fractures. Extensive horizons of FM cave development along coastal cliffs and inland scarps, representing previous sea-level stillstands, are present on all 3 islands (e.g., Middle Terrace, Aguijan; As Matmos, Rota; Suicide Cliffs, Tinian), while individual FM chambers can exceed 35 m x 70 m in area and 15 m in height (e.g., Liyang Dangkolo, Tinian). Contacts between non-carbonate and carbonate rock produce closed depressions and show evidence of point source, allogenic recharge (e.g., Lasu Recharge Cave, Tinian; Sabana Recharge Cave, Rota). Fresh-water discharge occurs along carbonate/non-carbonate contacts (e.g., Mattan Hanum, Rota) and along coastlines in the form of seeps and springs (e.g., Gecko Cave, Tinian). Fissure development, primarily as bank-margin failure fractures, has produced caves several hundred meters long and over 30 m deep (e.g., Masalok Fracture Cave Complex, Tinian) by enhanced dissolution along preferential flow paths provided by the fractures, which act as vadose fast flow routes. Tectonic uplift, glacio-eustacy, and cliff margin retreat overprint the various cave features.

A DECADE OF PROCESS-RESPONSE OBSERVATIONS OF A SINKHOLE COLLAPSE CYCLE IN PEBBLE PILE CREEK, LILBURN CAVE, CALIFORNIA

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In early 1989, a sinkhole collapsed in the thalweg of Pebble Pile Creek, a tributary to Redwood Creek in the Redwood Canyon karst, Kings Canyon National Park. A compass-and-tape survey of the sink indicated the minimum volume of the collapse to be at least 140-160 m³ of coarse cobbly alluvium. Three sizeable trees up to 0.9 m in diameter were also ingested. A berm of sandy sediment up to 0.3 m thick and largely lacking in fines was found ringing the stream-side of the sink, indicating the collapse was forceful enough to eject streambed sediment. However, the mechanism of ejection is speculative. About 120 m subsurface in Lilburn Cave, the detritus was transported through several conduits by flowing water and reached the South Seas (southern) sump, briefly compromising discharge at the Big Spring stage recorder. Water level at the Z-Room was raised 3-4 m, stabilizing at ~3 m for several years. Progressive in-filling of the sinkhole occurred as the north wall of the sink declined, and the creek transported bedload to the sink during runoff, eventually re-filling the sinkhole, restoring the pre-collapse stream gradient. The 1996-1997 El Nino winter cleared the spring system of its enlarged sediment plug (40 m of head) and restored in-cave sump levels to pre-collapse configurations. These observations reveal an intimate connection between surface events and hydrologic response at Lilburn Cave, and underscore the importance of high-discharge events in the evolution of the Redwood Canyon karst.

ORIGIN AND MINERALOGY OF A TECTONIC RHYOLITE CAVE IN BIG BEND NATIONAL PARK, TEXAS

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Mount Emory Cave is located on the upper flanks of the highest mountain in Big Bend National Park, TX, 2149 m msl. Tectonically formed in the Oligocene Burro Mesa Riebeckite Rhyolite (BMRR), the cave is a series of rifts along stress-release fractures that parallel the topographic contours of a mountaintop ridge. Meter and decimeter scale undulations in the passages and walls occur along variable-scale columnar joints. The cave has a known vertical range of 57.6 m; its lower limits coincide with the base of the jointing. The cave's passages total 151.5 m in horizontal length and generally narrow with greater penetration into the mountain.

X-ray diffraction and scanning electron microscopy was used to quantify the BMRR as about 45% (by weight) quartz and 55% albite feldspar with small amounts of weathered clay and hematite. Analyses were also performed on 3 types of secondary deposits. A sub-millimeter thick water-deposited white coating on many cave walls and breakdown is kaolinite, a weathering product of the feldspar. Pale brown rimstone-like features, generally about 1 cm in length and <1 mm high were mostly quartz, weathered feldspar, and kaolinite. They were water-deposited but their geometry is not always perpendicular to overall water flow patterns probably due to adhesion by the clays. Dark bluish-gray and pale brown coatings along fractures were predominantly weathered feldspar and clay; the darker color is consistent with organic staining. No unusual minerals were found for the geologic setting.

HISTORY

THE ROMANTIC & THE CAVES: JOHN MUIR & THE UNDERGROUND ENVIRONMENT

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Although not his primary focus, John Muir knew that in many regions caves were an integral part of the natural and human landscape. From his 1867 first ventures into Kentucky caves, his 1869 and 1876 visits to major California caves, to his 1904 tour of the Jenolan Caves in Australia, he was fascinated by the underground environment and its features. He was well aware of spelean variety, as he noted limestone caves, lava tubes and trenches, potholes or pits, and ice caves at the bases of glaciers. He was also a careful observer of how cultures and people utilized caves; as living shelters, and hiding places, for American Indians, as social and commercial spaces, and as places of wonder and beauty for Euro-Americans. Muir's ideas regarding caves mirrored his larger attitudes towards nature. In contrast to the prevailing notion of his day that all aspects of the natural world were potential useable resources, Muir was essentially a romantic who sought beauty, self-discovery, and the presence of God in caves. Implicit in his view of caves was the belief that they were important spaces to be conserved, much like the big trees and high mountains he so valued.

CHARLES DARWIN'S INTEREST IN CAVES

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The well known naturalist Charles Darwin noted only a few small sea caves in South America during his nearly 5 year trip around the world in the early l830s. His correspondence and published writings reveal a knowledge of and interest in various aspects of speleology. Prior to publication of *The Origin of Species*, Darwin requested information about cave adapted species and in *The Origin of Species*, he devoted 2 pages to this subject. His writings show that he was also interested in paleontological and archeological caves. However, poor health after his long voyage prevented any possible cave-related field work.

70 YEARS UNDER THE EARTH

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During the summer of 1933, my father led me down a pole ladder into Devils Kitchen, a spacious travertine cave and popular tourist attraction in Yellowstone National Park. Half a lifetime later, I found readily recognizable 19th Century stereo views of this cave including 2 by Jay Haynes, celebrated photographer of the park. Originally called "The Mammoth Cave of Wyoming", this cave has long been administratively closed because of supposedly lethal levels of CO_2. Also closed is nearby and possibly larger McCartneys Cave.

With new knowledge of safe exploration techniques in warm, hypercarbic caves and a need for fuller understanding of the depositional speleogenesis of various types of travertine caves, these and similar caves of Yellowstone should be reopened to appropriate scientific study.

LAVA TUBE SYMPOSIUM

MAZE DEVELOPMENT IN HAWAIIAN BASALT CAVE SYSTEMS

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The geologic literature presents a general perception of basalt tube systems as being relatively short, simple, and ephemeral features. This concept is based primarily on study of lava flow systems located throughout the western continental states of America. Two decades of study beneath 3 active shield volcanoes on the Island of Hawaii have revealed a very different "landscape". Working from >280 km of survey accumulated under Mauna Loa, Kilauea, and Hualalai, a very different pattern begins to emerge. In fact, a large percentage of these tube systems is composed of parallels, braids, or mazes. In a few examples, these maze systems constitute interconnected vertical layers to form some of the most complicated skeins of survey ever documented by the caving community.

CAVES OF THE 1919 FLOW, KILAUEA CALDERA, HAWAII

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Nearly 200 caves have been identified in the 1919 "Postal Rift" lava flow in Kilauea Caldera. Only a few of these are traditional lava tube caves, and these are limited to the upper slope of the flow. Despite the current Glossary of Geology definition of "tumulus" as a solid structure, several subtypes of hollow tumuli are readily identifiable here, including dome, sinuous, and transverse types. Individual drained flow lobes and complexes thereof constitute the commonest type of cave in the flow. Some of the latter are measured in hundreds of meters.

Lava rise caves are of 2 subtypes: Circumferential and linear. A spectrum of combined and intermediate forms of all these subtypes is present; a lengthy longitudinal flow lobe cavern is intermediate between ordinary flow lobe caves and lava tube caves. This suggests that simple subcrustal drainage of lava may be the initial phase of speleogenesis of a common type of lava tube cave.

VULCANOSPELEOLOGY IN ICELAND

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The 10th International Symposium on Vulcanospeleology convened in Iceland in September 2002 with an attendance of about 30 (only 2 Americans). It culminated more than a decade's systematic work by the Icelandic Speleological Society. Iceland is one of the world's great areas for lava tube caves and related volcanic phenomena, and wide varieties were visited during field excursions. Papers all were in English, and covered features in Iceland, the Azores, Australia, Hawaii, Samoa, Japan, Italy, Saudi Arabia, Korea, and elsewhere. Several included stream caves. Other topics were the Great Crack, Kilauea Volcano, HI, a hollow dike in Australia, tree mold complexes in Japan and open vertical volcanic conduits (the world's deepest is just behind the capital city of Reykjavik). Ground penetrating radar has shown a very large extension of the long-celebrated Surtshellir System with no entrance-yet. Field excursions covered caves with especially notable features in both SW and NE Iceland; one crossed the desolate glacier outwash plains of the center of the island where 4x4s are essential. Among the caves visited were Leitharendi, Arnahellir, Stefanshellir, Surtshellir, Vidgilmir, Flughellir, and 2 notable hollow linear tumulus caves containing gently flowing crystal-clear hot water. One of these streaming springs currently is too hot for swimming; the other is just plain wonderful. In contrast were massive ice cascades and other speleothems still present in several caves at the end of summer. New caves still are being found, and much work remains to be done.

LOOKING FOR LAVA TUBES IN COLORADO

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Unlike other adjacent states to the south and west, the state of Colorado has no known lava tubes. Recent tube-fed basaltic lava flows are rare in Colorado and tubes have not been documented in older flows, although some references to the possibility of tubes exist in the geologic literature. These references described entrances in a welded Oligocene ash flow tuff, and in Miocene basalts on Red Mountain and Flattop Mountain in central Colorado. In the San Luis Valley in south-central Colorado, candidate flows originate on the Los Mogotes Volcano, Volcano de la Culebra, and the State Line shield volcano. Here, indications of the existence of lava tubes in a Pliocene olivine andesite, a Pliocene theolitic basalt (Servilleta Fm.), and the Oligocene Hinsdale Fm., a basaltic lava, have been observed. A number of entrances were seen.

SPELEOTHEMS & LAVA FEATURES IN THE LAVA TUBE CAVES OF EL MALPAIS NATIONAL MONUMENT

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There are at least 8 tube-forming basalt flows within El Malpais National Monument. The lava tube caves within the Monument contain impressive lava features and numerous speleothems (secondary mineralization). The lava features include benches, gutters, linings, lava stalactites, stalagmites, columns, shelves, grooves, and cinder springs. Lava features provide information regarding the character of lava that flowed through the tubes. The speleothems are predominantly crusts, coralloids, iron-oxide coatings, and moonmilk; however, ice stalactites, stalagmites, draperies, flowstone, and columns are common during winter and spring. Speleothemic crusts, coatings, and moonmilk appear to be more abundant in the older lava tube caves. Not only do some interesting speleothems and minerals form in lava tube caves, but the speleothems have potential to reveal information regarding the timing of tube origin and general climate history. The microbiology related to some of these speleothems may also yield interesting findings.

THE RAPID LOSS OF ICE AT MERRILL ICE CAVE, LAVA BEDS NATIONAL MONUMENT

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Beneath the solid ice floor of Merrill Ice Cave, a large dome-shaped cavity formed within the 2-m thick ice that underlies the floor. How the cavity started and how long it took to grow is not known. The ice cavity was first seen in the fall of 1997, when its roof breached the top layer of the ice floor and the small hole created gave us a view into the 3-m-diameter chamber below. The cavity appears to have formed naturally, the result of air flow in the breakdown floor beneath the ice causing loss by sublimation. We assume the cavity had been gradually enlarging for many years unseen. Over the past 6 years we have monitored the continued growth of the cavity and simultaneous loss of ice by taking yearly measurements of cavity dimensions and ice floor levels. We have also documented artifacts, primarily trash from visitors, as they became exposed in the walls of ice. The entire 2 m thickness of ice appears to be historical in age. The ice is steadily disappearing and it is unclear whether the air flow through the breakdown will prevent ice from building up significant thicknesses again in the future.

PALEONTOLOGY & ARCHAEOLOGY

ARCHAEOLOGY OF THE KIPUKA KANOHINA CAVE SYSTEM, HAWAII COUNTY, HAWAII

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Kipuka is a Hawaiian word that describes an area of land left untouched by the most recent lava flows in the region. These smaller "islands" of ancient land preserve interesting and complex ecosystems on the surface, and often protect fascinating cave systems in the subsurface. The Kipuka Kanohina Cave System comprises one of these highly unusual environments. This prehistoric geologic unit was formed by a long and complex network of tube systems that has now been documented as the second longest basalt cave system in the world.

Many stone implements are still lying *in situ* on the surface of the kipuka. The ancient Hawaiians also extensively utilized the entrance and deep cave areas to collect both water and mineral resources. The cave environment provides constant temperature and humidity, so that an extensive collection of more perishable items has been left behind for the archeological community to investigate. This wealth of material has yet to be studied extensively, or comprehensively catalogued. Preliminary radiocarbon dating of charcoal and wood fragments has begun, raising some very interesting questions.

PLEISTOCENE VERTEBRATES FROM SKELETON CAVE, OREGON

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A small collection of bones and teeth were made from Skeleton Cave, OR in 1928 and 1929. The collection contains about 10 species of mammals. The extinct North American lion, *Panthera atrox,* is represented by 2 nearly complete metapodials and probably fragments of a scapula and humerus. These bones were misidentified in the collection as those of a short-faced bear *Arctodus*. A small horse is represented by 15 complete or fragmentary teeth from a single individual. These teeth most resemble those of *Equus conversidens*, a species previously known from Florida, the Great Plains and the Southwest. The remaining specimens in the collection are those of species from the historical or living fauna of the area.

VERTEBRATE REMAINS FROM NINE SNAKE RIVER LAVA TUBES, IDAHO

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Exposed samples of bones and teeth were collected during bioinventories conducted in 2000 from 8 BLM Snake River Plain lava tubes; teeth from an additional BLM lava tube were supplied in 2002. Species identified include: bat (*Myotis* sp.), western big-eared bat (*Plecotus townsendii*), pygmy rabbit (*Sylvilagus idahoenses*), jack rabbit (*Lepus* sp.), yellow-bellied marmot (*Marmota flaviventris*), Great Basin pocket mouse (*Perognathus parvus*), mouse (*Peromyscus* sp.), desert woodrat (*Neotoma lepida*), vole (*Microtus* sp.), northern pocket gopher (*Thomomys talpoides*), wolf (*Canis lupus*), dog or wolf (*Canis* sp.), red fox (*Vulpes vulpes*), grizzly bear (*Ursus arctos*), wolverine (*Gulo gulo*), badger (*Taxidea taxus*), spotted skunk (*Spilogale putorius*), horse (*Equus* sp.). The horse dentition patterns were not similar to any of the more distinctive patterns that are known to represent fossil species. Although none of these species are extinct, the grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), and the wolverine (*Gulo gulo*) are extirpated from this area of Idaho. A skull of a badger, *Taxidea taxus*, is remarkable in that some of its measurements exceed the maximum noted for this species in a standard reference. These remains apparently are of recent age.

These bone deposits were of at least 4 types. Some of the occurrences represent den sites, others were lost individuals that were not able to exit the cave, a few were transplanted by packrats or other animals, and some were not identifiable to a specific type of deposit.

INDEX TO VOLUME 65 OF THE JOURNAL OF CAVE & KARST STUDIES

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This index covers all articles and abstracts published in volume 65 numbers 1, 2, & 3, including selected abstracts from the 2003 Society meeting in Porterville, California.

The index has three sections. The first is a **Keyword** index, containing general & specific terms from the title & body of an article. This includes cave names, geographic names, etc. The second section is a **Biologic** names index. These terms are Latin names of organisms discussed in articles. For articles containing extensive lists of organisms, indexing was conducted at least to the level of Order. The third section is an alphabetical **Author** index. Articles with multiple authors are indexed for each author, & each author's name was cited as given.

Citations include only the name of the author, followed by the page numbers. Within an index listing, such as "Bats", the earliest article is cited first.

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