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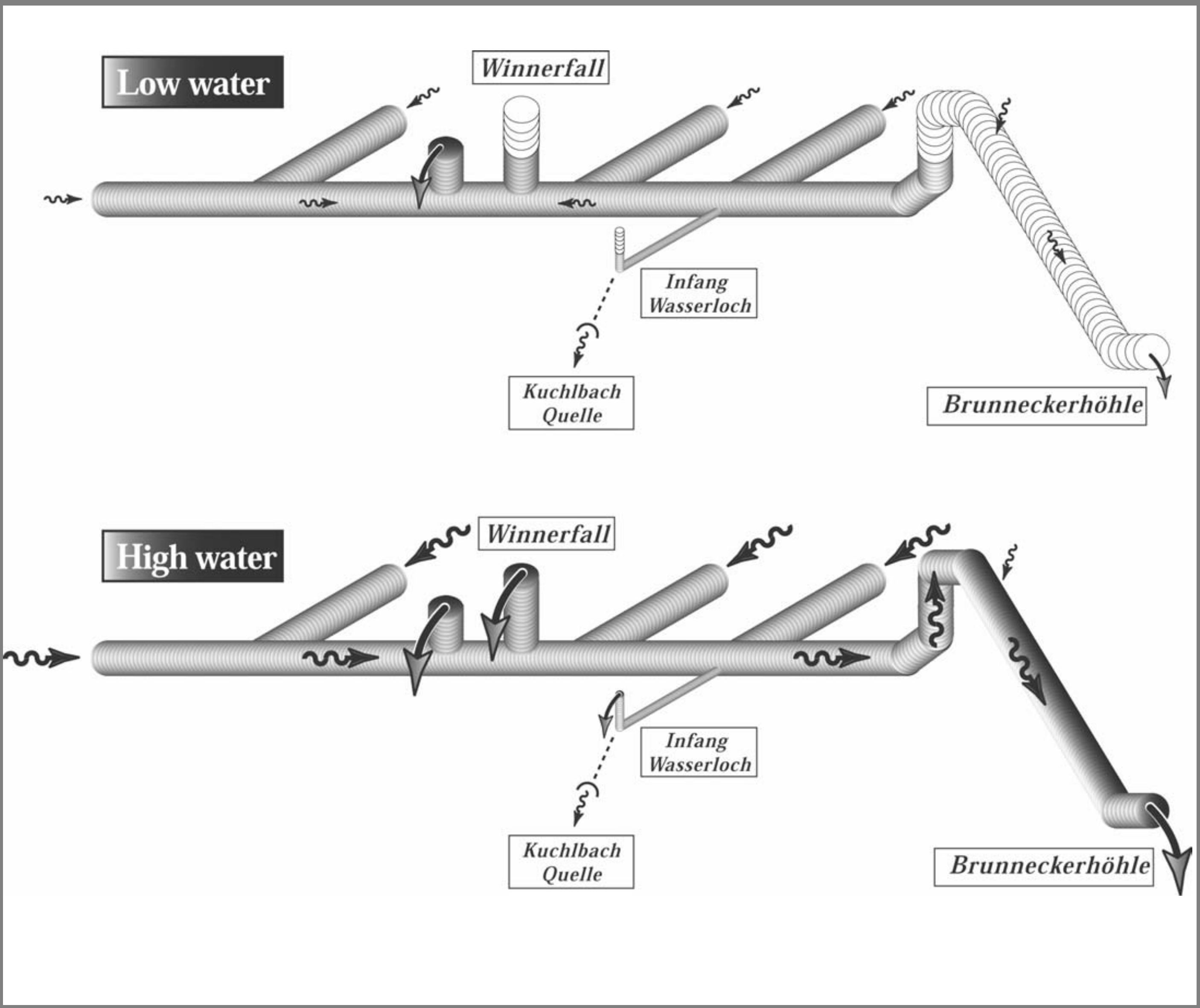

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POEM

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Cover: Brunnecker Cave System flow in the -700 m phreatic zone. See Philippe Audra, Yves Quinif, and Pierre Rochette, p. 153.

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THE GENESIS OF THE TENNENGEBIRGE KARST AND CAVES (SALZBURG, AUSTRIA)

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Research has been carried out in the Tennengebirge Massif (Salzburg, Austria) with specific attention to karst morphology, cave systems, and sediments. This study reveals the genesis of the karst and the underground systems of the Tennengebirge, since the Oligocene. Large horizontal systems, which date back to the Miocene, were studied through the example of the caves Hornhöhle and Eisriesenwelt, which respectively represent Ruinenhöhlen ("cave ruins") and Riesenhöhlen ("giant caves"). The Cosa-Nostra-Bergerhöhle System is typical of a mostly vertical, large, high-relief, alpine cave. The main characteristic of this network is major development in the vadose zone. Shaft morphology is in "stairs beneath a faulted roof." At greater depth, they connect to a perched epiphreatic zone, which is typical of a dammed karst. The main underground sediments are of paleoclimatic and hydrodynamic significance, corresponding to hot, stable, or unstable environments (flowstones, reworked weathered rocks) and cold environments (carbonate varves, glacial pebbles). A preliminary study of the Tennengebirge sediments reveals significant information about its evolution throughout Pliocene-Quaternary time.

HÖHLEN- UND KARSTGENESE IM TENNENGEBIRGE (SALZBURG, ÖSTERREICH)

Es handelt sich um Erforschungen des unterirdischen Höhlensystems im Tennengebirge mit Hilfe der Erforschung der Karstsedimente. Durch die Beobachtung der Morphologie und der Ausfüllungen kann die Geschichte der verschiedenen Höhlenorganisationen nachgezeichnet werden. Wir haben die großen horizontalen Höhlensysteme des Miozäns anhand der Hornhöhle und der Eisriesenwelt studiert, die wiederum ein Beispiel für Ruinen- und Riesenhöhlen sind. Das Cosa-Nostra-Bergerhöhle System ist ein Beispiel für die großen vertikalen Alpenschächten, das an seiner ausgeprägten Entwicklung der vadosen Zone erkenntlichist. Die Schächte haben die Morphologie von "Treppen unter einem Kluftdach". Sie sind tief unten mit einer gestuften phreatischen Zone verbunden, die einen abgedämmter Karst enthüllen.

Die wichtigsten unterirdischen Sedimente haben eine Bedeutung auf dem Gebiet der Paläoklimatologie und der hydrodynamik. Sie entsprechen entweder warmen und beständigen oder kalten Umgebungen oder einer Umbegung in der das natürliche Gleichgewicht unterbrochen wurde (Sinterformation, veränderte Sedimente aus Alteriten, Karbonatwarven, glazial Schotter). Die Erforschung der Sedimenten in der Bergerhöhle bringt wichtige Informationen über die Entwicklung der Höhlensysteme im Plio-Quartär. Durch die gesamte Erforschung kann die Entstehung der Höhlen- und Karstgenese im Tennengebirge seit dem Oligozän nachgezeichnet werden.

This article describes the main results of research carried out in the Tennengebirge Massif of Austria, specifically in the Cosa-Nostra-Bergerhöhle cave system. This research concerns the surface karst morphology and, especially, the cave morphology. The area contains 3 types of cave systems including unroofed caves (Ruinenhöhlen) located on the plateau surface and huge dry systems (Riesenhöhlen) like Eisriesenwelt, both related to Miocene conditions, and alpine systems, like Cosa-Nostra-Bergerhöhle, developed during the Plio-Quaternary and reaching considerable depth. Certain extensive underground sediment types are examined, each having specific paleoclimatic significance. The history of the cave system's evolution is linked to the local physical setting, which includes the altitude of the massif, its shaping during successive uplifts, and its current position in relation to base level. This research has enabled the tracing of the main pattern of karst development in relation to the regional evolution of the massif since the beginning of the Tertiary, and also the establishment of successive phases and conditions of speleogenesis, especially since the late Tertiary (Audra 1994).

The Tennengebirge, located 30 km south of Salzburg, is part of the limestone high Alps, dominating the Danubian

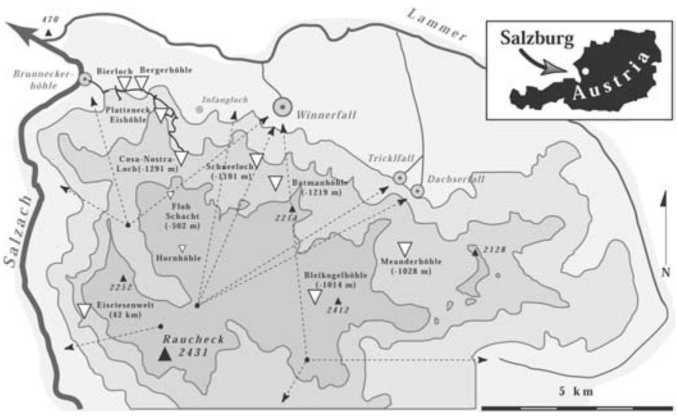


Figure 1. Topographic map of the Tennengebirge (C.I. = 500 m). Dashed lines correspond to water tracing.

Piedmont. This high triangular plateau (20 km x 10 km) rises to 2431 m altitude (Fig. 1). Nearly vertical escarpments and abrupt slopes encircle it. Thus, it dominates the surrounding valleys by ~1500-2000 m, especially the Salzach Valley to the west, which contains one of the region's main waterways. It is one of the richest and best known Austrian massifs for the number and size of its caves. It contains 5 systems >1000 m deep and two >30 km long.

The local carbonate strata extend from the Triassic to the Jurassic (Tichy *et al*. 1985). At its base is a thick series of Triassic dolomites, which are overlain by the 1000-m-thick Dachstein Limestone (Fig. 2). The Jurassic is represented by alternating reddish limestone (Rötlichen Knollenkalken), and shale. An overlying Oligocene quartz conglomerate cover, the Augensteine, caps the massif unconformably. The Tennengebirge consists of an overthrust sheet, in which the normal flank has resulted in a gently inclined plateau, slightly higher in the south. The frontal saddle accounts for the sudden northerly slope. This outcrop pattern has determined the erosional history of the different strata. The dolomites are exposed in the southern part. The karstified Dachstein limestone makes up the bulk of the plateau. It is locally sprinkled with gravel veneers of weathered Augensteine. Finally, the Jurassic layers have been preserved from erosion at the northern foot of the saddle.

THE MORPHOLOGY AND GENESIS OF DIFFERENT LEVELS OF KARSTIFICATION

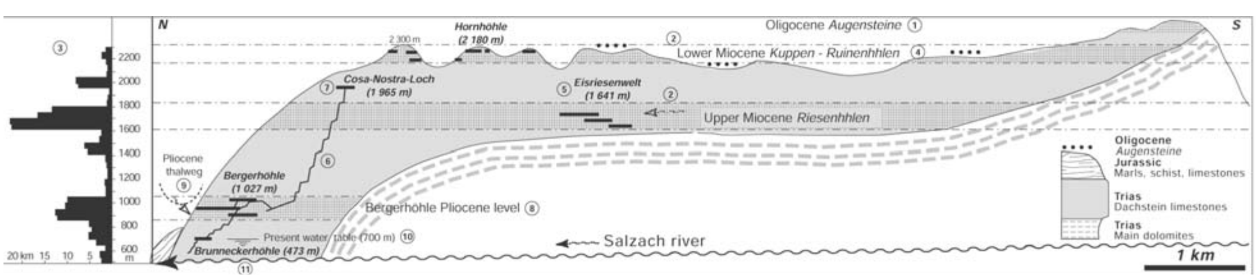
THE RUINENHÖHLEN ("CAVE RUINS"): THE HORNHÖHLE EXAMPLE

A karst landscape of Miocene heritage (Fig. 3). Hornhöhle is located at ~2200 m msl in a landscape consisting of large cones and depressions, containing destroyed karst forms such as kettle-shaped dolines, large grikes, arches, discontinuous tunnels, and unroofed corridors called Ruinenhöhlen (Lechner 1949; Goldberger 1951, 1955). The mainly horizontal tubular galleries whose rock walls are sculpted by scallops and the grain-size distribution of the clastic sediments show that these were once partly flooded, with slow current, and developed close to the water table. They are presently perched above current base level.

Augensteine sediments. Hornhöhle contains some relatively young flowstones that overlie older flowstone debris broken by neotectonic activity. Most of the older stalagmites are corroded and partly destroyed, bearing witness to their age. Fragments are also located at the entrances as well as on the surrounding land surface. This abnormal distribution of the flowstones is proof of slope erosion that intersected the cave. Clastic sediments include homogenous sands, bedded and hardened, consisting of quartz and iron oxides, as well as hardened clays. The latter sometimes contain large gravels consisting of rounded iron-oxide nodules and Augensteine (Fig. 4). These argillaceous, ferrous, quartzose sediments come from the reworking of the weathered superficial rocks (Augensteine).

A major karst level, known as the "Hochkönig level" (Seefeldner 1961), developed close to a former base level. This evolution was triggered by the partial erosional removal of the Augensteine from the Lower Miocene onward (Tollmann 1968). At that time the karst had rivers flowing through it from

Figure 2. The Cosa-Nostra-Bergerhöhle system and the Tennengebirge (see also text). To the left (3), relationship between cave passage altitude and old karst levels (after Klappacher & Knapczyk 1985). Karst development began during the Oligocene beneath Augensteine (1). During the Miocene, horizontal systems developed with alpine water inputs (2), showing different levels (3) related to successive phases of stability: Ruinenhöhlen (4) and Riesenhöhlen (e.g. Eisriesenwelt - 5). Following Pliocene uplift, alpine systems developed (e.g. Cosa-Nostra-Bergerhöhle - 6). Entrance horizontal tubes correspond to a Miocene level (7). Shaft series (6) connect to horizontal tubes from Bergerhöhle-Bierloch (8), corresponding to Pliocene base level (9). Present water-table at -700 m (10) pours into Brunnecker Cave, which connects to Salzach base level (11).



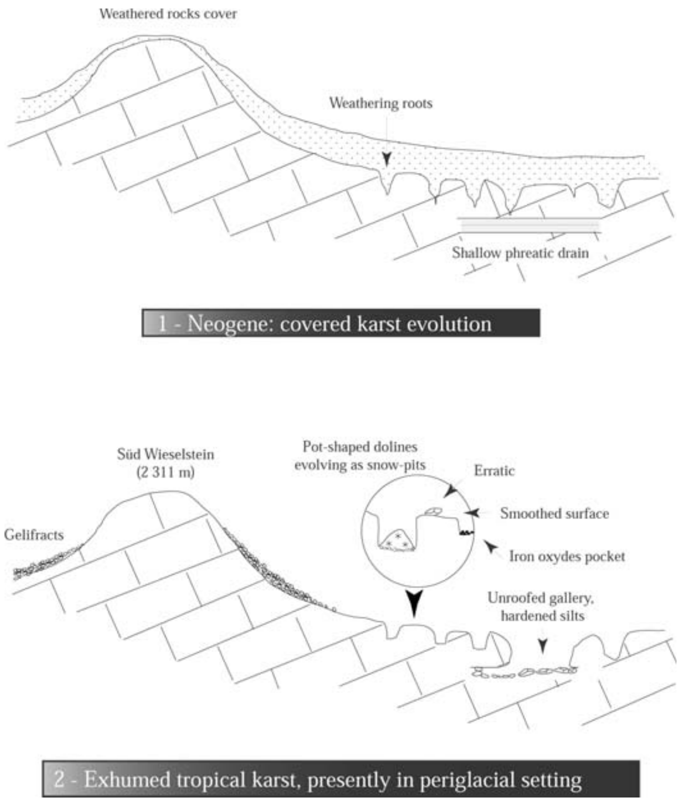


Figure 3. Diagram showing the evolution of the Windischriedel karst, from the late Tertiary (top) to the Pleistocene (bottom).

Figure 4. Reworked weathered rocks, mainly composed of quartz gravels (light) and iron oxides (dark).

the insoluble igneous and metamorphic rocks in the central Alps. These helped to feed the caves, as well as erode away the sedimentary cover, part of which is still trapped in the caves. This karst was then uplifted up to 2000-2200 m. These tectonic movements, along with Quaternary glaciation, accelerated superficial erosion. In such an unstable environment, the sedimentary cover was largely cleared from the surface, with reworked remnants preserved in the cave sediments. Glacial erosion of the karst was limited due to the fact that the area was located close to the crest of the massif. However, some carbonate rock was removed, exposing older caves and transforming the weathered low areas into kettle-shaped dolines, once the infilling of weathered rock was partially removed. The karst is still evolving as a result of periglacial activity (frost and snow action): kettle-shaped dolines act as snow-pits, and bare bedrock is sculpted by karren and covered with debris.

THE RIESENHÖHLEN ("GIANT CAVES"):
THE EISRIESENWELT EXAMPLE

The Eisriesenwelt is one of the world's most famous caves. Its underground ice formations extend through nearly one kilometer of a system that is 42 km long, which attracts thousands of tourists every year. It opens onto the western face of the Tennengebirge, about halfway up the steep cliff that dominates the Salzach Valley (Fig. 2). It is a dry cave consisting of vast sub-horizontal galleries filled with debris. Less common are tubular passages with scallops. The main level, whose initial shape has been obscured by rock debris, varies between altitudes of 1650 and 1750 m. Lateral tubular labyrinths are located in the range of 150 m both above and below the main cave axis. Links between different levels consist of steeply inclined tubes. A variety of interesting sediments can be found in the talus-floored galleries.

Allogenic fluvial sediments. Clastic sediments carried in by vadose flow are represented by sands and pebbles trapped in potholes (in the Fuchsgang and Gerade Kluft). Fine silts left by phreatic flow are abundant within all the tubular conduits, which they sometimes choke entirely. Sometimes these can form rounded, case-hardened bodies, known as Krapfen ("donuts"). They contain weathered residue from the local limestone and old karst cavities (limestone grains, quartz gravels, and iron oxides). The fluvial sediment composition gives evidence for a more remote origin, as was noticed by early researchers (Lehmann 1922; Pia 1923). Their content of quartz, mica, tourmaline, sphene, zircon, garnet, magnetite, and mica schist fragments suggests an input from the metamorphic zones of the central Alps. These sediments are usually rounded as the result of transport by turbulent flow. Relatively recent flowstone is rare, but older flowstone is common. Examples of the latter are very large, e.g., stalagmites in the Steinerne Wald ("Petrified Forest"), and thick, partly eroded flowstone floors (Pia 1923). Many of them consist of transparent calcite, which shows that their growth was under wood covering (Maire 1990). Their surfaces are commonly corroded by flowing water. Scallops in the dissolved profile of a stalagmite even show the direction of the paleo-current that sculpted it.

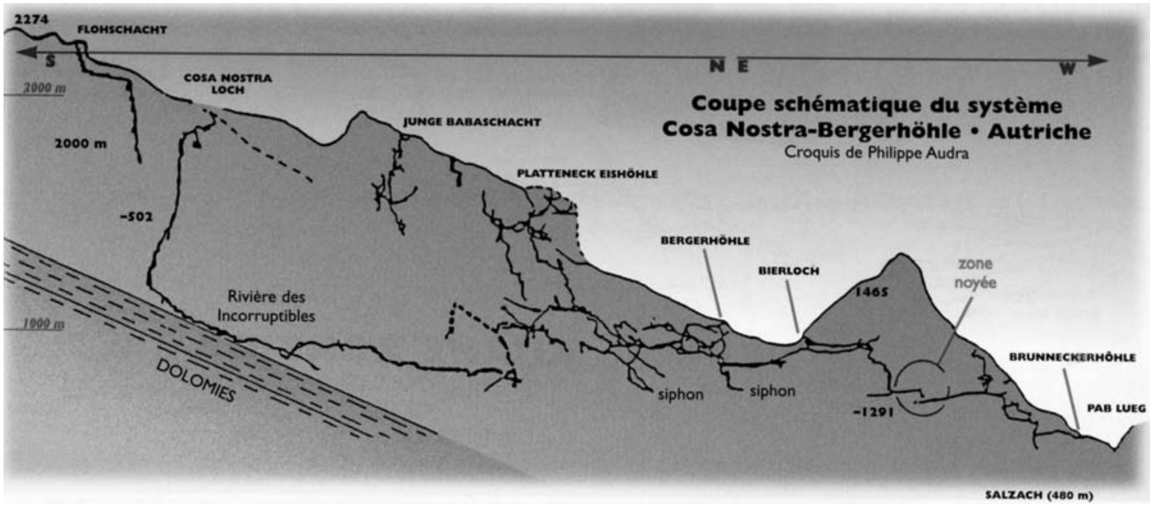


Figure 5. Cross section of the Cosa-Nostra-Bergerhöhle System.

An Upper Miocene cave related to fluviokarst. The Eisriesenwelt was fed by sinkholes located between 1650 and 1750 m msl, which is ~1000 m above the present Salzach Valley base level. As demonstrated by minerals within detrital sediments, the runoff came from the central Alps. Sediment from the central Alps was carried mainly into poljes where it disappeared into ponors. Large underground rivers developed, similar to those in the tunnel-like caves presently found in tropical climates. Considerable discharge flowed through these galleries, which reach 50 m in width, creating networks with many ramifications. Eroded flowstone and scallops confirm the direction of flow from the central Alps (SE to NW). Steep tubes and looping profiles demonstrate that the conduits were partially flooded and located close to the water table (Audra 1994; Häuselmann *et al*. in press). This system evolved during periods when the base level was stable, correlative with low-gradient sections of valley slopes. These comprise the "Gotzen level" and "level I" (Seefeldner 1961), which developed from the end of the Miocene to the beginning of the Pliocene (Tollmann 1968). The presence of eroded flowstone shows alternating wet and dry phases. These flowstones, dating from the active period of the Eisreisenwelt, are Pliocene age, as suggested by Lehmann (1922). The most recent flowstones, which are not eroded, probably date from the lower or middle Pleistocene, during a warm interglacial period (Trimmel 1992). As uplift continued, the Salzach Valley became entrenched. With the relative lowering of base level, the Eisriesenwelt became perched, drained, and intersected by scarp retreat. Neotectonic activity is responsible for the boulder chokes. Thus, the Eisriesenwelt is a good example of the Riesenhöhlen level of karst development, which is recognized throughout the limestone high Alps (Bauer & Zötl 1972).

The study of perched caves sediments clarifies the evolution of former karst environments. In Hornhöhle, the sediments are linked to the erosional removal of the Augensteine cover at the beginning of the Miocene. In the Eisriesenwelt, the transition to fluviokarst can be demonstrated by the less-weathered sediments, which were carried in by rivers from the central Alps. The mineralogical evolution of the sediments with altitude (and thus with the age of the caves), can also be found in the plateaus of the Hagengebirge and Steinernes Meer, located farther west (Langenscheidt 1986). Their composition is comparable to that of piedmont sandstones and conglomerates, also dated from the Miocene (Füchtbauer 1967; Tollmann 1968; Lemke 1984). Each level of karstification includes a link between superficial and deep forms, each of which contains diagnostic sediments. Hornhöhle is a Ruinenhöhle containing highly weathered sediments, developed in a karst cone in the upper level of the Hochkönig. Lower down, the Eisriesenwelt is a Riesenhöhle containing fluvial deposits linked to large poljes. Thus, the surface karst features correspond to the vertical arrangement of caves.

A TYPICAL ALPINE CAVE-SYSTEM: COSA-NOSTRA-BERGERHÖHLE

Shafts and dry tubes. The Austrian limestone high Alps are known as much for their large, vertical cave systems as for their cave systems with large galleries. The Cosa-Nostra-Bergerhöhle System combines these two aspects, giving rise to a vast Pliocene-Pleistocene network, under the joint influence of the last phase of uplift and glaciation. The Cosa-Nostra-Bergerhöhle System is located in the northwestern Tennengebirge, extending from 2300 m msl at the Wieselstein summit all the way down to the Salzach at the Lueg Pass (470 m), the low point of the massif (Figs. 1 & 5). The entrance of the Cosa-Nostra-Loch is at 1965 m msl, 350 m below the Wieselstein summit. However, other as-yet unconnected shafts extend right up to the high point (e.g., Flohschacht, with a depth of 502 m) and probably constitute the upstream end of the system. Lower down, a dozen linked entrances to the Platteneck ice caves (Platteneck Eishöhle), are located between 1400 and 1600 m beneath the Platteneck summit. These two caves are the uppermost entrances to the Cosa-Nostra-Loch-Bergerhöhle and are linked to the main part of the system by sub-vertical conduits. Beyond the entrance series, the Cosa-Nostra-Loch consists of a vertical profile known as a "staircase beneath a faulted roof" (Fig. 6). At -600 m, the Rivière des Incorruptibles ("River of the Incorruptables")

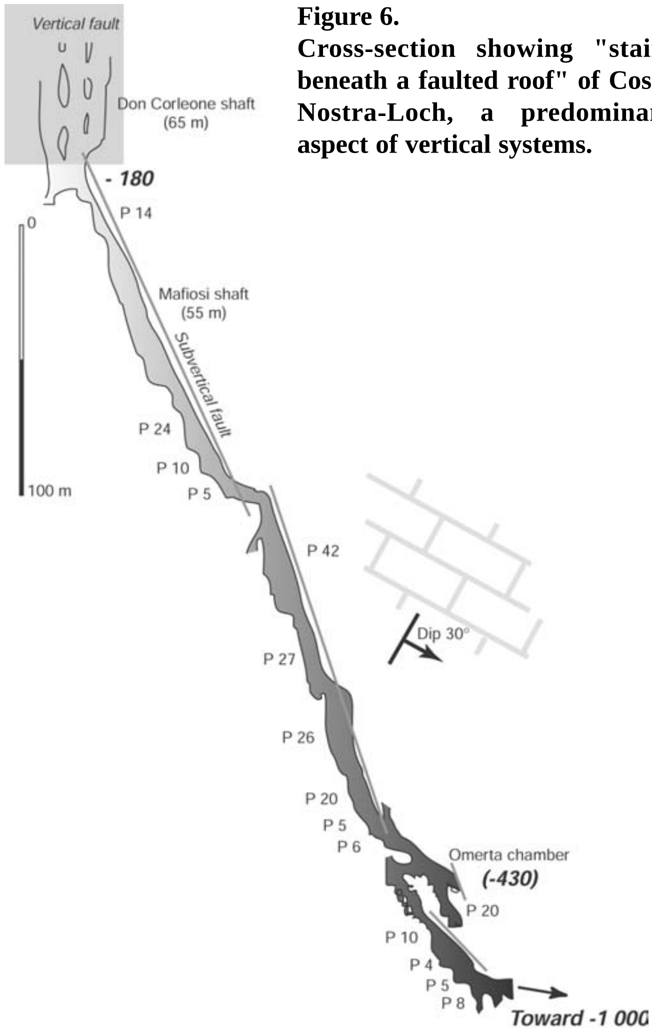


Figure 6.
Cross-section showing "stairs beneath a faulted roof" of Cosa-Nostra-Loch, a predominant aspect of vertical systems.

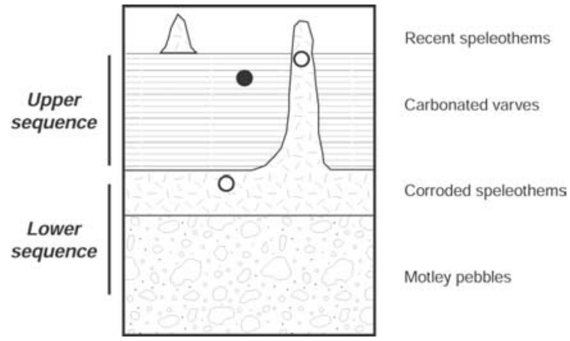


Figure 7. Generalized stratigraphic section of the sediments in the Bergerhöhle and Bierloch system. Black circles = normal paleomagnetic orientation; white circles = reversed paleomagnetism.

appears. The gradient decreases because of the presence of dolomite beds, which are only slightly permeable (Fig. 5). Beyond -1000 m, the river can no longer be followed. The conduit, even though a dry tube, has a nearly horizontal profile, which in places is broken by sudden level changes. A kilometer beyond, this passage connects with the Bergerhöhle-Bierloch System, a labyrinth of ~25 km of dry, partly horizontal tubes, but containing many vertical sections. A number of streamlets have entrenched the floors of the tubes into steeply sloping canyons interspersed with shafts, which lead to the present phreatic zone at minus 700-750 m. There are two entrances at this level of horizontal galleries, Bergerhöhle and Bierloch, which are located in the glacial hollow below the ~1000 m msl Platteneck summit. The lowest part of the system is Brunneckerhöhle. Its geometry is completely different from that of the Bergerhöhle-Bierloch. During periods of high water, the phreatic zone, normally 700 m msl at the sump in the Schotter Galerie ("Pebble Gallery"), forms a torrent that pours into a canyon consisting of ramps and cascades that eventually joins the Salzach level. Although the upper and lower parts of the system are still not connected by exploration, the whole system has a vertical range of >1500 m. In all, it contains about 30 km of surveyed passages.

Tertiary and Quaternary sediments. The Cosa-Nostra-Loch contains hardly any sediment. From -1000 m downward, varved carbonate sediments begin to appear that are typical of the Bergerhöhle network, covering the cave floor in a thick layer. Some sections include older sediments preserved beneath the varves. There are 2 successive sequences of sediments (Fig. 7). The lower sequence consists of a variety of pebbles (e.g. in Bierloch). These are overlain by a first generation of large speleothems. The pebbles come from the Jurassic strata overlying the Dachstein limestone. These strata have practically disappeared from the plateau. Their erosion was probably very long ago because there is no evidence of their presence in the sediments of the plateau. Today these strata remain only on the northern flank of the massif several hundred meters below the cave system. The pebbles were rounded by fluvial action before being trapped in the karst and, for this reason, they are known as "fake cave pebbles" (Schauberger 1961). They appear to provide evidence for old waterways draining across the Jurassic beds along the northern part of the massif at ~1000 m msl and, thus, ~500 m above the current level of the Lammer River. This suggests that the water inputs for the initial development of the system could have been allogenic. These high levels of fluvial erosion are apparently Pliocene (Toussaint 1971). The highly varied grain size of this sediment (clays with cobbles), indicates violent discharges with heavy loads. This suggests a climate with abundant, irregular, and occasionally heavy precipitation. Similar sediments, in the form of pebble conglomerates, which also contain Jurassic components, can be found on the neighboring Dachstein massif in the Hierlatzhöhle (Schauberger 1983). In the same way, these are linked to former periods of intense surface erosion, combined with torrential subterranean throughflows. The first generation of flowstone after the pebble deposits represents a cessation of stream flow, perhaps as the result of lowering of base level. Their micromorphology (micrite, alternating with transparent calcite containing fine reddish layers that include considerable clastic material) indicates that they were deposited in an unstable environment,

Table 1. Paleomagnetism results. Specimen NRM intensity, characteristic directions obtained from AF demagnetization, magnetostratigraphic interpretation.

Sample	Sediment type	NRM Int. (mA/m)	Decl. (°)	Incl. (°)	Polarity	Age (ka)
3 BR5 a	Stalagmite	0.001	342	59	Normal	< 780 ka
3 BR5 b	Brunnecker	0.002	340	55	Normal	< 780 ka
3 BR5 c		0.002	342	60	Normal	< 780 ka
1 BR5	Varves	0.02	012	00	Normal	< 780 ka
2 BR5	Brunnecker	9.5	334	04	Normal	< 780 ka
BR4	Stalagmite Bru.	0.4	340	68	Normal	< 780 ka
BH4 a1	Varves	11	021	12	Normal	< 780 ka
BH4 b1	Bergerhöhle	11	028	12	Normal	< 780 ka
BH4 a2		11	022	12	Normal	< 780 ka
BH4 b2		13	029	18	Normal	< 780 ka
BH2 a	Flowstone	0.1	094	-75	Reverse	> 780 ka
BH2 b	Floor	0.2	176	-59	Reverse	> 780 ka
BH2 c	Bergerhöhle	0.3	176	-59	Reverse	> 780 ka
BH3 a	Stalagmite	0.02	131	-50	Reverse?	> 780 ka?
BH3 b	Bergerhöhle	0.02	194	-73	Reverse?	> 780 ka?
BH3 c		0.008	148	-47	Reverse?	> 780 ka?

with sparse soil in the process of being removed. The upper sequence consists of varved carbonate sediments locally covered with more recent flowstone. These varved carbonates were deposited in a glacial environment. Thus, they correspond to one or more glaciations of the middle or late Pleistocene. This glacial phase is noted above all for its filling of karst voids at all levels. Even the intercrystalline pores of the ancient weathered flowstones of Bierloch are filled by calcite. Erosion is only superficial, as can clearly be seen on the flowstones in Bergerhöhle. In the Hierlatzhöhle (Dachstein massif), the glacial varves reach 5 m thick in the Lehmtunnel ("Clay Tunnel"), at an altitude close to those of Bergerhöhle (Schauberger 1983). This study noted a black film covering the varves in Hierlatzhöhle, in the Schwartzhalle and Schwartzgang ("Black Hall" and "Black Passage"), and in the Dachstein-Mammuthöhle, which gives a dull and sinister look. This can also be found in the Bergerhöhle as well in the Untersberg Caves (Haseke-Knapczyk 1989). Schauberger (1961) attributed these coatings to underground soot deposited after a huge fire that ravaged the Dachstein massif during the Atlantic interval (~7.5-4.5 ka), when the forest was widespread on all the high plateaus. However, the presence of this film in other areas undermines this unconvincing hypothesis. The film is probably simply due to superficial oxidation in contact with air. The end of the upper sequence has sparse speleothems, with some still active in the lower wooded areas of the karst above the Bierloch-Brunnecker System. These speleothems give evidence for a return to a biostatic environment (development of thick soils during a period of tectonic stability, when biotic activity was at a maximum).

Several samples have been dated. Paleomagnetism has been applied to stalagmites, flowstones, and varves. The natural remnant magnetizations (NRM) were measured with a rotating remanometer (JR5A Spinner Magnetometer) during demagnetization in an increasing alternating field (AF), up to 100 mT (Table 1). The measured intensity in flowstones was weak, which raised some difficulties in interpreting the result, as intensity became too low. However, varves show a strong magnetic intensity. Samples BR 4, BR 5, BH 4 (Fig. 8) have strong directional stability during demagnetization with characteristic directions showing normal polarities pointing toward deposition in the Brunhes period (<780 ka). Samples BH 2, BH 3 (Fig. 8) have a poorly defined behavior due to low intensity; nevertheless their direction seems to show reverse polarities that could be related to Matuyama period (>780 ka). However, these values are not completely reliable. Varves show a horizontal inclination, linked to sedimentation mechanisms. Magnetic anisotropic susceptibility measurements from BH 4 and BR 5 samples do not show any preferential axis, sedimentation occurring by decantation, without any current. This also proves primary magnetizations, acquired during sediment deposition (Audra & Rochette 1993).

Two speleothems were dated using U-series (alpha-counting). The weak $^{230}Th/^{232}Th$ ratio might show a contaminated system opening, so calculated ages are unreliable (Table 2). However, Holocene age for BR 2 is quite certain and concords with sediment stratigraphy. For BL 2, the calculated age corresponds to isotopic stage 6, the early beginning of last glacial stage "Riss." A low probability of speleothem development in a glacial context, indications of system opening, and incoherence with sediment stratigraphy suggest an older age, hence this date can not be taken at face value.

These data show the difficulties in establishing long-term chronology in karst environment, linked firstly to the lack of widespread dating methods for the ancient periods and secondly to stratigraphic discontinuities that often hinder correla-

Table 2. Geochemical data and sample radiometric age.

Sample	$[U]_{ppm}$	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	$^{234}U/^{238}U_{t=0}$	Age (ka)
BL 2	0.038 (± 0.002)	1.254 (± 0.072)	0.795 (± 0.043)	4.8 (± 0.4)	1.395	157.3 (+23.5/-18.5)
BR 2	0.228 (± 0.012)	1.357 (± 0.073)	0.047 (± 0.007)	2.2 (± 0.6)	1.362	5.2 (+0.9/-0.8)

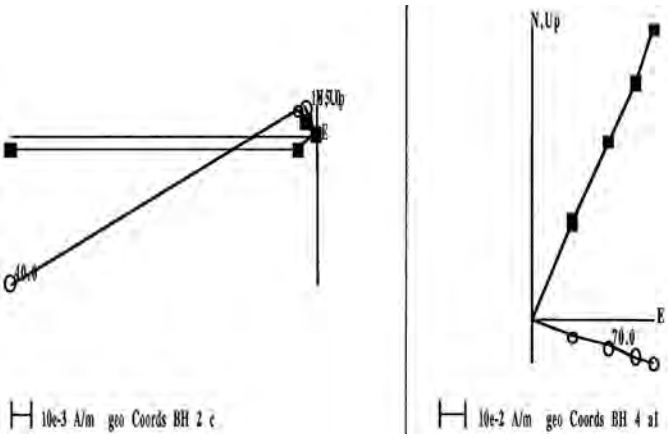


Figure 8. Orthogonal Zijderveld plots showing the NRM vector evolution during AF demagnetization up to 100 mT (BH 2, BH 4 samples).

tions. Nevertheless, these initial datings give evidence for 2 distinct periods (Fig. 2).

Bergerhöhle-Bierloch lower sequence old age is confirmed, its upper part corresponding to flowstones showing signs of reverse polarities, older than 780 ka. Paleomagnetic data are compatible with an early Pleistocene or Pliocene age. The conduits are located at a passage level controlled by local runoff, probably allogenic. Lowering of base level interrupted this process, allowing extensive calcite deposition to take place. All of this occurred in an unstable environment with extremely violent high waters, corresponding alternatively with either surface erosion bringing clays or the regrowth of woodland cover giving rise to calcite deposition. This stage can be linked both to the progressive cooling of the climate, as well as to continued uplift of the massif. Additional research is necessary to confirm this hypothesis.

Interpretation of the second depositional period is based on more solid evidence. The Brunnecker Pleistocene upper sequence seems to have developed during a recent normal period, being younger than 780 ka. It is still difficult to attribute its origin to one or more identified glaciations and to precisely identify the Salzach valley entrenchment steps. Advancing glaciers reactivated the deep karst, causing repeated flooding to heights of >600 m, partially choking the conduits with sediment. After this phase, the system drained and speleothems developed. But, the correlation of late Tertiary karst phases is not clear on a regional scale. This cave system has revealed its potential; the fairly similar layout of Pliocene-Quaternary cave systems of the high limestone Alps makes it possible to compare them and gives solid evidence for this evolutionary model. An accurate chronology, based on a detailed stratigraphy combined with dating, would be of interest.

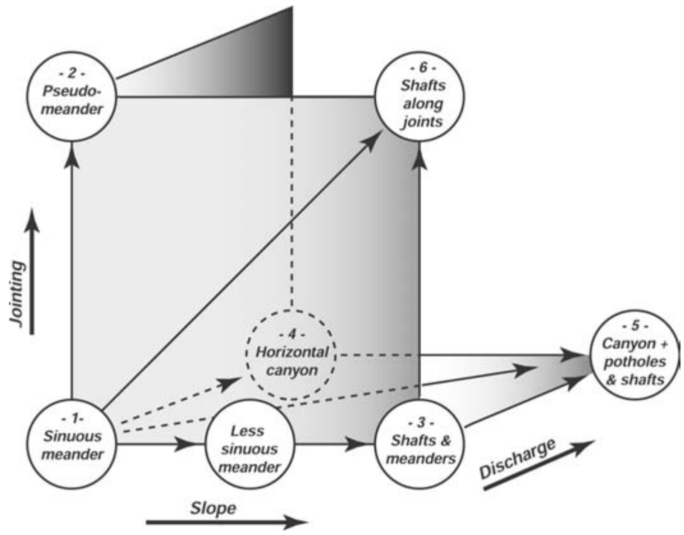


Figure 9. Predominant conduits in the vadose zone, in relation to slope, jointing, and discharge.

PARAMETERS DETERMINING THE CURRENT MORPHOLOGY AND HYDROLOGY

CONDUIT MORPHOLOGY IN VADOSE SYSTEMS

Parameters that determine the pattern of vadose conduits. A study of all kinds of vadose conduits leads to a model that incorporates 3 parameters: slope, jointing, and discharge (Fig. 9). The origin of a meander involves a number of factors. Jointing must be moderate (Fig. 9/1). If the slope is gentle, sinuous meanders will evolve into an angular system of joint-controlled pseudo-meanders (Fig. 9/2). If the slope is steep, shafts will dominate by capturing the runoff (Fig. 9/3). In addition, the discharge must remain moderate. Otherwise the conduits widen and become rather straight canyons. Depending on the amplitude of the initial floods, the original tubes will either be hardly affected or will alternatively form a “keyhole.” In the Tennengebirge, meanders are rare because of intense jointing and steep conduit gradients. Canyons (in the context of this paper) are underground galleries higher than they are wide, with abrupt rock walls entirely dissolved in limestone. Their main characteristic is their size, which is several meters wide and several dozens of meters to >100 m high. This type of canyon is generally not sinuous. The condition necessary for the establishment of such a canyon is great discharge (several 100s of L/sec to m^3/sec). These flows can move large clasts, such as pebbles several decimeters in diameter, as seen at Brunnecker. If the overall slope is small (Fig. 9/4), then the canyon will consist of a series of basins with channels linking them (e.g., Skocjan Cave in Slovenia). With increasing slope, small potholes appear. At the foot of each vertical drop, mechanical erosion will form potholes with the aid of suspended pebbles (Fig. 9/5). This is the classic morphology of tropical mountains, where high-relief shafts are fed by inputs from large perched basins (e.g., Mexico and China; Zhang *et al*. 1991). Brunnecker includes a canyon that consists of a series of inclined ramps interspersed with cascades of pits and potholes, where the high-water discharge can reach several m^3/sec. For there to be shafts there must be sufficient topographic potential. In most places, vertical routes are developed along joints, which enable rapid penetration of the limestone layers (Fig. 9/6). Thus, the large vertical systems, with successions of pits, are more likely in highly jointed carbonate rocks. The Austrian limestone high Alps have all these characteristics, and the large vertical shafts are a common feature particular to this area (some being >400 m deep). The intersection of a vertical fault and an inclined fault of 70° or 80° is typically responsible for the "staircase beneath a faulted roof" (Fig. 6). The inclined fault provides a steeply sloping roof, which guides the conduit. Beneath this fault roof, a succession of pits develops. Each pit, separated by narrow windows, forms a giant stairway that can extend over a vertical range of several hundred meters.

Jointing and vertical cross-sectional shape of the systems. As with detailed conduit morphology, jointing is a determining factor in the organization of vadose networks. Two kinds of vadose networks can be distinguished, depending on how well they are adapted to the geologic structure. Where jointing is moderate, conduits have a gentle slope, with meandering canyons predominating over shafts (Fig. 10, top). These conduits have many high-order tributaries and are fed by large drainage basins. The whole network has a slightly concave-upward profile. This makeup is common in gently sloping plateau karst (such as in the Vercors of France). On the other hand, where jointing and topographic potential are very strong, as in massifs with overthrusts, it is typical to have shaft series with a steep descent to the horizontal conduits (Fig. 10, bottom). Each one drains a relatively small basin, in places less than one hectare. The result is a great number of catchments, each with small discharge, leading to the low-gradient conduit system with only a very slight hierarchical arrangement. The whole network has a very concave-upward profile. These are common in the Austrian high alpine karsts.

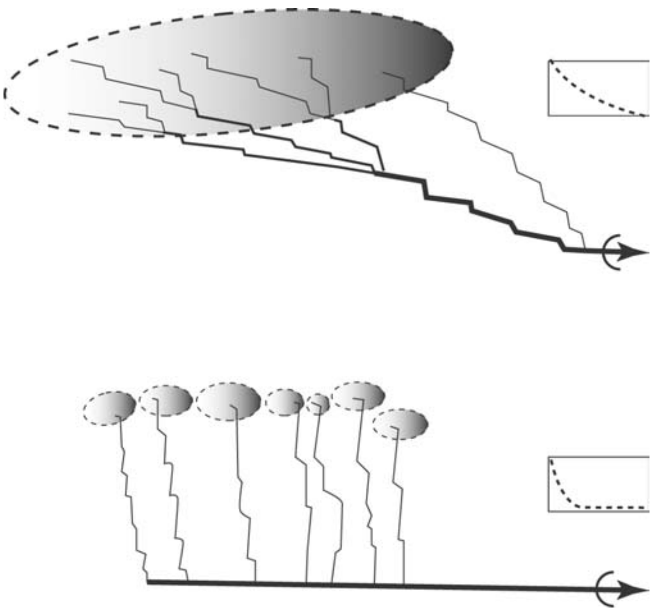


Figure 10. Morphology of passage in relation to jointing intensity. Above, with little jointing, profile is slightly concave and strongly hierarchical (e.g., Vercors). Below, in highly jointed rock, profile is strongly concave and only slightly hierarchical (e.g., Tennengebirge).

A DAMMED KARST

Karst drainage is determined by several parameters, such as structure of the karst aquifer, position of base level, and duration and phases of karst development. The great homogeneity of the Tennengebirge strata provides no significant differences on scale of the entire massif. The base-level position, having continually dropped since the late Tertiary, is a determining factor in the evolution of the karst and the nature of the runoff. The vertical speleogenetic potential, presently >1500 m, was developed before the Pleistocene, thus all of the major cave systems were developed before the Pleistocene. All of these variables determine the organization of underground circulation in the northwestern Tennengebirge, including that of the Cosa-Nostra-Bergerhöhle system.

The vadose zone. The vadose zone is typified by large shaft systems. As in all high mountain karsts, discharge is highly variable, and peak flows are very powerful. Intense jointing allows the drainage area to be partitioned into many small basins of several hectares each. Thus, it is not uncommon for 2 neighboring shafts to penetrate deep into the limestone without interconnecting. In the Cosa-Nostra-Loch, the River of the Incorruptibles enters at -600 m and then leaves the passage again at -1073 m. Most of the runoff comes from the Wieselstein area. Its discharge can vary from a few liters to 100s of L/sec. This water feeds the phreatic zone beneath the Bergerhöhle-Bierloch system at ~700-750 m msl.

The phreatic zone. The phreatic zone, whose top is at an elevation of ~700 m, drains most of the northwestern part of the Tennengebirge. The known tributaries come from the Wieselstein (Cosa-Nostra-Loch), Platteneck, and from the area

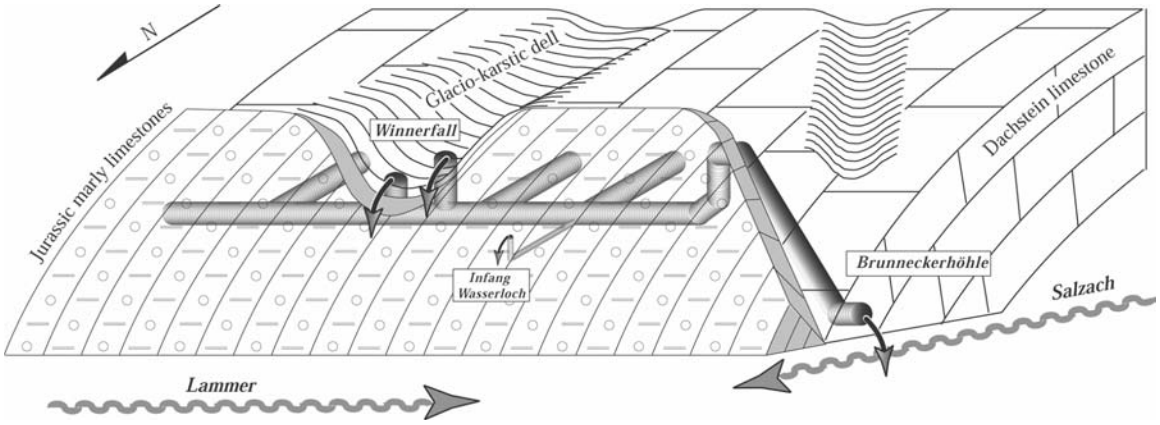


Figure 11. Impermeable Jurassic strata dam the Dachstein Limestone aquifer (not to scale). Spring outlets are located at structural lows where glaciers have eroded the Jurassic beds.

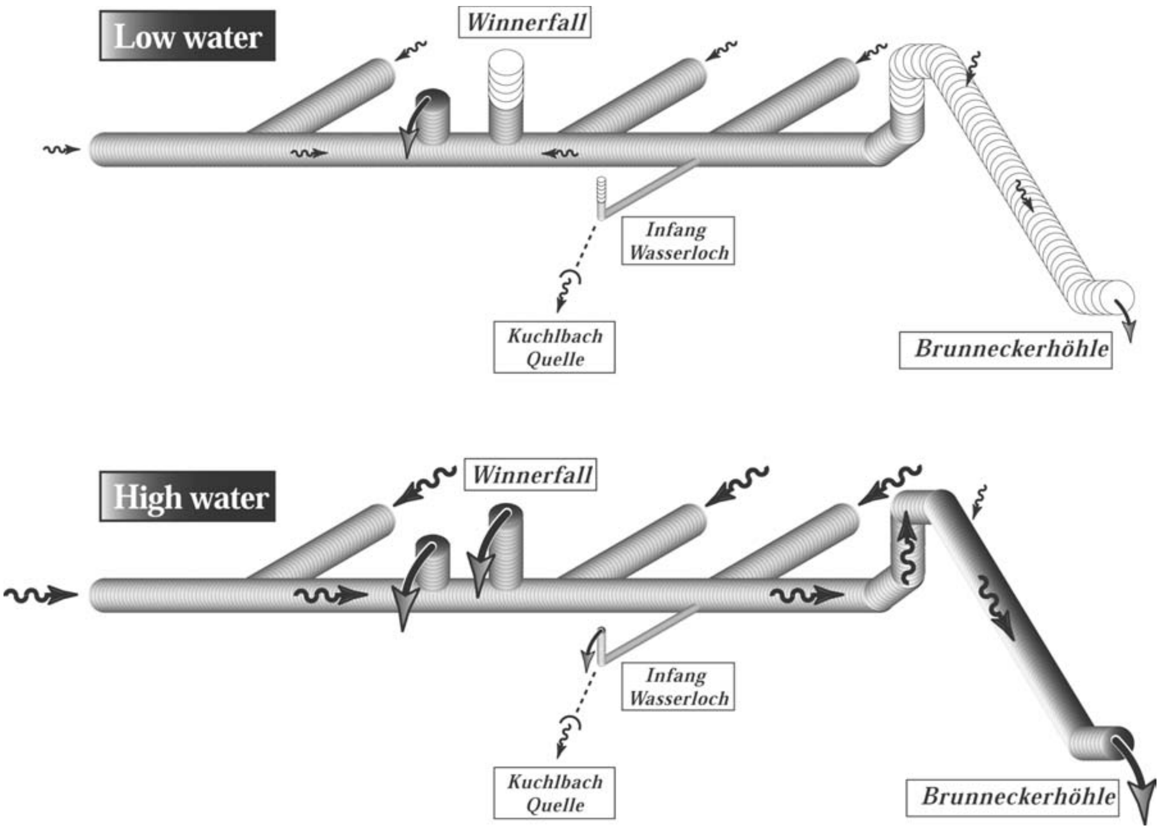


Figure 12. Nature and direction of the low water (top) and high water (bottom) flow in the -700 m phreatic zone.

above Bierloch. The latter passages are captured by the large N-S Bierloch fault, which during low water acts as a drain toward the north and as a low-permeability dam to water from the east. This phreatic zone originates from the Jurassic beds of marly schist, which have been preserved from erosion at the northern foot of the massif (Fig. 11). These act as a dam for water in the Dachstein Limestone aquifer. Outlets are located at low points in the geologic structure, which correspond to areas where the Jurassic layers have been eroded the most. The geological map shows these hollows to be located at the foot of glacial valleys (e.g., Winnerfall Spring), or at the outlet of the Salzach Gorge (Klappacher & Tichy 1986). Glaciers seem to have produced the localized erosion that determined these emergence points, and as a result they have controlled the organization of the entire phreatic zone. According to Toussaint (1971), this level of -700 m, which is clearly marked by horizontal galleries and levels of springs, corresponds to a former static base level. This would correspond to the "level V," dating from the Lower Pleistocene. Its development is linked to glacial activity, which supports the idea of evolution during this period. The only place where this structural dam has completely disappeared is at the level of the Salzach Gorge, where the erosional power of the glacier was much greater, and where the plunging saddle of Dachstein limestone is dissected by the valley. As a result, this potential outlet of the aquifer below 500 m msl has led to the development of the Brunnecker Cave System, which forms a link between the 700-m high phreatic zone and the present Salzach base level.

During low water, low discharge occurs (Fig. 12, top). The entire phreatic zone seems to be drained by the Kuchl Creek Spring (Kuchlbachquelle), which emerges at 670 m msl in the Infang Meadows (Infangalm), through the slightly karstified Jurassic beds. Their weak transmissivity is enough, however, to transmit moderate discharges. Thus, the "lithologic dam" is only a relative concept.

The epiphreatic zone. The level and amplitude of the epiphreatic zone fluctuates seasonally according to the amount of runoff. During high water resulting from storms or snow melt, the input can be 100 or even 1000 times greater than its usual flow, to the point that runoff from many sources reaches the water table more or less simultaneously (Fig. 12, bottom). The Kuchlbach Spring is unable to handle such a large input, even when its overflow outlet, the Infang Wasserloch, becomes active. As a result, the top of the phreatic zone in the aquifer rises several tens of meters, for example ~50 m for Bierloch and the Winnerfall. This rise activates higher-level springs with great discharges. One of these outlets, located ~80 m deep in the Bierloch phreatic zone, bypasses the damming influence of the Bierloch fault, discharging several m^3/sec into the Brunnecker sump. This runoff pours into the Brunnecker canyon, filling the bottom of the cave system, resulting in flooding to depths up to 50 m. In July 1991, after 10 days of heavy rainfall, the Brunnecker spring discharge was ~5 m^3/sec. Similarly, farther east, following a 50-m high flood, the Winnerfall Spring became active. However large these floodings in the epiphreatic zone may seem, at no time do they reach the 600 m mark, which is the level reached during Pleistocene glacial phases.

The emergences. The phreatic zone drains through a series of outlets, of which the main ones are (from east to west) the Dachserfall, Tricklfall, and Winnerfall. These are the 3 largest springs in the massif (Fig. 1). Directly connected to the phreatic zone, these are located at ~700 m msl and are perched ~150 m above the low parts of the Lammer valley. The average discharge is several 100s of l/sec. The Brunneckerhöhle, located at the Salzach level (500 m), has grown by capturing the phreatic zone at 700 m, which still remains perched above the cave (Fig. 11). This phreatic zone extends along the northern edge of the massif. It has an unusual drainage pattern. As the inflowing vadose water arrives, these infeeders do not have a preferential direction but instead diverge toward the springs, some of which are far apart from each other. Dye introduced in the western part emerged from both Winnerfall and Brunnecker (Toussaint 1971; Fig. 1). Thus, the behavior of the phreatic zone depends on the hydraulic conditions. At low water, the drainage is oriented along a south-to-north axis, and the phreatic water is able to drain through the structural dam. In contrast, during high water the structural dam serves as a significant choke, and so the bulk of the discharge is oriented east-to-west, where it escapes by overtopping the structural dam. The runoff then uses better-organized drains at a higher level, which are more capable of evacuating the water.

THE KARST SEDIMENTS: PALEOCLIMATIC AND HYDRODYNAMIC MARKERS

The deep karst is an environment well suited to preservation. It harbors old sediments that are no longer at the surface because of erosion. Their study is of prime importance to the understanding of karst genesis and paleoclimates (Audra 1995).

TYPICAL SEDIMENTS OF HOT OR TEMPERATE ENVIRONMENTS

Reworked weathered rocks. During the Tertiary, the warm, wet climates were responsible for intense chemical erosion of the rocks that produced the clastic covers of the Augensteine, the thick residuum of weathered rocks that were reworked and transported into the karst (Fig. 4). These reworked, weathered rocks are mainly made up of Augensteine, clays, and iron oxides (Weingartner 1983). These make up the oldest deposits in the studied caves, some certainly being linked to the first phases of the cave development. The weathered rocks were trapped in the cavities after the removal of the surficial cover. This erosion was linked to the change of precipitation patterns in the late Tertiary, as well as the climatic degradation at the end of the Pliocene. In any case, this climatically induced erosion was enhanced by tectonic uplift. The clearing of these covers, followed by their trapping in the inside of the karst, seems to be a common characteristic of the Pliocene-Quaternary evolution of temperate mountain karsts (Maire 1990; Fernandez-Gibert *et al*. 1994).

Speleothems of warm or temperate periods. The growth of flowstone is a function of vegetation cover, and thus of climate (Quinif 1992). As a result, speleothems do not normally develop in high alpine karst areas. Their complete absence in the Cosa-Nostra-Loch is considered evidence for a cold mountainous environment. In contrast, flowstone developed in the nearby perched horizontal galleries during the late Tertiary, such as Hornhöhle, indicating warm paleoclimates. Today speleothems are able to form at lower altitudes as soon as there is a vegetation cover (e.g., Bierloch and Brunnecker caves; Table 2). The crystalline fabric of the flowstone gives indications of the environment of deposition (Maire 1990). Transparent calcite indicates growth within a biostatic environment, with thick vegetation cover that blocks the descent of clastic sediment into deep openings and promotes supersaturation of infiltrating water, causing rapid speleothem growth. This was especially true for the first-generation speleothems of the Miocene and Pliocene Bergerhöhle and Eisriesenwelt. These characteristics can also indicate age, because such biostatic conditions have not existed in these mountains for a considerable length of time. Conversely, red and brown impurities and a succession of micro-layers indicate deposition in an unstable environment, when detrital material was carried in from overlying soil, with numerous interruptions of calcite deposition. This sudden acceleration of geomorphic processes, shown by the flowstones in old Tennengebirge cavities, appears to correlate with droughts, as was often the case during the late Tertiary, or periods of widespread cooling, as occurred several times during the Plio-Pleistocene. The flowstone surfaces also recorded events following their development. An eroded surface means that the cave has been reactivated by increased discharge following calcite deposition. Most flowstones in Tertiary caves contain such features, indicating complex climatic cycles during the late Tertiary or due to Pleistocene glaciation.

GLACIO-KARSTIC SEDIMENTS

Carbonate-rich varves in the epiphreatic zone. Glacial abrasion of the limestone massifs pulls off rock particles, which are then brought underground by sub-glacial streams. These particles are composed of calcite flakes (amounting to a total of 35-62% $CaCO_3$) as well as angular quartz grains. Seasonal glacial melting releases large amounts of runoff that overwhelms the underground systems, causing them to flood to heights of several hundred meters. The calcite particles are transported in a "uniform suspension" (Riviere 1977) that extends throughout the flooded conduits. Later the runoff decants during the slow winter draining of the system. The resulting sediments form alternating light and dark laminae that correspond to the successive hydrologic phases. Thus, these seasonal lacustrine deposits of glacial origin can be considered varves (Maire 1990), which give unquestionable evidence for past glaciation. In the absence of current and with calcite supersaturation, the erosive capacity of the melt water in the epiphreatic and phreatic zones is very weak. Their speleogenetic effect is mainly to seal the cave systems. There is much evidence for their inability to enlarge caves, such as the preservation of older flowstones, whose surfaces are slightly smoothed. Therefore, this suggests that these deep networks are in many cases pre-glacial and that they have been affected by a variety of runoff and environmental conditions (Bini *et al*. 1998).

Coarse glacial deposits in the vadose zone. Vadose conduits close to glacial meltwater streams contain easily identifiable fluvio-glacial sediments derived from the erosion of moraines. Their varied petrography consists of numerous crystalline and metamorphic phases carried in from high alpine areas by valley glaciers. These subterranean streams are very competent and can transport cobbles several dozens of centimeters long, for example at Brunnecker Spring (Fig. 13).

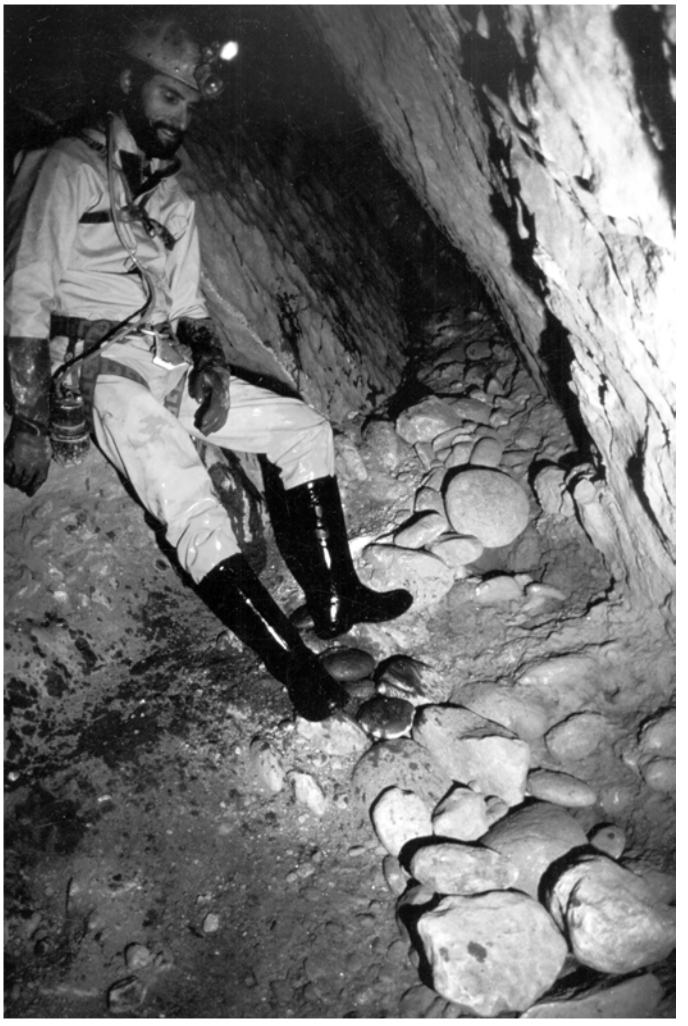


Figure 13. Wassergang ("Water gallery") in Brunneckerhöhle, showing deposits of allogenic moraine-derived pebbles. (Photograph by S. Caillault.)

CONCLUSION: EVOLUTION AND GENESIS OF THE TENNENGEBIRGE KARST

The Tennengebirge is distinguished by its great limestone thickness and steep local dips. Due to this thickness, along with alternating periods of uplift and stability, the massif retains a very clear record of all the different karst stages, exemplified by distinct passage levels (Fig. 2). This evidence will benefit future research on this subject, especially as more dates are obtained on deposits. Despite their altitude, the glacio-karstic features are very widespread, and their long evolution dating from the end of the Paleogene has left a strong geomorphic evidence for their Tertiary heritage. The karst is strongly linked with allogenic inputs, including:

- a widespread fluviokarst during the Miocene,
- a fluviokarst limited to the northern slope during the Pliocene,
- a Quaternary glacio-karst, fed by allogenic glaciers, which also blocked the outlets of deep cave systems.

The contribution of these external factors, especially the major allogenic water inputs, is the main explanation for the large size of the cave systems. Similar characteristics are well developed in the northern pre-Alpine massifs of France (Audra 1994). During this long developmental history, the hydrologic function of the karst depended on variations in the nature of the water inputs. High-water periods can be linked to "tropical" precipitation patterns or glacial melting. Concentrated infiltration during these brief periods caused sediment chokes and reactivation of higher-level passages and perched drains (Audra 1997). This sort of coincident activation of drains is still quite apparent today. Thus, not only does the Tennengebirge have all the characteristics of high alpine karst, but it also contains evidence for a long karstic evolution, which many other more relatively recent evolved alpine massifs do not have. For example, the Tennengebirge contrasts with certain massifs of Savoy (France) and Switzerland, where the exposure of carbonates by erosion of their insoluble cover has occurred much more recently (Maire 1990).

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REFERENCES

Audra, P., 1994, Karsts alpins. Genèse de grands réseaux souterrains. Exemples : le Tennengebirge (Autriche), l'Ile de Crémieu, la Chartreuse et le Vercors (France) [Alpine karsts. Genesis of large cave systems] [thesis]: Karstologia Mémoires, France, Grenoble 1 University, v. 5, 280 p.

Audra, P., 1995, Signification des remplissages des karsts de montagne [Signification of mountain karst infillings]: Karstologia , v. 25, p. 13-20.

Audra, P., 1997, Le rôle de la zone épinoyée dans la spéléogenèse [The epiphreatic zone part in the speleogenesis], in Proceedings, 12th International Congress of Speleology, La-Chaux-de-Fond: International Union of Speleology / Swiss Speleological Union, la Chaux-de-Fonds, v. 1, p. 165-167.

Audra, P., & Rochette, P., 1993, Premières traces de glaciations du Pléistocène inférieur dans le massif des Alpes. Datation par paléomagnétisme de remplissages à la grotte Vallier (Vercors, Isère, France) [First traces of lower Pleistocene glaciations in the alpine massif. Datation by paleomagnetism of the fillings in the Vallier cave (Vercors, Isère, France)] : Compte-rendu à l'Académie des sciences, S. 2, 317, 11, Académie des sciences, Paris, p. 1403-1409.

Bauer, F., & Zötl, J., 1972, Karst of Austria: Karst, the important karst regions of the Northern Hemisphere, Elsevier, Amsterdam, p. 225-265.

Bini, A., Tognini, P., & Zuccoli, L., 1998, Rapport entre karst et glaciers durant les glaciations dans les vallées préalpines du Sud des Alpes [Karst and glaciations in the southern pre-alpine valleys]: Karstologia, v. 32, p. 7-26.

Fernandez-Gibert, E., Palomarès, M., Rossi, C., & Tortosa, A., 1994, Analisis de procedendia en arenas karsticas: Evidencia de una cobertera permotriasica erosionada en el macizo occidental de Picos de Europa [The origin of karst sands: Evidence of Permo-Triassic cover erosion in Western Picos de Europa massif], *in* Actas del 1 congreso internacional sobre Picos de Europa, Oviedo 1991: Asturian Speleological Federation, Oviedo, p. 1-14.

Füchtbauer, H., 1967, Die Sandsteine in der Molasse nördlich der Alpen [Molasse sandstones in the Northern Alps]: Geologische Rundschau, v. 56, p. 266-300.

Goldberger, J., 1951, Reste abgetragener Höhlen auf dem Hochkönig [Relics of eroded caves in Hochkönig]: Die Höhle, v. 1, p. 9-11.

Goldberger, J., 1955, Die Altlandschaft auf dem Hochkönig [Inherited landscapes in Hochkönig]: Mitteilungen der Österreichischen Geographischen Gesellschaft, v. 97, p. 183-191.

Häuselmann, P., Jeannin, P.-Y., & Monbaron, M., in review, Genesis of caves - A new, comprehensive model: Zeitschrift für Geomorphologie.

Haseke-Knapczyk, H., 1989, Der Untersberg bei Salzburg [The Untersberg near Salzburg]: Wagner, Innsbruck, 224 p.

Klappacher, W., & Knapczyk, H., 1985, Salzburger Höhlenbuch [Salzburg's caves book]: Landesverein für Höhlenkunde, Salzbourg, v. 4 (Tennengebirge), 557 p.

Klappacher, W., & Tichy, G., 1986, Geologische Karte des Tennengebirges [Tennengebirge geological map]: Salzburger Höhlenbuch: Landesverein für Höhlenkunde, Salzbourg , v. 4 (Planbeilagen).

Langenscheidt, E., 1986, Höhlen und ihre Sedimente in den Berchtesgadener Alpen [Caves and their sediments in the Berchtesgaden Alps]: Forschungsbericht , Berchtesgaden National Parc, v. 10, 95 p.

Lechner, J., 1949, Neue karst - und quellengeologische Forschungen im Toten Gebirge [New karstic and hydrogeologic researches in Totes Gebirge]: Vollversammlung der Bundeshöhlenkommission, Vienna, v. 3, p. 32-38.

Lehmann, O., 1922, Die große Eishöhle im Tennengebirge (Salzburg). (Eisriesenwelt) [The large ice-cave in Tennengebirge (Salzburg), (Eisriesenwelt)]: Speläologisches Jahrbuch , v. 2, p. 52-121.

Lemke, K., 1984, Geologische Vorgänge in den Alpen ab Obereozän im Spiegel vor allem der deutschen Molasse [Geological conditions in the Alps from Upper Miocene compared to the German molasse]: Geologische Rundschau, v. 1, p. 371-398.

Maire, R., 1990, La haute montagne calcaire [The calcareous high mountain] [thesis]: Karstologia Mémoires, Nice University, v. 3, p. 731.

Pia, J., 1923, Die große Eishöhle im Tennengebirge (Salzburg), (Eisriesenwelt). Geologische Beobachtungen [The large ice-cave in Tennengebirge (Salzburg), (Eisriesenwelt), geologic observations]: Speläologisches Jahrbuch 2, p. 48-65.

Quinif, Y., 1992, L'apport des méthodes de datation absolue : la méthode Uranium/Thorium [Contribution of absolute dating methods: The U/Th series method]: Journées Pierre Chevalier, Grenoble, Spéléo-club de Paris, p. 248-260.

Riviere, A., 1977, Méthode granulométrique. Techniques et interprétations [Granulometric method. Technic and interpretations]: Masson, Paris, 167 p.

Schauberger, O., 1961, Über falsche Höhlenschotter [The fake cave pebbles]: Die Höhle, v. 12, p. 12-14.

Schauberger, O., 1983, Geologische und morphologische Beobachtungen in der Hierlatzhöhle (Dachstein) [Geologic and morphologic observations in Hierlatzhöhle cave (Dachstein)]: Schiftenreihe des Heimatmuseums, "Ausserland", v. 4, p. 1-21.

Seefeldner, E., 1961, Salzburg und seine Landschaften: Eine geographische Landeskunde [Salzburg and its landscapes: A geographic contribution]: Bergland-Verlag, Salzbourg , p. 573.

Tichy, G., Klappacher, W., & Knapczyk, H., 1985, Geologische Übersicht [Geological overview]: Salzburger Höhlenbuch, v. 4, p. 27-45.

Tollmann, A., 1968, Die paläogeographische, paläomorphologische und morphologische Entwicklung der Ostalpen [Paleogeogaphy, palaeomorphology and morphologic evolution of the Eastern Alps]: Mitteilungen der Österreichischen Geographischen Gesellschaft, v. I-II, p. 224-244.

Toussaint, B., 1971, Hydrogeologie und Karstgenese des Tennengebirges (Salzburger Kalkalpen) [Hydrogeology and karst genesis of the Tennengebirge (Salzburg calcareous Alps]: Steirische Beitrage zur Hydrogeologie, v. 23, p. 5-115.

Trimmel, H., 1992, Quelques remarques sur le développement des grottes des Alpes orientales au Pléistocène et à l'Holocène [Some remarks about Eastern Alps cave evolution from Pleistocene to Holocene]: Karst et évolutions climatiques, hommage à J. Nicod, Talence, University Press, p. 285-292.

Weingartner, H., 1983, Geomorphologische Studien im Tennengebirge [Geomorphological studies in Tennengebirge]: Arbeiten aus dem Institüt für Geographie der Universität Salzburg (A. G. I. S.), v. 9, p. 205.

Zhang, S., Audra, P., & Maire, R., 1991, Les systèmes karstiques et les cavités [Karst systems and caves (in China)]: Karstologia Mémoires, Gebihe 89, karsts de Chine, v. 2, p. 150-161.

DESIGNATION OF PROTECTED KARSTLANDS IN CENTRAL AMERICA: A REGIONAL ASSESSMENT

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The IUCN World Commission on Protected Areas has recognized karst landscapes as important targets for designation as protected areas, and this study is a regional inventory of the Central American karst conservation situation.

Central America is a significant international carbonate karst landscape, covering ~154,000 km², roughly a quarter of the regional land area. The karstlands exhibit considerable topographic diversity, including "cockpit" and "tower" styles, together with extensive dry valleys, cave systems, and springs. Some of the karst areas are well known, but others have yet to receive detailed scientific attention. Many of them have archaeological, historical, cultural, biological, aesthetic, and recreational significance, but human impacts have been considerable.

Conservation and protection legislation is variable in nature and effectiveness, and enforcement is problematic. About 18% of the Central American karst landscape has been afforded nominal protection through designation as protected areas. Regional levels of karstland protection are highly variable, with significant protection in the Yucatan peninsula, Honduras, and Belize; intermediate protection in Guatemala, Costa Rica, and Panama; and, as yet, no protected areas in Nicaragua or El Salvador. The situation remains fluid, and the future of the Central American karstlands is uncertain.

Central America constitutes a significant international carbonate karst landscape, with an area totaling ~154,300 km², or ~23% of its total land (Kueny 2000; Day & Kueny in press). Seventy-five percent of Central America's karst is on the Yucatan Peninsula, with other significant areas in Guatemala, Belize, and Honduras. Considerable geologic, topographic, and environmental heterogeneity characterizes the region, but Central America contains many dramatic karst landscapes, including cockpits, towers, dry valleys, sinkholes, cenotes, and extensive cave systems, plus an impressive marine karst landscape, including the world's second longest barrier reef, off the Caribbean coast of Belize.

In 1997, the International Union for the Conservation of Nature and Natural Resources (IUCN) World Commission on Protected Areas (WCPA) recognized karst landscapes worldwide as being in significant need of protection (Watson *et al*. 1997). This need for environment protection and the establishment of protected areas is also gaining regional acceptance and support through both government and non-government efforts of, for example, the Central American Commission on Development and the Environment (CCAD) (WCMC 1992; Hamilton-Smith 1999).

The World Conservation Monitoring Centre (WCMC) has compiled a database of protected areas in Central America, but does not identify protected karst areas or any other landscape type in its database. Gillieson (1996), however, calls for the establishment of databases that detail protection and conservation efforts in these landscapes. This study addresses these issues by providing an initial inventory and assessment of protected karst areas in Central America.

METHODOLOGY

For the purposes of this study, Central America is regarded as the isthmus between Mexico and South America, plus the Yucatan Peninsula (Blouet & Blouet 1997). This region includes the karsts of Belize, Guatemala, Honduras, El Salvador, Costa Rica, Nicaragua, and Panama, plus those of the Mexican states of Yucatan, Campeche, and Quintana Roo.

The primary objective of this study is to assess the extent to which the Central American karst landscape is afforded at least nominal protection by its designation as protected areas. To this end, two sets of data are employed: one on the extent of the regional karstlands, the other on the location and size of regional protected areas.

Information about the extent of carbonate karstlands within the region is available from a number of diverse sources, including geologic and topographic maps, atlases, previous research, and personal experiences. For a summary of this information, which is of variable reliability, see the list of references, particularly Middleton and Waltham (1986) and Kueny (2000), and Table 1. To ensure consistency, we assume that all expanses of carbonate rocks indicated in geologic sources do, in fact, represent karst landscapes. For this reason, all karst-area data should be regarded as approximate, which may ultimately result in a conservative calculation of the proportion of karst designated as protected areas.

Reliable information on protected areas is equally difficult to acquire, particularly given the wide array of protected-area legislation, variations in size and terminology, and the difficulties of *de facto* verification. The primary source of information is the United Nations List of Protected Areas, which is main-

Figure 1. Location of major karstlands in Central America.

Table 1. Selected sources of information about karstlands in Central America.

Country	Sources
Belize	Day 1993, 1996; Miller 1996; Reeder *et al.* 1996; Middleton & Waltham 1986; Veni *et al*. 1996.
Costa Rica	Instituto de Costarricense de Turismo 1995; Day 1993; Mora 1992; Middleton & Waltham 1986; Peacock *et al*. 1993; Troester *et al*. 1987.
El Salvador	Day 1993; AID 1966.
Guatemala	Day 1993; Middleton & Waltham 1986; Instituto Geografico Nacional 1970.
Honduras	Day 1993; Middleton & Waltham 1986; AID 1966.
Nicaragua	Day 1993; Middleton & Waltham 1986; AID 1966.
Panama	Day 1993; Middleton & Waltham 1986; AID 1967.
Mexico	Day 1993; Middleton & Waltham 1986; Troester *et al*. 1987.

tained and updated by the World Conservation Monitoring Centre (WCMC). These data are supplemented by information on additional protected areas obtained from individual government sources and other studies, particularly those by Day

Table 2. Karst styles of Central America.

Country	Towers	Cockpits	Sinkholes/ Dry Valleys	Marine
Belize	X	X	X	X
Costa Rica		?	X	X
El Salvador			X	
Guatemala	X	X	X	
Honduras	?	X	X	X
Mexico,Yucatan			X	X
Nicaragua		?	X	
Panama		?	X	X

Figure 2. Sinkholes (dolines) at Uxmal, Yucatan.

(1993) and Kueny (2000), which do not necessarily conform to UN criteria. Protected areas include national, state, and private parks and forests and wildlife, forest, and archaeological reserves, without regard to issues of effective protection or future status.

KARST AREAS OF CENTRAL AMERICA

The carbonate rocks of Central America (Fig. 1) represent discontinuous carbonate deposition from the Jurassic (208-144 Ma) to the Quaternary (<1.6 Ma). Dissolution of these carbonate rocks has produced a range of karst landscapes including dry valleys, sinkholes and cockpits, residual towers, and extensive cave systems (Table 2; Figs. 2-7). Karst landscapes in Central America have been and still are influenced by tectonic, eustatic, and climatic changes (Weyl 1980; Whitmore & Prance 1987; Gardner 1987; Dengo & Case 1990; Mann 1995) and have also undergone significant alterations as the result of human activity (Day 1993).

The most extensive Central American carbonate karst area is in the Yucatan Peninsula (Fig. 1; Table 3), where >125,000 km² of Tertiary and Quaternary carbonates give rise to a subdued karst landscape characterized by shallow sinkholes, low residual hills, cenotes, and flooded cave systems (Figs. 2-3). A second extensive karst area, including cockpit and tower karst

Figure 3. Cenote, Chichen Itza, Yucatan.

Figure 4. Polygonal (cockpit) karst, Peten, Guatemala.

Table 3. Protected karst in Central America

Country	Karst Area km²	Protected Karst Area km²	% Karst Protected	Number Protected
Belize	5000	3400	68	18
Costa Rica	2000	68	3	5
El Salvador	300	0	0	0
Guatemala	15000	1517	10	7
Honduras	10000	3500	35	7
Mexico:				
Campeche	45000	7232	16	1
Quintana Roo	35000	7712	22	3
Yucatan	35000	4407	13	3
Nicaragua	5000	0	0	0
Panama	2000	80	4	1
TOTALS	154300	27916	18	45

Source: Kueny 2000

developed in Cretaceous and Tertiary carbonates, extends through the Peten of eastern Guatemala into Belize (Figs. 4-8), covering nearly 15,000 km², with other karst areas in the Alta Verapaz and Huehuetenango Departments of Guatemala (Fig. 1).

Honduras has three major karst areas covering ~10,000 km²: the Montana Santa Barbara in the northwest, the Cordillera Agalta in central Honduras, and the Sierra de Colon and Cordillera Entre Rios in the southeast bordering Nicaragua. The karst in both Montana Santa Barbara and

Figure 5. Polygonal karst depression hillslope, Peten, Guatemala.

Figure 6. Karst tower, Gracy Rock, Belize.

Cordillera Agalta have received only moderate scientific attention and that on the Sierra de Colon has received even less due

Figure 7. Dry valley, Hummingbird karst, Belize.

to its remoteness and dense vegetation (Middleton & Waltham 1986).

There are also significant carbonate karst areas in Nicaragua and throughout Costa Rica (Troester *et al.* 1987; Mora 1992; Peacock & Hempel 1993) (Fig. 1). Karst occurs in Panama in the Archipielego de Bocas del Toro along the northwest border with Costa Rica, in the Maje Mountains of central Panama near the Río Chepo o Bayano, and in the eastern Darien Department (Fig. 1; AID 1967; Reeves 2000). El Salvador has <300 km^2 of karst, located along the border with Honduras and Guatemala south of Anguiatu (Fig. 1; AID 1966).

Considerable topographic variation characterizes the karst of Central America as a whole, although three distinct karst terrain styles–doline, polygonal (cockpit/cone), and tower–are recognized by Day (1979, 1993). Dry or underdrained valleys and subdued depressions or dolines (Figs. 2 & 7) occur throughout the region but have received little scientific attention. Cockpit, cone, and tower karst occurs in Belize, Guatemala, Honduras, and Nicaragua (Table 2; Figs. 4-6). Variations of these types occur throughout Central America and are not restricted to the areas described above. Caves, formed by the underground dissolution of carbonate rock, are also abundant (Middleton & Waltham 1986).

Widely published scientific research has been conducted in some Central American karst areas, notably in Belize (Miller 1996, 2000; Veni *et al*. 1996) and Costa Rica (Troester *et al* 1987; Mora 1992; Peacock & Hempel 1993), but overall the regional karst offers considerable scope for future research (Day & Kueny in press). The karst areas of Honduras and Nicaragua, in particular, warrant further study, although this may be hindered by problems of accessibility.

KARST ENVIRONMENTS

The Central America karstlands are far from homogeneous with respect to geologic and geomorphic factors. Moreover, climate, soils, and biota are also variable, leading to a wide

Figure 8. Tikal, Peten, Guatemala

range of specific karst environments.

The karst rocks themselves range from pure, dense, hard, fractured, crystalline limestones, some much altered from their original state, to impure, powdery, soft, porous, amorphous carbonates (Day 1979; Troester *et al.* 1987; Mora 1992; Miller 1996). Some are covered by volcanic ash, some are brecciated, and others have been folded and faulted. Karst landscape elevations range from sea level up to 2000 m msl; some are mountainous, others planar; some are hydrologically isolated, others receive surface drainage from higher, adjacent non-karst terrains.

Climate varies too, with mean annual precipitation ranging from <1000 mm to >3000 mm. Precipitation is influenced by shifting atmospheric pressure belts, prevailing winds, and orographic effects (Clawson 1997). Rainfall generally increases with elevation, and leeward locations experience higher temperatures and lower precipitation than karst areas to the windward. As a result of shifting atmospheric pressure belts, there are distinct winter dry periods of differing intensity and duration, with prevailing winds and elevated landmasses also accounting for spatially uneven rainfall distribution (Clawson 1997). Late summer hurricanes and tropical depressions can cause severe flooding in normally dry karst areas. Temperatures are influenced mainly by altitude and ocean currents, generally decreasing with increasing altitude and with increasing distance from the coast (Clawson 1997).

The predominant soil types in the Central American karst are calcimorphic mollisols and vertisols, although complex associations of other orders also occur (Furley & Newey 1983; Whitmore & Prance 1987; Blouet & Blouet 1997). Karstland soils are extremely variable, but generally tend to be clay-rich, heavily leached, patchy and thin, except in depressions and valley bases, where they are deeper. Steep slopes may have no soil cover except in joints and solutional pockets. Differences in climate, vegetation, age, and relief account for major differences in karst soil types throughout Central America, and many soils have been altered by agricultural practices (Blouet & Blouet 1997).

The natural karstland vegetation varies from xerophytic scrub to wet tropical broadleaf forest, including both deciduous and evergreen trees, although much of the original forest has been cleared, with only fragments remaining in remote karst areas. For general overviews of karst landscape ecology, see Gillieson (1997) and Vermeulen and Whitten (1999), and for a Central American perspective see Day (in press). Central America also supports one of the world’s most diverse wildlife assemblages (Iremonger & Sayre 1994), and specifics of the regional karstland ecology warrant additional studies. Biological significance is a major factor in designation of protected areas within the Central American karst, as elsewhere (Hamilton-Smith 1999).

Human impact on Central American karst landscapes has been long-term and severe, in particular through forest clearance, species introduction, agriculture, degradation of water resources, and industrial activities, including mining and quarrying (Watts 1987; Day 1993). Important archaeological sites, both surface and subterranean, are significant facets of karstlands throughout Central America (Hartshorn *et al*. 1984; Day 1993; Fig. 8).

Particular threats to the Yucatan karst include hotel expansion along the coast, illegal quarrying activities, and the potential impacts of inappropriate attempts to restore quarried areas (Hamilton-Smith 1999). In Belize, adverse impacts range from agricultural expansion to increasing tourism (Day 1996). Forest reserves continue to be logged despite local opposition and quarrying of limestone for construction projects is ongoing. In Guatemala and Honduras, the World Conservation Monitoring Centre (1992) lists major threats as including the exploitation of floral and faunal resources, the establishment of settlements within protected areas, and unclear or ineffective legislation.

PROTECTION OF KARST LANDSCAPES

With a restricted land area of 679,435 km² (Europa 1999) and a dense population approaching 126 million (CIA 1999), pressures on natural resources in Central America are severe, although most nations now recognize the importance of resource protection for environmental, economic, and social reasons. Particular stress on karstlands results from forest clearance, agriculture, degradation of water resources, and industrial activities, including mining and quarrying (Watts 1987; Day 1993; Vermeulen & Whitten 1999). Throughout the region, efforts to conserve natural resources have involved the establishment of protected areas in which human activities and impacts are restricted.

The importance of karst landscape protection was highlighted in 1997 by the International Union for the Conservation of Nature and Natural Resources (IUCN) Working Group on Cave and Karst Protection, which published guidelines for the design and maintenance of protected karst areas. Rationales for the protection of karst areas as significant landscapes include the following: habitats for endangered species of flora and fauna; areas possessing rare minerals and/or unique landscape features; important historic and prehistoric areas with cultural importance; important areas for scientific study across a variety of disciplines; religious and spiritual areas; areas of specialized agriculture and industry; important areas to the understanding of regional hydrology; and as recreation and tourism areas with important economic and aesthetic value (Watson *et al*. 1997). These rationales notwithstanding, very few karst areas are designated for protection because of their intrinsic overall value as karst landscapes. Rather, they are selected for protection in recognition of the specific biological or cultural traits associated with, and inextricably linked to the karst.

REGIONAL PROTECTED AREAS LEGISLATION

Protected areas legislation throughout Central America is highly variable as a result of the multiplicity of sovereign nations, government agencies, and non-government organizations. The Central American Commission on Development and the Environment (CCAD) is one regional arbiter of conservation strategies, but the levels of participation by the countries considered here are variable. All have adopted both the UN Convention for the Protection of World Natural and Cultural Heritage and the UNESCO Man and the Biosphere Program (MAB). Some of the legislation relevant to karst landscapes is summarized in Table 4, and additional details are provided by the World Conservation Monitoring Centre (1992).

Several countries have cooperated in establishing protected areas that traverse political boundaries. For example, in 1982 Costa Rica and Panama signed the Basic Convention for Creation of the Park (Convenio Básico de Creación del Parque), a binational agreement for the establishment of the La Amistad Transfrontier Park. Costa Rica and Nicaragua have also cooperated to create a protected areas system between their countries (WCMC 1992), yet establishment of a protected area is incomplete. Costa Rica, Guatemala, Honduras, and Mexico participate in the UN Food and Agriculture

Table 4. Protected area legislation in Central America.

Belize	Forest Ordinance (1927, revised in 1958)
	The Crown Land Ordinance (1924, revised in 1958)
	National Parks System Act No. 5 (1981)
	Wildlife Protection Act No. 4 (1981)
Costa Rica	Forestry Law No. 4465 (1969)
	National Parks Service Law No. 6084 (1977)
	Wildlife Conservation Law No. 6919 (1984)
	Reformation of the Forestry Law No. 7174 (1990)
	Ministry of Natural Resources, Energy And Mines established under Law No. 7152 (1986)
El Salvador	Forestry Law (1973)
	Ministerial Decree No. 236 National Parks and Wildlife Section (1981)
	Basic Land Reform Law (1981)
Guatemala	Forestry Law (1921)
	Forestry Law Decree No. 7089 (1989)
	National Environment Commission established under Law for the Protection and Improvement of the Environment Decree No. 6886 (1986)
	Law of Protected Areas Decree No. 4 89 (1989)
	Department of Petén Biosphere Reserve Decree No.590 (1990)
	Eastern Lowlands Biosphere Reserve Decree No. 4990 (1990)
Honduras	1982 Constitution declares all natural resources to be state property
	Forestry Law Decree 85 (1971)
	Decree Law No. 103 (1974) established the Honduran Forest Development Corporation
	Decree No. 123 (1974) established General Directorate for Forest Resources and Wildlife
	General Forestry Regulation, Resolution No. 634 (1984)
	Cloud Forest Law, Decree No.87 (1987)
Mexico	1st protected area created in 1876
	Forestry Law (1926)
	Forestry Law (1942)
	Forestry Law (1948)
	General Law for Ecological Equilibrium and Environmental Protection (1988)
Nicaragua	Law for the Creation of the Nicaraguan Institute of Natural Resources and the Environment (1979)
	Law for the Establishment of the National Parks Service, Decree No. 340 (1979)
	Decree No. 1194 (1983) established a national parks act
	Decree No. 1294 (1983) created a wildlife refuge act
	Decree No. 1320 (1983) declared 14 protected areas as nature reserves
	Decree No. 527 (1990) created
	Decree No. 42 91 (1991) declared protected remnant montane ecosystems in the central part of the coun try, pine forests of the Caribbean coast, and vol canic craters of the Pacific slope mountains
Panama	General Forestry Law No. 39(1966)
	National Institute of Natural Renewable Resources (1986)
	National Plan for Environmental Protection and Rehabilitation (1989)
	Forestry Action Plan for Panama (1990)

Source: World Conservation Monitoring Centre, 1992.

Organisation's Latin American Network Program, which "aims to coordinate the activities of participating countries, to assist in the implementation and functioning of a coherent and effective national system of protected areas in each country" (WCMC 1992).

Conservation in Central America began before European contact, with the implementation of protective measures in sensitive areas (Gómez-Pompa & Kaus 1990), planting of trees, and creation of botanical gardens and zoological parks (WCMC 1992). Some Central American countries inherited colonial legislation restricting certain activities in designated areas, although this was largely intended to protect economic rather than environmental interests, particularly those in timber production and mining.

Most protected-areas legislation is of more recent, post-independence vintage, with the majority of Central American countries adopting late 20th century constitutional provisions for the designation of protected areas (Table 4). Throughout the region, significant karst landscapes are variously encompassed within national parks (e.g., Tikal in Guatemala, Cocos Island in Costa Rica, and Santa Barbara in Honduras), forest reserves (e.g., the Vaca and Chiquibul Forest Reserves in Belize), wildlife reserves, refuges and sanctuaries (e.g., Machaquila-Cuevas de San Miguel Wildlife Refuge in Guatemala) and other conservation areas (e.g., the Río Bravo Conservation and Management Area in Belize). Karstlands are present in at least 5 UNESCO World Heritage Sites: Tikal, Cocos Island, Darien, La Amistad, and Sian Ka'an, the last 3 of which are also Man and the Biosphere Reserves. Much of the Guatemalan Peten karst is incorporated in the Maya Biosphere Reserve.

Regionally, the pattern of protected-areas legislation is inequitable, with levels of protection reflecting population, economic, and political pressures and with application and enforcement minimal. There is considerable scope regionally for the continued development and implementation of effective protected areas policy and enforcement (Margules & Pressey 2000).

International non-governmental and inter-governmental organizations also play a role in the proposal, identification, establishment, and management of protected areas. Organizations involved nationally and regionally include the International Union for the Conservation of Nature and Natural Resources (IUCN), the World Wide Fund for Nature (WWF), Conservation International (CI), the Nature Conservancy (TNC) and the International Council for Bird Preservation (ICBP).

PROTECTED KARSTLANDS: THE REGIONAL SITUATION

About 23% of the total Central American land area, ~154,300 km², is karst landscape. Protected karst areas for individual countries and the region as a whole are shown in Table 3. Regionally, there are 45 protected karst areas, collectively encompassing 27,916 km², ~18% of the regional karst total. Considering individual countries, the greatest number of protected karst areas (18) is in Belize, where 68% of the karst is protected, with the largest total area of protected karst (19,351 km²) in the Mexican Yucatan states, where ~18% of the total karst is protected.

It is interesting to compare the karstland situation with overall national levels of protected area designation (Table 5), although it is important to note that the UN/WCMC data are constrained by criteria of size and legal status, so that the protected area totals in Tables 3 and 5 are not directly comparable. Belize and the Yucatan states have relatively high levels of protected-area designation both for karst and non-karst landscapes; in contrast protected-area designation in El Salvador is minimal in both cases. Honduras has designated only 10% of its total landscape as protected, but it affords protection to seven karst areas, representing 35% of its total karst. By contrast, Guatemala has designated 20% of its total landscape as protected, but its seven protected karst areas represent only 10% of the national karst total. Karst protected areas in Costa

Table 5. 1997 total protected areas and population density in Central America (km²).

Country	Area km²	Population Density/km²	Total Protected Area km²	Number Protected
Belize	22965	10	9118 (40%)	36
Costa Rica	51100	67.8	11972 (23%)	88
El Salvador	21041	243.3	52 (0.25%)	2
Guatemala	108889	100.4	21649 (20%)	34
Honduras	112492	56.3	11298 (10%)	51
Mexico:				
Campeche	56798	11.3	14282 (25%)	2
Quintana Roo	39376	17.9	7730 (20%)	5
Yucatan	43257	36	4407 (10%)	3
Nicaragua	148000	26	16334 (11%)	60
Panama	75517	36	15464 (21%)	23

Sources: Europa World Year Book 1999; World Conservation Monitoring Centre 1997.

Rica and Panama are comparatively small, both in area and proportion, and El Salvador and Nicaragua have yet to designate any karst areas as protected. Nicaragua has designated 11% of its total land area as protected, but so far this includes no karst. Costa Rica (23%) and Panama (21%) both have reasonable national protected areas systems, but neither includes much karst.

PROTECTED KARST AREAS: SELECTED EXAMPLES

The 18% of the Central American karst landscape afforded protected area status includes some individual karstlands that are extensive and significant in terms of scientific, cultural, and recreational criteria. The majority of the 45 protected karst areas are so designated because of their biological, archaeological, or recreational significance, rather than on the basis of geomorphic criteria.

The Yucatan Peninsula is the largest karst area, with the most protected karst in Central America (Table 3; Fig. 1). The largest single protected area is the 7232 km² Calakmul Biological Reserve in Campeche, established in 1989, which adjoins the Maya Biosphere Reserve in Guatemala. Quintana Roo has three protected karst areas: Sian Ka'an Biological Reserve (5281 km²), Yum-Balam Flora and Fauna Protection Area (1540 km²), and Uaymil Flora and Fauna Protection Area (891 km²). Yucatan also has three protected karst areas: Arrecife Alacranes National Park (3338 km²), Rio Celestun Special Biosphere Reserve (591 km²), and Rio Lagartos Special Biosphere Reserve (478 km²).

Belize has the highest level of karst protection in the region (Day 1996; Table 3). The largest area is the Chiquibul National Park, established in 1991, which encompasses 1865 km² in the western Cayo District. The park contains the Caracol Archaeological Reserve, as well as portions of the Chiquibul Cave System, the longest known cave system in Central America, presently surveyed to 55 km (Miller 1996, 2000). The Rio Bravo Conservation and Management Area (1010 km²) in the Orange Walk District is managed by the Programme for Belize, a non-government organization established in 1988 to promote conservation of natural heritage and wise use of natural resources. Other significant protected karst areas include the Vaca Forest Reserve (210 km²) and parts of the Bladen Branch Nature Reserve and the Columbia River Forest Reserve (Day 1996).

Two small karst areas in Belize that are protected, at least in part, for their intrinsic karst value, are the Blue Hole National Park and Five Blues Lake National Park in the Cayo District. Blue Hole National Park, established in 1986, is 2.3 km² in area and is managed by the Belize Audubon Society, receiving about 6000 visitors annually (Rath 2000). Five Blues Lake National Park is focused around a large sinkhole lake and is 4 km² in area.

A proposed agreement between Belize and Mexico is designed to protect the border areas between the two countries. An international protected area in the Gran Petén, encompassing parts of Mexico, Guatemala, and Belize, is also under consideration and would include the Rio Bravo area. A third proposed binational agreement includes the Chiquibul/Mayan Mountain project between Guatemala and Belize (WCMC 1992).

Guatemala has 1517 km² of protected karst contained in seven protected areas (Table 3). The karst of Guatemala has "major significance due to its profusion and diversity." (Middleton & Waltham 1986: 95). The Río Chiquibul-Montanas Mayas Biosphere Reserve (619 km²) is the largest contiguous protected karst area in Guatemala. Located in the Petén Department, the Reserve adjoins the Vaca Forest Reserve in Belize. The Machaquila-Cuevas de San Miguel Wildlife Refuge contains 148 km² of karst in south-central Petén. Laguna Lachua National Park (150 km²), in the Alta Verapaz Department, is one of the most important karst areas in Guatemala, characterized by towers, cones, dolines, and poljes (Middleton & Waltham 1986). The largest protected area in Guatemala is the Maya Biosphere Reserve (18,449 km²) established in 1990 (Sundberg 1997), located in the Department of Petén. The reserve contains many important archaeological sites, including El Mirador, El Zotz, Piedras Negras, Tikal, and Uaxactun. The protected karst is contained in 2 areas: Tikal National Park (576 km²) and the Mario Dary Biotope for the Conservation of the Quetzal (12 km²). Despite its protected status, the Maya Biosphere Reserve loses an estimated 485 km² of forested land to unauthorized agricultural clearance each year (Aburto 1995).

The largest protected karst area in Honduras covers 2400 km² within the Patuca National Park and Tawahka Anthropological Reserve, in the Cordillera Entre Ríos and the Montañas de Colon in southeastern Honduras. Patuca National Park contains ~1600 km² of karst and Tawahka Anthropological Reserve ~800 km² of karst. The area is considered threatened by immigration and is the last homeland of the Tawahka (Sumo) culture, one the most threatened indigenous groups in Honduras (Instituto Hondureno de Turismo, 1998).

The second largest protected karst area is Sierra de Agalta National Park (655 km²) in central Honduras. Karst is also designated as protected within the Pico Pijol National Park (160 km²), the Cerro Azul Copan National Park (155 km²), the Santa Barbara National Park (130 km²) and the Cuevas de Taulabe National Monument.

Costa Rica has ~2000 km² of karst landscape distributed in small areas throughout the country (Mora 1992). The largest protected karst area is the Isla del Coco National Park (24 km²) in the Pacific Ocean off the Peninsula de Nicoya. On the Peninsula de Nicoya, karst is protected within the Barra Honda National Park (23 km²) and the 3 relatively small protected karst areas of Cabo Blanco Nature Reserve (12 km²), Ostional National Park (8 km²) and Curu National Park (1 km²).

SUMMARY AND CONCLUSIONS

Approximately 18% of Central America's karst landscape is afforded at least nominal protection through its designation as protected areas. Its 45 protected karst areas total ~28,000 km², with the single largest area (19,351 km²) in the Yucatan peninsular states, representing 18% of the total karst area. There are also extensive protected karst areas in Honduras, Belize, and Guatemala, with smaller areas in Costa Rica and Panama (Table 3). El Salvador and Nicaragua have yet to designate any karstlands as protected areas. Panama, Costa Rica, and El Salvador have only limited karstlands, with relatively low levels of protection. Combined with Nicaragua, their protected karstlands constitute only 148 km², or <1% of the regional total (Table 3).

We accept that some of the data sources upon which these conclusions are based are not as reliable as we would wish, but we regard them as the best sources available at the regional scale. More detailed field surveys of the extent of karstlands and protected areas in individual countries are warranted, particularly if the effectiveness of protection "on paper" is to be ascertained. This is particularly true in Nicaragua and Honduras, where there is considerable uncertainty about both the extent of the national karst and the status of the protected areas.

Regionally, Belize has the highest percentage of karst protection, with 68% of the total karst incorporated within 18 protected areas. Half of all the protected areas in Belize incorporate karstlands (Tables 3 & 5), although few of the protected areas are so designated primarily because of their karst landscape. The high level of karst protection in Belize reflects the overall national commitment to protected area establishment, which results in some 40% of the country being designated as protected (Table 5). Another important factor is Belize's low population density, which stands in marked contrast to that of other Central American countries (Table 5). Although detailed analysis of the factors influencing the differing levels of karstland protection has not yet been undertaken, population pressure would appear to be an important factor (Table 5).

Conferral of protected area status does not necessarily result in effective protection from such threats as forest clearance, agricultural incursion, water contamination, and the looting of archaeological materials. Because of limited finances and manpower, management and policing of Central America's protected karst areas are of variable effectiveness and, in some instances, non-existent. Some of the largest and most significant of the reserves are the most vulnerable.

It is difficult to assess the Central American situation by comparison with other parts of the world, since few comparable studies have yet been undertaken. Parallel studies of protected karst areas in the Caribbean and Southeast Asia (Kueny & Day 1998; Day & Urich 2000) suggest that approximately 14% and 12% respectively of the karst in those regions is designated as protected.

In the broader conservation context, the protected karst area percentage exceeds the figure of 10-12% that is sometimes suggested as the near-term land area protection target for nations and ecosystems (Noss 1996). The relevance of such low numerical targets is, however, questionable (Soule & Sanjayan 1998).

The protected-areas situation in Central America is volatile, with reserves being created and disestablished on a regular basis. Even within the duration of this study the numbers, sizes, and status of many countries' protected karst areas have changed, in some cases dramatically. The numbers presented here will almost certainly be outdated by the time of publication. The contemporary regional attitude towards conservation is not always encouraging, and it will be interesting to follow the future trend in the status of the protected karst areas. The current modest levels of protection may increase in terms of area, proportion, and efficacy, or they may decrease as other pressures on natural resources increase.

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REFERENCES

Aburto, G., 1995, Guatemala farmers receive forested land grants: www.txinfinet.com/mader/ecotravel/center/0995guatemala.html

AID, 1966, National inventory of the physical resources Central America and Panama: El Salvador: Agency for International Development Resource Inventory Center, Corps of Engineers and Bureau for Latin America. Washington, D.C. 1:500,000.

AID, 1966, National inventory of the physical resources Central America and Panama: Honduras: Agency for International Development Resource Inventory Center, Corps of Engineers and Bureau for Latin America. Washington, D.C. 1:1,000,000.

AID, 1966, National inventory of the physical resources Central America and Panama: Nicaragua: Agency for International Development Resource Inventory Center, Corps of Engineers and Bureau for Latin America. Washington, D.C. 1:500,000.

AID, 1967, National inventory of the physical resources Central America and Panama: Panama: Agency for International Development Resource Inventory Center, Corps of Engineers and Bureau for Latin America. Washington, D.C. 1:1,000,000.

Blouet, B. & Blouet, O. (1997). Population: Growth, distribution and migration, *in* Blouet, B.W., & Blouet, O.M., (eds.), Latin America and the Caribbean: A systematic and regional survey, 3rd ed.: Wiley, New York: p. 112-138.

CIA, 1999, World factbook. www.cia.gov.

Clawson, D., 1997, Latin America and the Caribbean: Lands and peoples: Brown and Benchmark, Dubuque, Iowa, 382 p.

Day, M.J., 1978, The morphology of tropical humid karst with particular reference to the Caribbean and Central America [PhD dissertation]: Oxford University, 611p.

Day, M.J., 1979, Surface roughness as a discriminator of tropical karst styles: Zeitschrift fur Geomorphologie N.F., Supplementbande, v. 32 p.1-8.
Day, M.J., 1993, Human impacts on Caribbean and Central American karst, *in*, Williams, P.W. (ed.), Karst terrains: Environmental changes and human impact, Catena Supplement 25, Cremlingen-Destedt, Germany, p. 109-125.
Day, M.J., 1996, Conservation of karst in Belize: Journal of Cave and Karst Studies v. 58, n. 2, p. 139-144.
Day, M.J., in press, Some observations on karst landscape ecology and conservation in Belize: Journal of Belizean Affairs.
Day, M.J., & Kueny, J.A., in press, Central America, *in* Gunn, J. (ed.), Encyclopedia of Caves and Karst, Fitzroy Dearborn, London.
Day, M.J., & Urich, P.B., 2000, An assessment of protected karst landscapes in Southeast Asia: Cave and Karst Science, v. 27, n. 2, p. 61-70.
Dengo, G., & Case, J.E. (eds.), 1990, The Caribbean region: Geological Society of America, Boulder: 528 p.
The Europa World Year Book, 1999, Volumes 1 and 2: Greshman Press, Cornwall, 4126 p.
Furley, P.A., & Newey, W.W., 1983, Geography of the biosphere: Butterworths, London, 413 p.
Gardner, T.W., 1987, Overview of Caribbean geomorphology, *in* Graf, W.L. (ed.), Geomorphic systems of North America: The Geological Society of America, Boulder, p. 343-347.
Gillieson, D., 1996, Caves: Processes, development, management: Blackwell, Oxford, 324 p.
Gillieson, D., 1997, Dynamics of soil-vegetation systems on limestones and karst management, Cave and Karst Management in Australia v. 11, p. 25-33.
Gomez-Pompa, A., & Kaus, A., 1990, Traditional management of tropical forests in Mexico, *in* Anderson, A.B. (ed.), Alternatives to deforestation: Steps toward sustainable use of the Amazon Rainforest: Columbia University Press, New York, p. 45-64.
Hamilton-Smith, E., 1999, IUCN/WCPA Working Group on Caves and Karst Circular #9: 5 p.
Hartshorn, G., Nicolait, L., Hartshorn, L., Bevier, G., Brightman, R., Cal, J., Cawich, A., Davidson, W., DuBois, R., Dyer, C., Gibson, J., Hawley, W., Leonard, J., Nicolait, R., Wever, D., White, H. & Wright, C., 1984, Belize: Country environmental profile: Trejos, Hnos, San Jose, 151 p.
Instituto de Costarricense de Turismo, 1995, Parque Nacionales de Costa Rica: www.nacion.co.cr/netinc/costarica/parques/parquesnac.html.
Instituto Geografico Nacional, 1970, Mapa geológico de la Republica de Guatemala, 1:500,000.
Instituto Guatemalteco de Turismo, 1998, The Lachua National Park: www.tradepoint.org.gt/inguin/enarespro0701.html.
Instituto Hondureno de Turismo, 1998, Mapa de areas protegidas de Honduras, 1:1,000,000.
Iremonger, S., & Sayre, R., 1994, Rapid ecological assessment of the Bladen Nature Preserve, Toledo District, Belize: The Nature Conservancy, Arlington VA, 77 p.
Kueny, J.A., 2000, An assessment of protected karst areas in Central America and the Caribbean [MS thesis]: University of Wisconsin-Milwaukee, 85 p.
Kueny, J.A., & Day, M.J., 1998, An assessment of protected karst landscapes in the Caribbean: Caribbean Geography, v. 9, n. 2, p. 87-100.
Mann, P. (ed.), 1995, The geologic and tectonic development of the Caribbean Plate boundary in southern Central America: Geological Society of America Special Paper 295, Boulder, 349 p.
Margules, C.R., & Pressey, R.L., 2000, Systematic conservation planning: Nature, v. 405, n. 6783, p. 243-253.
Middleton, J., & Waltham, T., 1986, The underground atlas, a gazetteer of the world's cave regions: Robert Hale Ltd., UK, 239 p.
Miller, T., 1996, Geologic and hydrologic controls on karst and cave development in Belize: Journal of Cave and Karst Studies, v. 58, n. 2, p. 100-120.
Miller, T., 2000, Chiquibul Cave: National Geographic Magazine, v. 197, n.4, p. 55-71.
Mora, S., 1992, Controls on karst in Costa Rica, *in* Back, W., Herman, J., & Paloc, H. (eds.), International contributions to hydrology: Hydrology of selected karst regions, v. 13: Verlag Heinz Heise, Hannover Germany, p. 467-474.
Noss, R.F., 1996, Protected areas: How much is enough? *in* Wright, R.G. (ed.), National Parks and protected areas: Their role in environmental protection: Blackwell Science, Cambridge, MA, p. 91-120.
Peacock, N., Hempel, J.C., & Flurky, A., 1993, Studies in the Río Corredor Basin: NSS Bulletin, v. 55, n. 1&2, 100 p.
Rath, J., 2000, Tourism in the karst areas of the Cayo and Toledo Districts, Belize [MA thesis]: University of Wisconsin-Milwaukee, 95 p.
Reeder, P., Brinkman, R., & Alt, E., 1996, Karstification on the Northern Vaca Plateau, Belize: Journal of Cave and Karst Studies, v. 58, n. 2, p. 121-130.
Reeves, W., 2000, Caves of the Maje Mountains, Panama: NSS News, v. 58, n. 6, p. 172-173.
Soule, M.E., & Sanjayan, M.A., 1998, Conservation targets: Do they help?: Science, v. 279, p. 2060-2061.
Sundberg, J., 1997, NGO landscapes: Conservation in the Maya Biosphere Reserve, Petén, Guatemala: www.txinfinet.ccm/mader/planeta/1197/1197maya.html
Troester, J.W., Back, W. & Mora, S.C., 1987, Karst of the Caribbean, *in* Graf, W.L., Geomorphic systems of North America: Geological Society of America, Boulder, p. 347-357.
Tronvig, K., & Belson, C., 1999, Karst Waters Institute's top ten list of endangered karst ecosystems: NSS News, v. 57, n. 9, p. 265-267, 283.
Veni, G., Hose, L.D., & Pisarowicz, J.A. (eds.), 1996, Special theme issue on Belize: Journal of Cave and Karst Studies, v. 5, n. 2, p. 67-151.
Vermeulen, J., & Whitten, T., 1999, Biodiversity and cultural property in the management of limestone resources: Lessons from East Asia: World Bank, Washington DC, 120 p.
Watson, J., Hamilton-Smith, E., Gillieson, D., & Kiernan, K., (eds.), 1997, Guidelines for cave and karst protection: IUCN, Gland, Switzerland and Cambridge, UK, 63 p.
Watts, D., 1987, The West Indies: Patterns of development, culture and environmental change since 1492: Cambridge University Press, Cambridge, 609 p.
Weyl, R., 1980, Geology of Central America: Gebruder Borntraeger, Berlin, 371 p.
Whitmore, T.C. and Prance, G.T., 1987, Biogeography and Quaternary history in tropical America: Clarendon, Oxford, 214 p.
WCMC, 1992, 1992 Protected areas of the world: A review of national systems: World Conservation Monitoring Centre, www.wcmc.org.uk/cgi-bin/pa_paisquery
WCMC, 1997, 1997 United Nations list of National Parks and Protected Areas: World Conservation Monitoring Centre, www.wcmc.org.uk/protected_areas/data/

Richard L. Josephs - A late Pleistocene ceiling collapse in Bogus Cave, Jones County, Iowa: A potential relationship to coeval accelerated mass wasting events across the central Midwest. *Journal of Cave and Karst Studies 64*(3): 175-179.

A LATE PLEISTOCENE CEILING COLLAPSE IN BOGUS CAVE, JONES COUNTY, IOWA: A POTENTIAL RELATIONSHIP TO COEVAL ACCELERATED MASS WASTING EVENTS ACROSS THE CENTRAL MIDWEST

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*A thick accumulation of boulder-size dolostone blocks, the result of one or more episodes of ceiling collapse, was encountered during geoarchaeological excavations in the front room of Bogus Cave, east-central Iowa. The rockfall layer was buried by a veneer of Holocene sediments that contained prehistoric artifacts dating to the Woodland Period (2500-1000 yr BP). An AMS ^{14}C age of 17,260 ±120 yr BP, obtained from a caribou (*Rangifer tarandus*) mandible found wedged among the boulders, dates the collapse near the close of the last glacial maximum, a time when the projected mean annual temperature for this area was at least 14°C lower than at present. Paleoenvironmental evidence based on ä^{13}C values from select vertebrate remains and their encompassing sediment, together with a uranium series age of 16,900 ± 4800 yr BP from a stalagmite formed atop one of the boulders, strongly support a late Wisconsinan age for the collapse. The episode (or episodes) of collapse appears to be the result of cryoclastic processes associated with late glacial conditions and the onset of accelerated mass wasting that has been previously documented across the central Midwest.*

The transition from late Pleistocene to Holocene time encompasses a period of major environmental change across the central Midcontinent (Van Zant 1979; Baker *et al*. 1986, 1992, 1996, 1998; King & Graham 1986). During the last glacial maximum (21,500-16,000 yr BP), the landscape immediately south of the glacial margin consisted of open tundra and parkland inhabited by arctic and subarctic flora and fauna (Baker *et al*. 1986; King & Graham 1986). Sediment features and soil patterns (e.g., ice-wedge casts and relict patterned ground) indicate that permafrost developed across this region and extended as far south as 38° 30'N latitude between 21,000 and 16,000 yr BP, the coldest interval of the late Wisconsin, when postulated mean annual air temperature was at least 14°C colder than at present (Johnson 1990; Walters 1994). At most localities, permafrost probably existed for <1000 years. Its development and subsequent degradation appear to be time-transgressive and closely related to ice margin proximity (Johnson 1990). Furthermore, evidence for accelerated mass wasting within this region has been dated to the late glacial period and suggests a causal link with the periglacial climate and the development of permafrost (Harris 1987; Mason 1995; Mason & Knox 1997).

As part of a geoarchaeological investigation conducted at Bogus Cave, Jones County, Iowa (Fig. 1), two test units were excavated in the front room of the cave, the principal site of human occupation. The excavations revealed a layer of boulder-size dolostone blocks buried beneath an organic-rich, sandy loam veneer (Josephs 2000). This accumulation represents at least one episode of ceiling collapse. Through a combination of sedimentologic, stratigraphic, micromorphologic, and isotopic geochemical and geochronologic techniques, this paper proposes a correlation between late glacial accelerated mass wasting, previously documented throughout the region, and the ceiling collapse recorded in the subsurface profile of the cave.

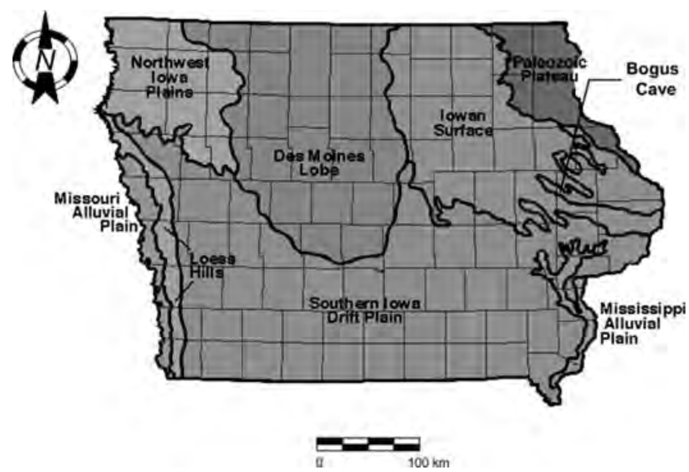

Figure 1. Site location plotted on physiographic map of Iowa (from Iowa Department of Natural Resources, Geological Survey Bureau).

SITE LOCATION AND SETTING

Bogus Cave is located ~6 km northwest of the town of Anamosa, Jones County, Iowa, at 42°08'47"N latitude, 91°20'33"W longitude. This section of Jones County lies within a heavily wooded, karstic region of the Southern Iowa Drift Plain along its interdigitated boundary with the Iowan Erosion

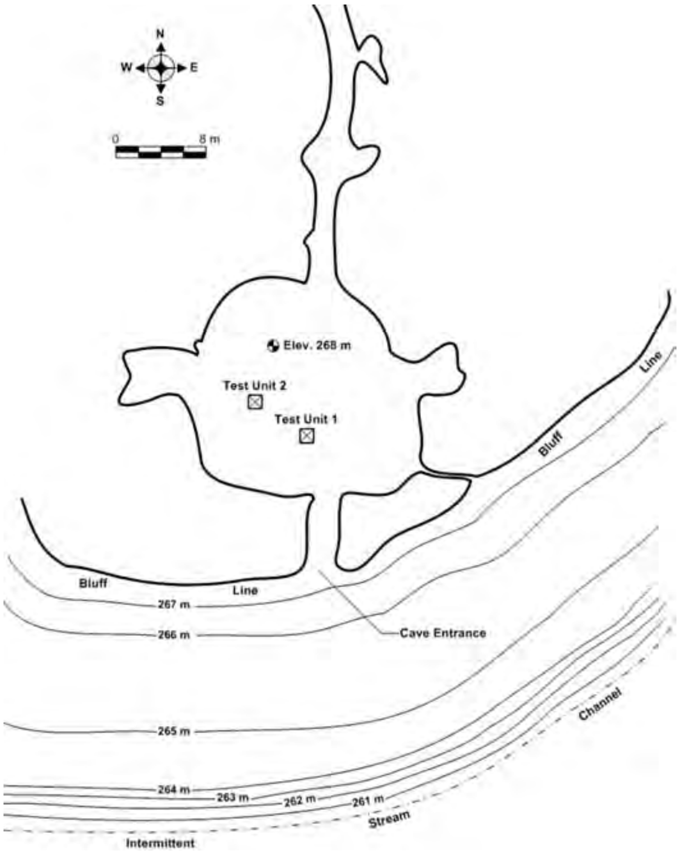

Figure 2. Map of Bogus Cave showing the location of the test units.

Surface (Prior 1991; Fig. 1). This irregular boundary closely approximates the Grassland-Deciduous Forest Contact as defined by Shelford (1963). The main entrance to the cave opens toward the south along a bluff line about 7 m above the channel of an unnamed, ephemeral first-order stream (Fig. 2). Present access into the cave is through a tunnel-like passageway that leads into a dome-shaped front room that is ~3 m high near its center and averages roughly 20 m in diameter. Passages of various size and shape radiate from this central area.

Bogus Cave has formed in the Anamosa Member of the Upper Silurian Gower Formation (Witzke *et al*. 1998). The Anamosa member is a non-fossiliferous, flat-lying, laminated dolostone (Witzke 1992). The age of Bogus Cave has yet to be determined. Hedges & Darland (1963) suggested that the cave "probably" formed during pre-Illinoian time. The development of karst in this area is controlled by the bedrock's "pre-karst" porosity (bedding-plane partings and joints), hydraulic conductivity, and clay content. Passage morphology in many of the shallow, phreatic caves formed in Silurian strata is controlled by the interrelationships among joints and the preferred direction of groundwater flow (Bounk 1983).

RESULTS

While excavating two test units, each roughly 1 m², in the front room of Bogus Cave, a buried, clast-supported accumulation of angular to subangular, boulder-size dolostone was contacted 35-55 cm below the existing cave floor (Fig. 3). A brown (10YR 4/3) silt loam fills the interstices. Micromorphological examination of the silt loam revealed a well-sorted, exogenous sediment, most likely deposited by infiltrating water. The majority of the mineral grains are silt-size quartz and feldspar. This stratum (Stratum II) is overlain by a veneer of dark olive brown (2.5Y 3/3) sandy loam (Stratum I) that contains a mixed assemblage of historic and prehistoric artifacts. The earliest prehistoric artifacts date to the Woodland Period (2500-1000 yr BP), a time when cave and rockshelter sites in this area were most intensively exploited (Alex 1968; Jaenig 1975; Logan 1976; Benn 1980; Marcucci & Withrow 1996; Josephs 2000). The collapse layer rests on a densely packed stratum (Stratum III) of cobble- and gravel-size, subangular to rounded, dolostone clasts in a culturally sterile, brownish-yellow (10YR 6/8) clay loam matrix. Thin sections of the clay loam matrix revealed an endogenous sediment formed largely by *in situ* chemical weathering.

Owing to the size and composition of the clasts and the location and extent of the accumulation, the only plausible explanation for its emplacement is having fallen directly from the ceiling in one or more catastrophic collapse events, the most likely culprit being cryoclastism. Attempts to use attributes related to clast morphology to identify specific processes responsible for cave-ceiling collapse have proven largely unsuccessful. Freeze-thaw, heating and cooling, and hydration spalling, all possible agents for ceiling collapse, produce indistinguishable debris accumulations (Farrand 1985).

Caves typically acquire an air temperature that approximates the mean annual temperature of the area in which they are located. The current mean annual temperature for Jones County, Iowa, is 8.6°C (Minger 1991). The mean annual temperature for this area between 21,000 and 16,500 yr BP, the coldest part of late Wisconsin time, is projected to have been -6°C (Johnson 1990; Walters 1994). This supports freeze/thaw as the likely agent for initiating the collapse.

During the excavation of the rock fall unit (Stratum II) in test unit 1, the left half of a caribou mandible (*Rangifer tarandus*) was recovered from the south profile, 93 cm below the cave floor (Fig. 4). Despite having been wedged tightly among the boulders, it was in remarkably good condition. Its age at time of death is estimated to have been between 6 and 9 years old (Arthur E. Spiess, pers. comm., 2000). Its presence in the cave is a matter of speculation; however, carnivore predation is a likely explanation. Following laboratory examination, the roots of the third molar (M_3) were separated from the tooth crown and submitted to the Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand, for accelerator mass spectrometry (AMS) ^{14}C dating and analysis of $\delta^{13}C$ content. The $\delta^{13}C$ value reflects the relative proportion of C_3 (cool, moist climate) ver-

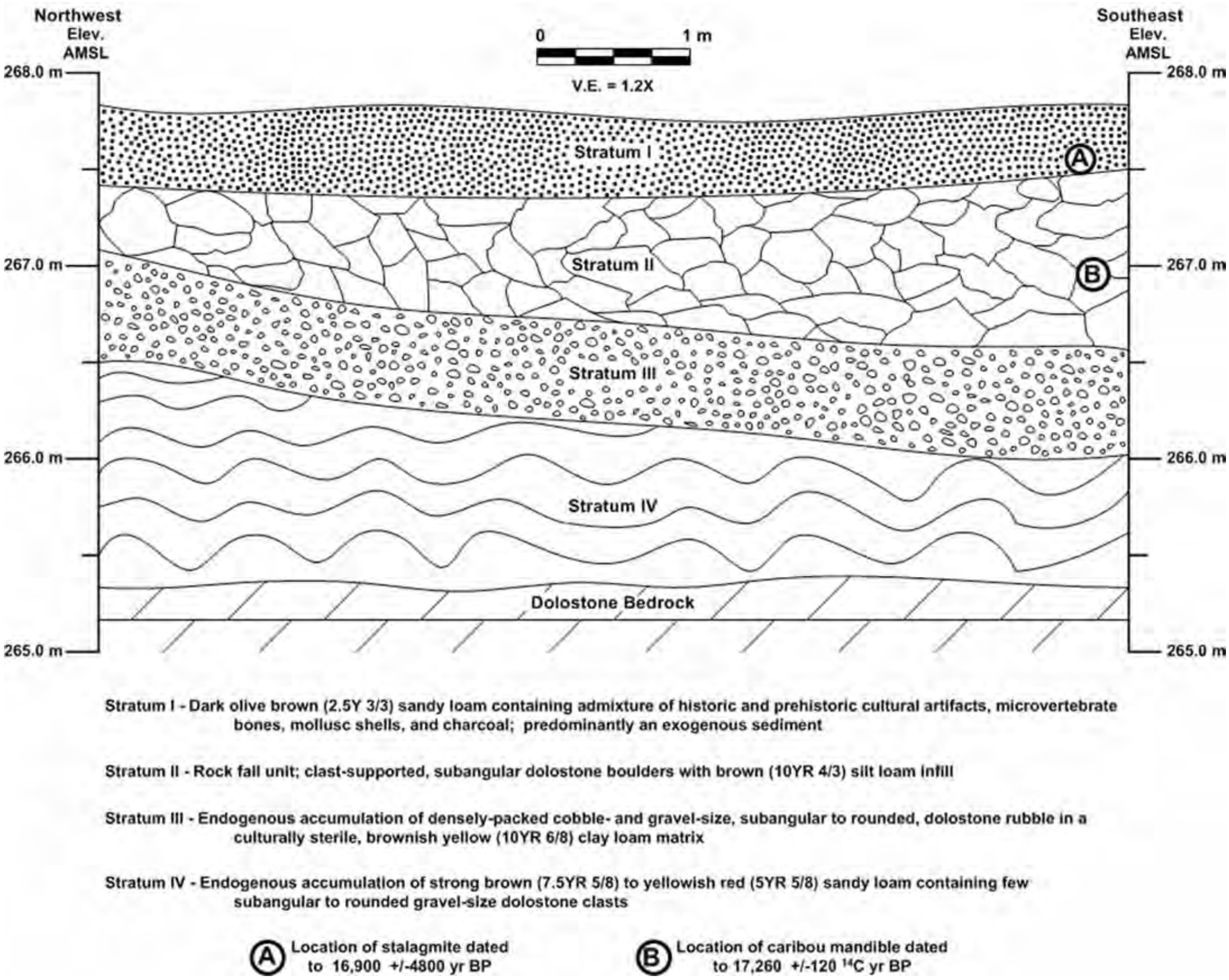

Figure 3. Northwest – southeast profile of Bogus Cave stratigraphy.

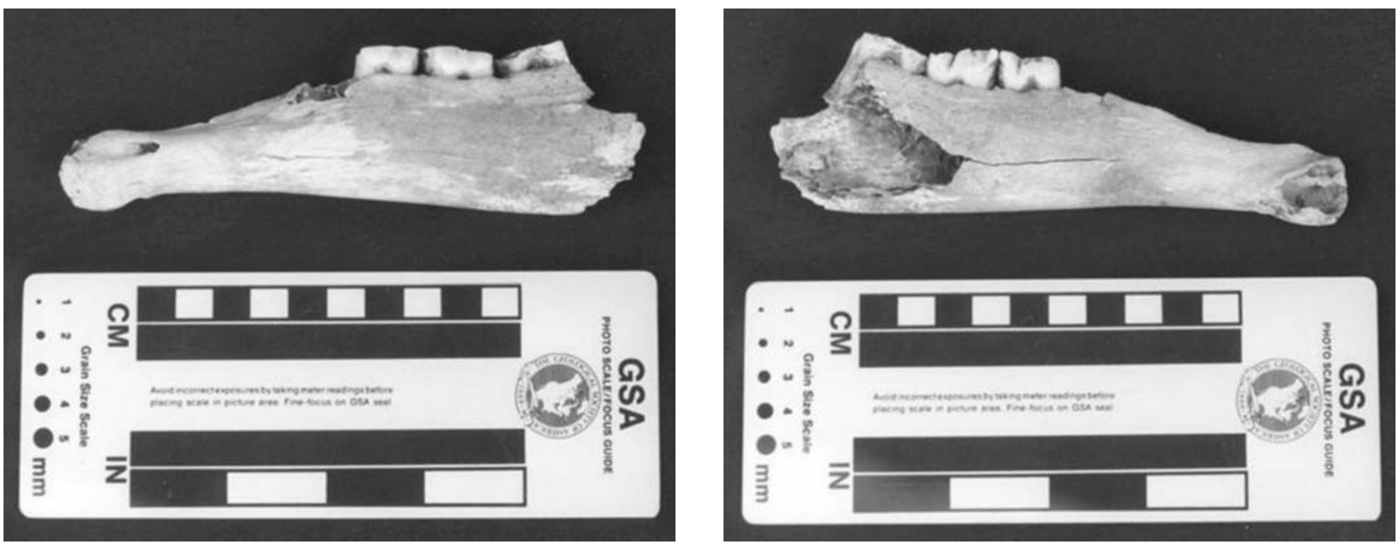

Figure 4. Left half of *Rangifer tarandus* mandible: left photo buccal view, right photo lingual view

sus C_4 (warm season grasses and herbs) plants in the environment at a given time (Herz 1990). The $\delta^{13}C$ values range between -35 and -20‰ for C_3 plants and -16 and -9‰ for C_4 plants (van der Merwe 1982). The relative proportion of C_3 and C_4 plants is correlated with mean annual temperature and mean annual precipitation; therefore, the $\delta^{13}C$ value serves as a valuable proxy for paleovegetation and paleoclimate (Herz 1990; Boutton 1996). It is also the most popular isotopic technique for studying paleodiet in both human and non-human mammals (Reitz & Wing 1999).

An age of 17,260 ±120 ^{14}C yr BP together with a $\delta^{13}C$ value of -18.4‰ were obtained for this sample (NZA 10448). The -18.4‰ $\delta^{13}C$ value falls well within the range for a terrestrial herbivore feeding on C_3 (cool, moist climate) vegetation (Herz 1990; Reitz & Wing 1999) and agrees well with the paleoenvironmental scenario for this region during the full glacial (Baker *et al*. 1986). A sample of the silt loam fill was submitted to Geochron Laboratories, Cambridge, Massachusetts, for ä^{13}C analysis of its organic carbon content. The value obtained was -24.1‰ (CR-101624), which further supports the evidence for paleovegetation dominated by C_3 flora. A post-collapse stalagmite that had formed atop one of the boulders in the northeast corner of test unit I, just beneath the Stratum I sediments, was removed and submitted to the Paul H. Nelson Stable Isotope Laboratory, Department of Geoscience, University of Iowa, for uranium series (^{238}U-^{234}U-^{230}U) disequilibrium dating (Faure 1986; Reagan *et al*. 1994). It produced a U-series age of 16,900 ±4800 calendar years before present (Rhawn F. Denniston, pers. comm., 1999).

As part of a separate investigation, micromammalian remains were collected from buried contexts in the rear (northern) portion of Bogus Cave, a section not suitable for human habitation (Slaughter 2001). The results of AMS ^{14}C dating and ä^{13}C analyses performed on select tooth and jaw samples, together with their biostratigraphic relationships, support the geochronologic and paleoclimatic scenario evinced in the front room of the cave (Josephs 2000; Slaughter 2001).

CONCLUSIONS

Geologic and paleoenvironmental evidence from Bogus Cave, Jones County, Iowa, supports the following conclusions:

1. The buried accumulation of dolostone boulders found within Bogus Cave is the result of one or more episodes of ceiling collapse.

2. Mean annual temperatures below 0°C support freeze/thaw as the most likely initiating agent for the collapse.

3. Radiometric methods (AMS ^{14}C and U-series) date the collapse near the close of full-glacial conditions, *circa* 17,000 years before present.

4. Stable carbon isotope analyses ($\delta^{13}C$ values) of vertebrate remains and their encompassing sediment corroborate previous paleoenvironmental reconstructions for this area, at this time.

5. The date of the collapse and associated climatic conditions coincide with other mass wasting events documented from this area at this time.

It is, therefore, presumed that the Bogus Cave ceiling collapse was the result of cryoclastic processes associated with transitional, glacial-to-interglacial, conditions that initiated a period of accelerated mass wasting across the central Midwest.

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REFERENCES

Alex, R.A., 1968, The Rock Run shelter: A stratified Woodland site in east-central Iowa [MS thesis]: Iowa City, University of Iowa, 62 p.

Baker, R.G., Rhodes, R.S., II, Schwert, D.P., Ashworth, A.C., Frest, T.J., Hallberg, G.R., & Janssens, J.A., 1986, A full-glacial biota from southeastern Iowa, USA: Journal of Quaternary Science, v. 1, n. 2, p. 91-107.

Baker, R.G., Maher, L.J., Chumbley, C.A., & Van Zant, K.L., 1992, Patterns of Holocene environmental change in the midwestern United States: Quaternary Research, v. 37, n. 3, p. 379-389.

Baker, R.G., Bettis, E.A., III, Schwert, D.P., Horton, D.G., Chumbley, C.A., Gonzalez, L.A., & Reagan, M.K., 1996, Holocene paleoenvironments of northeast Iowa: Ecological Monographs, v. 66, n. 2, p. 203-234.

Baker, R.G., Gonzalez, L.A., Raymo, M., Bettis, E.A., III, Reagan, M.K., & Dorale, J.A., 1998, Comparison of multiple proxy records of Holocene environments in the midwestern United States: Geology, v. 26 , n. 12, p. 1131-1134.

Benn, D.W., 1980, Hadfields Cave: A perspective on late Woodland culture in northeastern Iowa: Report No. 13, Iowa City, IA, Office of the State Archaeologist, 238 p.

Bounk, M.J., 1983, Some factors influencing phreatic cave development in the Silurian strata of Iowa: The Proceedings of the Iowa Academy of Sciences, v. 90, n. 1, p. 19-25.

Boutton, T.W., 1996, Stable carbon isotope ratios of soil organic matter and their use as indicators of vegetation and climatic change, *in* Boutton, T. W., & Yamasaki, S., (eds.), Mass spectrometry of soils: New York, Marcel Dekker, Inc., p. 47-81.

Farrand, W.R., 1985, Rockshelter and cave sediments, *in* Stein, J.K., & Farrand, W.R., (eds.), Archaeological sediments in context: Orono, Center for the Study of Early Man, University of Maine, p. 21-39.

Faure, G., 1986, Principles of isotope geology: New York, John Wiley and Sons, 589 p.

Harris, C., 1987, Mechanisms of mass movement in periglacial environments, *in* Anderson, M.G., & Richards, K.S., (eds.), Slope stability: Geotechnical engineering and geomorphology: New York, John Wiley and Sons, p. 531-560.

Hedges, J., & Darland, G.W., Jr., 1963, The Scotch Grove strath in Maquoketa River Valley, Iowa: Iowa Academy of Science Proceedings, v. 70, p. 295-306.

Herz, N., 1990, Stable isotope geochemistry applied to archaeology, *in* Lasca, N.P., & Donahue, J., (eds.), Archaeological geology of North America: Boulder, Colorado, Geological Society of America, Centennial Special Volume 4, p. 585-595.

Jaenig, M.E.W., 1975, The prehistoric cultural ecology of eastern Iowa as seen from two Woodland rockshelters [PhD dissertation]: Madison, University of Wisconsin, 551 p.

Johnson, W.H., 1990, Ice-wedge casts and relict patterned ground in central Illinois and their environmental significance: Quaternary Research, v. 33, n. 1, p. 51-72.

Josephs, R.L., 2000, Sedimentology and speleostratigraphy of Bogus Cave, Jones County, Iowa [PhD thesis]: Iowa City, University of Iowa, 153 p.

King, J.E., & Graham, R.W., 1986, Vertebrates and vegetation along the southern margin of the Laurentide Ice Sheet: Programs and abstracts 9th Biennial Meeting, American Quaternary Association, University of Illinois, Urbana-Champaign, p. 43-45.

Logan, W.D., 1976, Woodland complexes in northeastern Iowa: Publications in Archaeology 15, National Park Service, U.S. Department of the Interior, Washington, D.C., 203 p.

Marucci, D.J., & Withrow, R.M., 1996, Small rockshelters and patterns of use in eastern Iowa: Paper presented at the 54th Annual Plains Conference, Iowa City, Iowa.

Mason, J.A., 1995, Effects of glacial-interglacial climatic change on mass wasting, southern Minnesota [PhD thesis]: Madison, University of Wisconsin, 346 p.

Mason, J.A., & Knox, J.C., 1997, Age of colluvium indicates accelerated late Wisconsinan hillslope erosion in the Upper Mississippi Valley: Geology, v. 25, n. 3, p. 267-270.

Minger, M.J., 1991, Soil survey of Jones County, Iowa: U.S. Department of Agriculture, Soil Conservation Service, 287 p.

Prior, J.C., 1991, Landforms of Iowa: Iowa City, University of Iowa Press, 153 p.

Reagan, M.K., Morris, J.D., Herrstrom, E.A., & Murrell, M.T., 1994, Uranium series and beryllium isotope evidence for an extended history of subduction modification of the mantle below Nicaragua: Geochemica et Cosmochimica Acta, v. 58, p. 4199-4212.

Reitz, E.J., & Wing, E.S., 1999, Zooarchaeology: Cambridge, Cambridge University Press, 455 p.

Shelford, V.E., 1963, The ecology of North America: Urbana, University of Illinois Press, 610 p.

Slaughter, R.W., 2001, Terminal Pleistocene and Holocene mammal remains from Bogus Cave, Jones County, Iowa [Ph.D. thesis]: Iowa City, University of Iowa, 83 p.

van der Merwe, N.J., 1982, Carbon isotopes, photosynthesis, and archaeology: American Scientist, v. 70, p. 596-606.

Van Zant, K.L., 1979, Late-glacial and postglacial pollen and plant macrofossils from Lake West Okoboji, northwestern Iowa: Journal of Quaternary Research, v. 12, n. 3, p. 358-380.

Walters, J.C., 1994, Ice-wedge casts and relict polygonal patterned ground in north-east Iowa, USA: Permafrost and Periglacial Processes, v. 5, p. 269-282.

Witzke, B.J., 1992, Silurian stratigraphy and carbonate mound facies of eastern Iowa, field trip guidebook to Silurian exposures in Jones and Linn counties: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 11, 73 p.

Witzke, B.J., Ludvigson, G.A., McKay, R.M., Anderson, R.R., Bunker, B.J., Giglierano, J.D., Pope, J.P., Goettemoeller, A.E., & Slaughter, M.K., 1998, Bedrock geology of northeast Iowa: Iowa Geological Survey, Iowa City, Iowa.

SELECTED ABSTRACTS FROM THE 2002 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN CAMDEN, MAINE

BIOSELEOLOGY

UNIQUE MICROBIAL DIVERSITY IN AN APHOTIC CAVE HOT SPRING

Hazel A. Barton, Department of Biology, University of Utah, 257 S. 1400 E, Salt Lake City, UT 84112 USA; Fred Luiszer and Norman R. Pace; Departments of Geological Sciences and Molecular, Cellular and Developmental Biology, University of Colorado at Boulder, Boulder, CO 80309 USA

Glenwood Hot Springs, Colorado, a sulfide-rich hot-spring system, issues from numerous springs before eventually flowing into a commercialized pool. To examine the effect of light energy on microbial community structure in such a sulfide-rich environment, we examined microbial communities from two of these springs; the photic 'drinking spring' and the aphotic 'dark-zone,' which flows through a cave. Both of these springs contain white, filamentous microbial communities, and the water flowing through them is chemically and physically identical. Molecular-phylogenetic analysis using 16S rRNA, revealed significant differences in community structure between the photic and aphotic filament communities. The filaments from the photic 'drinking spring' consisted predominantly of a single phylotype, an Epsilon-Proteobacteria related to a hydrothermal-vent symbiot. In the aphotic 'dark zone', the filamentous community displayed significant microbial diversity, with 58 phylotypes representing 7 domains of the Bacteria, including the Proteobacteria, Green non-sulfur and OP11 divisions. In addition, Archaeal species not previously identified under the conditions of temperature and pH found in the hot spring were identified only in the aphotic spring. The results suggest that the absence of light has a profound influence on microbial community structure, presumably through the development of complex metabolic networks required for chemolithotrophic energy conservation. This may suggest a higher degree of complexity in sulfur cycling by aphotic, subterranean communities.

TROGLOMORPHY IN THE CAVE FISH *POECILLIA MEXICANA*, FROM CUEVA DE VILLA LUZ, TABASCO, MEXICO

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The cave fish *Poecillia mexicana*, a type of molly, is found only in Cueva de Villa Luz (aka Cueva de las Sardinas) in Tabasco, Mexico. The cave has mixed energy inputs from sulfur, bats, and through multiple skylights. This rich food base supports an amazing density of the cave fish. Studies done in the 1950s and 1960s stated that the fish showed increasing troglomorphic adaptations and less hybridization with surface forms deeper into the cave. However, the previous data show considerable variation and overlap of characteristics by sample location, and no statistical analyses were done. We wanted to determine if fish in remote areas of the cave had smaller eyes than those in areas near the surface stream. We used a Polaroid camera to take pictures of captured fish for measurements and analysis. Our results show variation in troglomorphy, but no statistical differences in fish from any part of the cave. The rich food base in this cave may reduce pressure to develop troglomorphy.

METABOLIC AND ISOTOPIC DIVERSITY OF CHEMOAUTOTROPHIC SULFUR-OXIDIZING BACTERIA FROM LOWER KANE CAVE, WYOMING

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Microbial communities from Lower Kane Cave (Wyoming) were investigated using phylogenetic analyses of 16S rRNA gene sequences and detailed isotopic surveys. Microbial mats from three sulfidic spring locations were discretely sampled along flow transects, from anaerobic waters in the spring orifices through the aerobic discharge channels, with mats extending 10-15 m from the orifices. Dense mats were 3–10 cm thick, and had short (<1 cm) and long (>10 cm) white filaments interconnected with white web-like films on the surface, and a gray-brown gel of filaments underneath. Discontinuous patches of yellow biofilms also intermixed with short filaments. Most of the microorganisms identified from the mats were sulfur-oxidizing bacteria. *Thiobacillus* spp. were detected from yellow patches, and short filaments along the stream channels were closely related to *Thiothrix unzii*. The most abundant bacterial populations in all the filamentous samples belonged to an uncharacterized group of sulfur-oxidizing bacteria within the epsilon-Proteobacteria class. Similar organisms have been found in other sulfidic systems, including Cesspool Cave (VA) and Parker Cave (KY). Microbial mats from Lower Kane had an average $\delta^{13}C$ value of -36‰, demonstrating chemoautotrophic fractionation against ^{13}C from an inorganic carbon reservoir (cave water was -8.9‰). Each of the sulfur-oxidizing bacterial morphotypes, however, had distinct carbon isotope compositions, indicating that pathways for obtaining carbon may be slightly different. These complex populations provide energy for the cave ecosystem as chemoautotrophs, while driving speleogenesis due to sulfide oxidation and the production of sulfuric acid.

CAVE DIPLURA OF GEORGIA

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Examination of 27 collections of campodeid diplurans from 20 caves in northwestern Georgia revealed five distinct species belonging to the genus *Litocampa*. Each species belongs to a different species group. The *cookei* group is represented by the widely dispersed *L. cookei*, having been found in Howards Waterfall Cave in Dade County. The *henroti* species group is represented by an undescribed species known from caves in Dade and Walker counties, and from other caves in Tennessee and Alabama. The *valentinei* and *pucketti* species groups are each represented by an undescribed species, having been found in caves in Chattooga County and Walker County, and Dade County and Walker County, respectively. Both of these species are also known from neighboring Alabama caves. Lastly, a new undescribed species belonging to the primitive *condei* species group was collected from a cave in Bartow County. The discovery of this new species offers further support for the hypothesis that the ancestral home for most of the cavernicolous species of *Litocampa* in the United States was the highlands of southeastern Tennessee.

ANOTHER CHAPTER IN THE BIOSPELEOLOGICAL INVENTORY OF VIRGINIA CAVES

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Since the publication of Holsinger & Culver's 1988 work on the cave invertebrates of Virginia and northeastern Tennessee, biospeleological inventories of cave invertebrates have continued. Their work included records of invertebrate fauna from 319 of 2377 Virginia caves known in 1988. From late 1989 to 2000, a total of 317 Virginia caves have yielded new records from identified collections of cave invertebrates in 25 of the 26 solutional cave-bearing counties in the Virginia Valley and Ridge province, and solutional caves in one county each in the Virginia Blue Ridge and Piedmont provinces. No new identifications were made in Frederick County. Records from caves in Bedford (Blue Ridge province), Clarke, and Loudoun (Piedmont province) are the first cave invertebrate records from these counties. Of the 317 caves reported in this study, 83 were included in the earlier study but have yielded addition records. The two studies have yielded identified cave invertebrates in 553 caves out of the 3884 Virginia caves known in 2001. Both studies include other caves from which no collections were made, or from which collections have not been identified.

In addition to a better understanding of the biological resources of Virginia caves, these studies have saved some caves from destruction or minimized impacts of roads and other land-use changes. Regrettably, Virginia caves continue to be affected by land-use changes. In some cases, we now know that biological resources have been lost by habitat destruction or cave destruction.

DISTRIBUTION AND ABUNDANCE OF THE MIDGE *GOELDICHIRONOMUS FULVIPILUS*, IN CUEVA DE VILLA LUZ, TABASCO, MEXICO

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The terrestrial and aquatic ecosystems in Cueva de Villa Luz (aka Cueva de las Sardinas) in southern Tabasco, Mexico, are based on energy inputs of both organic material and sulfur. Sulfur bacteria in the stream are a major source of food for the chiromomid larvae of *Goeldichironomus fulvipilus* (formerly *Tendipes*, then *Chironomus*). Several aspects of the life history of this midge have been studied. Adults lay abundant egg cases just at the waterline, which hatch into minute red larvae. The larvae live in cases, with the highest density found in rapidly flowing water. When they pupate, the adult midges emerge from the water. Adults do not feed, but often reach such high densities that they produce an audible buzzing sound, as noted in the naming of the Buzzing Passage and the Other Buzzing Passage. Adult midges are initially red from larval hemoglobin, but change to a green color within 24 hours. The ratio of red to green midges is significantly different in different parts of the cave. Capture of emerging midges also shows a variable distribution, with productivity ranging from < 1/m² per day in silt-bottomed areas of the cave, to several hundred per m² per day in riffle areas. The productivity determines the ratio of red to green adults. The midges are an important source of food for the cave fish in the stream and support large numbers of spiders in the terrestrial system.

A SYSTEMATIC APPROACH TO SAMPLING THE ARTHROPOD ASSEMBLAGE OF GREGORYS CAVE, GREAT SMOKY MOUNTAINS NATIONAL PARK

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Recent extensive bioinventories such as the All Taxa Biodiversity Inventory (ATBI) in progress in Great Smoky Mountains National Park (GSMNP) have spawned several studies both above and below ground. Though faunal inventories are common in biospeleology, quantitative sampling techniques for cave arthropod populations are few, and studies of this nature in GSMNP are non-existent. In this study, a systematic sampling approach with standardized, repeatable methods determined population sizes and spatial distributions of 11 arthropod taxa in Gregorys Cave, and a comprehensive species list was compiled. Monthly sampling trips, from May 2000 to April 2001, yielded 46 arthropod species representing 35 families, 16 orders, and 5 classes. Of these, 29 were new records for the cave, with two being undescribed species and at least one a new record for GSMNP. Of the 11 taxa studied in detail, all but two showed significant fluctuations, both of their monthly population and their distribution within the cave relative to the entrance. Aquatic arthropod populations were also monitored, and their presence and abundance compared to factors influencing the water table. Richness and dissimilarity indices were calculated for the 12 months of sampling. The greatest numbers of species were observed during November 2000, December 2000, and February 2001, and the peak changes in taxon composition occurred between May 2000 and June 2000. I propose that epigean weather parameters brought on by seasonal change greatly influence the arthropod community in Gregorys Cave.

POPULATION STUDIES OF THE AQUATIC SNAIL *PHYSA SPELUNCA* (GASTROPODA: PHYSIDAE) FROM LOWER KANE CAVE, WYOMING

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Most cave ecosystems are energetically limited, depending on the transport of organic materials into the system from the surface. In contrast, Lower Kane Cave, Wyoming, contains sulfidic waters that support abundant communities of sulfur-oxidizing microbes, which use chemical energy to produce food. Other cave systems containing comparable microbial communities have abundant and diverse invertebrate fauna associated with this type of sulfur-based production (e.g., Movile Cave, Romania; Frasassi Caves, Italy). While its invertebrate fauna assemblage is not as diverse as similar systems, Lower Kane Cave contains an extremely abundant aquatic snail, *Physa spelunca*. Stable isotope analyses show that *P. spelunca* sampled from within the cave feed on the microbial mats, with both δ^{13}N (7.5‰) and δ^{13}C (-36‰) values exhibiting typical trophic effects. In contrast, snails collected from the entrance of the cave had δ^{13}C values (–26‰) typical from terrestrial C3 photosynthesis, indicating a shift to surface productivity. The abundant microbial food source has led to extremely high population densities in the immediate vicinity of the mats, with estimates as high as 6800 individuals/m². Although *P. spelunca* was originally described as exhibiting classic troglomorphic features (i.e., eye reduction and pigment loss), observations of the Lower Kane Cave population indicate that there are at least two other color morphs present (red and black). Preliminary investigations into the genetics of this unusual cave population have been initiated based on internal transcribed spacer gene regions, in order to estimate genetic diversity and evaluate population structure.

WHEN CAVE FISH SEE THE LIGHT: REACTION NORM TO LIGHT EXPOSURE DURING DEVELOPMENT IN EPIGEAN, TROGLOMORPHIC, AND HYBRIDS OF *ASTYANAX FASCIATUS* (CHARACIDAE)

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The study of phenotypic plasticity among hypogean fauna has been virtually ignored. Anecdotal accounts suggested that the development of troglomorphic features such as blindness and depigmentation could be epigenetically influenced by exposure to light. We conducted a series of experiments to ascertain the reaction norm to light on eyes, pigmentation, and behavior among epigean (eyed, pigmented), troglomorphic (blind, depigmented), and hybrids (epigean X troglomorphic) individuals of *Astyanax fasciatus* (Pisces: Characidae). Results show that light (or its absence) can strongly influence the development of pigmentation in the regressed eye and swimming behavior of different stocks of this fish species. These results may have important implications in the understanding of the reduction or loss of features during evolution. The ability to respond to changes in light regimes may explain the different phenotypes among many taxa that can be found in the hypogean environment. Further, this phenotypic plasticity may be an adaptive feature on which natural selection acts to determine survivability in the cave environment.

PRELIMINARY REPORT ON INVESTIGATIONS OF RED IMPORTED FIRE ANT (*SOLENOPSIS INVICTA*) IMPACTS ON KARST INVERTEBRATE COMMUNITIES AT FORT HOOD, TEXAS

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Red Imported Fire Ant (RIFA), *Solenopsis invicta*, predation upon karst invertebrate communities in central Texas has been reported in studies by Elliott, Reddell, and Cokendolpher. We have begun a year-long study of 6 caves that seeks to quantify aspects of this phenomenon. The study sites are at Fort Hood (Bell and Coryell counties, Texas), near the northern limit of the Edwards Plateau. Caves there harbor a variety of troglobitic macroinvertebrates, including several narrowly endemic taxa. Above ground, we use timed bait censusing to measure RIFA foraging activity on a grid of points centered over cave entrances and conduct mound counts within the study plots. Inside the caves, timed RIFA bait traps are placed along an in-cave transect. Visual censusing in a 0.1 m² quadrate frame quantifies diversity and abundance of cavernicoles along the in-cave transect. Preliminary results corroborate earlier observations, in that RIFA mound density and foraging activity are higher at disturbed, open sites. RIFA foraging on the trogloxene *Ceuthophilus secretus* in and outside of caves suggests that the interactions between these two species could have a negative impact on cave communities. We have observed an active RIFA foraging trail in the dark zone of a cave (2 cm soil temperature 17.0°C) while epigean 2 cm soil temperatures were too low for surface foraging by RIFA (average 12.8°C), demonstrating that RIFA can use the cave community as a food source when temperatures near the surface are too low for foraging.

CAVE RESCUE

FALL FACTORS AND COW'S TAILS: THE DANGERS OF USING STATIC AND DYNAMIC ROPES FOR COWS TAILS

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Static rope should NEVER be used for cow's tails or other applications where it may be required to catch a fall. Any slack between the climber and the anchor when using static rope can be fatal if the climber falls. Static rope is not capable of absorbing energy. The different forces that affect a fall can be seriously underestimated on short falls, such as one might experience when falling on a cow's tail. Falling 4 feet on 2 feet of static rope creates a fall factor that significantly exceeds the maximum fall factor of 2, and can cause anchors, carabiners, and harnesses to fail. It can also cause serious injury or death. Dynamic rope is a safer alternative for cow's tails but still must be treated with caution. The ability of a dynamic rope to absorb the energy of a fall is primarily a function of how much rope is between the climber and the anchor.

Cavers should try to keep possible falls below a fall factor of 1. The easiest way to do that is to make sure that the anchor is always kept above the point where the cow's tail attaches to the harness, and to use a dynamic attachment. A two-foot fall on two feet of dynamic rope creates a fall factor of 1. This fall is half as hard as a fall factor of 2. Commercial available products like the Zypher and sewn cow's tails are the safest alternative, as they are designed to absorb considerable energy in case of a fall. Traversing should never be done with cow's tail alone. An ascender must always be on the rope as well.

CREATING A PREPLAN FOR CAVE RESCUE

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A previously prepared plan for a cave rescue helps with activities during a stressful time. As a trip leader, you may have to send an inexperienced person to call for help. A PrePlan gives that person a checklist and resource list so when they reach the surface, they don't have to depend on memory. It also helps the first arriving rescuers, since they are probably not trained cave rescuers. Fire Departments live by SOGs, Suggested Operating Guidelines, and SOPs, Suggested Operating Procedures, so one doesn't have to depend on memory during a stressful event. Giving the commanding officers SOPs or SOGs is giving them a road map, and turning an event that was an unknown quantity into something understandable.

Including a rescue PrePlan in a cave management plan allows people to determine the potential trouble spots. Then you can assign the resources needed to move patients in various conditions from those spots to the surface. You can also determine what extreme measures, such as bolting formations or passage modification, might be needed and acceptable. Thom Engel created an excellent rescue PrePlan as part of the management plan for the Knox Cave Preserve.

COMMUNICATIONS AND ELECTRONICS

OPERATING LED HEAD LAMPS AT THREE VOLTS AND BELOW

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A 24 LED head lamp operating from a single $LiSO_2$ D cell with a 7.5 AH capacity is a good combination for use in expedition caving. It can operate at maximum brightness for 12 hours. This is made possible by the addition of a low-dropout, 3-terminal voltage regulator to a LED head lamp that uses a switching supply based on the MAX1698 integrated circuit. Efficient operation is possible over a range of 2 to 9 volts, but the battery voltage must be at least 2.6 volts for the light to start operating. Operation is also possible using other battery combinations including 3 to 6 NiMH cells or even 6-volt gel cells. Over 4 hours of light at maximum output is possible with 4 rechargeable 1.8 AH AA NiMH cells. By adjusting the light output to only what is needed, the light can operate for well over 8 hours.

WATER TRACING EXPERIMENTS IN BELIZE USING AN INEXPENSIVE TOTAL DISSOLVED SOLIDS METER

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A low-cost ($39 US), pocket-sized, temperature-compensated, digital Total Dissolved Solids (TDS) meter and an alcohol/glass thermometer were used to collect data from several water sources in the Barton Creek Cave system and from associated insurgences, springs, and surface streams. A TDS meter measures electrical conductivity, corrected for temperature, but is typically calibrated in parts per million (ppm) of calcium carbonate. The data collection and dye tracing were part of the 2002 Barton Creek Cave Mapping project, under the auspices of the Western Belize Regional Cave Project directed by Jaime Awe for the Belize Department of Archaeology.

Several insights resulted from these simple measurements. We concluded that 3 streams (120 ppm/21.4°C; 127 ppm/22.2°C; and 367 ppm/24.4°.C) found near the terminal breakdown in Barton Creek Cave come from separate sources. Our on-site guess was that the Slate Creek insurgence (18 ppm/21.1°C on the surface) was the main source of the first stream and the insurgence in the "Vega" near Mountain Equestrian Trails (45 ppm/22.2°C) was part of the source of the second stream. Dye tracing, with materials and analysis generously donated by Nicholas Crawford of Western Kentucky University, later proved these guesses to be correct. The third stream comes from a large crystal clear siphon. It may not be a good bet for diving because the TDS and temperature suggests that the water has been underground for a long time and may come from diffuse sources in the karst aquifer.

CONSERVATION AND MANAGEMENT

LA CUEVA DE LAS BARRANCAS, PROTOTYPE SITE FOR MARS STUDIES

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La Cueva de las Barrancas, a desert cave first entered in 1991, is managed as a pristine subterranean laboratory for speleological research. The cave management prescription, approved by the US Forest Service in 1999, prioritizes scientific investigation in the cave. In Barrancas, science goes first, before exploration, survey, or cartography. Sampling and investigation for microbial life are initiated in each new passage before other scientists or cavers are allowed to enter. Some areas are left untainted by human entry, preserved as virgin sites for future studies.

Because this cave offers a protected environment for scientific study, the management plan contains innovative features describing limits of acceptable change and protocols for exploration, survey, and research. Included in the plan is a Minimum Impact Code of Conduct for cavers and scientists entering the cave, and Barrancas is managed cooperatively through a "Memorandum of Understanding" with cavers who assisted in writing the management plan.

Science in Barrancas has progressed from doing initial baseline studies of subsurface microbial life to establishing the site as a prototype for subterranean studies on Mars and other planets. Grants awarded by the NASA Institute for Advanced Concepts support using Barrancas as a test environment to develop low-impact operational logistics and no-impact *in situ* techniques for the study of microbial life in sensitive environments. These efforts will advance the study of other pristine and previously impacted cave sites, as well as the study of fragile surface environments.

CONSERVATION EFFORTS AT SPENCER MOUNTAIN, VAN BUREN COUNTY, TENNESSEE

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Tennessee State rules protect streams determined to be "High Quality" against degradation by pollutants or the removal of habitat. A decision to allow the discharge of treated wastewater into Dry Fork Creek, a karstic High Quality stream that flows through Fall Creek Falls State Park, prompted a hydrogeologic study in the Spencer Mountain area of Van Buren County. The study, carried out in summer and fall of 2000, defined major subsurface flow paths and delineated groundwater basins. The results are available to the permitting agency, the permit applicant, environmental advocacy groups, and the Tennessee Water Quality Control Board to help decision-makers evaluate potential impacts of the proposed wastewater discharge and identify discharge alternatives.

A coalition of environmental groups was formed to encourage Spencer and the permitting agencies to protect the stream and associated cave system. The coalition cooperated with US Environmental Protection Agency to study alternatives to the stream discharge. A biologic survey found 24 cave-dwelling species, including 19 unique or rare species. The US Fish and Wildlife Service filed for emergency listing of species at risk and asked the state not to allow the discharge. In order to use public opinion for political leverage, the discharge issue and existence of the caves beneath Spencer were revealed to the news media. The coalition found significant deficiencies with implementation of federal and state environmental protection laws. The issue was heard by the state Water Quality Control Board, and lawsuits are filed in state and federal courts. Final resolution is pending.

THE BECKIS PROJECT - ESTABLISHING A GIS FOR CAVE AND KARST CONSERVATION IN BERMUDA

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The islands of Bermuda, located in the Western Atlantic Ocean ~1000 km off the coast of North Carolina, contain many significant caves. Bermuda is a densely populated country with ~65,000 inhabitants and a land area of roughly 57 km². Approximately 150 caves have been discovered in Bermuda, many of them profusely decorated with delicate and unique speleothems. Many caves include passages that extend to sea level and contain deep anchialine pools and extensive underwater networks. A large variety of cave-adapted life, including previously unknown species, has been found in these underwater caves. Of the species identified in Bermuda's caves, 25 are currently on the critically endangered species list. The high population density and resultant development pressures, vandalism, pollution, and other negative factors have had a significant impact, and continue to threaten Bermuda's unique cave resources.

In early 2002, the Bermuda Cave and Karst Information System (BeCKIS) project was established, with the primary goals of increasing public awareness of Bermuda's caves and cave life, increasing awareness of negative impacts on these resources, and promoting the scientific study of Bermuda caves. The BeCKIS uses GIS software to maintain a database and inventory of cave locations, and incorporates field observations and other measurements along with both dry cave and submerged cave survey data and maps. GIS maps have been used to establish baseline quality information from past observations, and additional GIS projects are proposed.

CAVE ASSESSMENT, MAPPING, AND CAVE POLICY FORMULATION RESEARCH PROJECT IN SIX BARNAGAYS OF RAJAH SIKATUNA NATIONAL PARK, BOHOL, PHILIPPINES

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An 8-month cave exploration and mapping policy formulation research project was carried out in 6 barangays containing part of Rajah Sikatuna National Park in Sierra Bullones, Bohol, Philippines, from June 2001 to February 2002. The research project had 2 parts: technical exploration and mapping and the development of cave management guidelines and policies. All aspects of the research were carried out with the active participation of local barangay residents. A total of 26 caves with horizontal entrances were explored and mapped in the study. Information collected included surface vegetation, cave features, resources inventories, flora and fauna inside the cave, extent of damage and evidence of treasure hunting, and cave history. A cave coding system was instituted. Thirteen different speleothem types were observed. Resources in the caves included guano, rock phosphate, sand, speleothems, water, and bird nests. Six caves showed evidence of treasure hunting. All data and results were presented to individual participant barangays. A workshop was held on policy and cave management guidelines. The study caves were classified for eco-tourism (show and wild caving), resource use (guano, water, swift nests), and scientific value. Ten strategies for proper cave use were formulated. The research showed local residents can explore, map, and determine management policies and strategies, if given proper guidance and training. Further studies are underway at the site.

CAVE PERMIT SYSTEM OF GUADALUPE RANGER DISTRICT, LINCOLN NATIONAL FOREST

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The Lincoln National Forest, New Mexico, implemented a closure order in 1972, restricting cave access to those with a permit. Over the years, the permitting process has evolved to provide enhanced protection for cave resources, while still allowing recreational use of most of the Guadalupe Ranger District caves.

Following policy and direction set in the Forest Service Manual, Lincoln National Forest Plan, the Federal Cave Resources Protection Act of 1988, and Lincoln National Forest Cave Ecosystem Management Direction, the Lincoln National Forest caves are managed as nonrenewable resources to maintain their geologic, scenic, educational, cultural, biological, hydrologic, paleontological, and recreational values. Caves have been assigned management classifications, based on visitor potential impact on the caves' ecosystems. Management classifications range from Class 1 to Class 6. Class 1 defines a cave as highly developed, and Class 2, 3, and 4 as undeveloped. Class 5 and 6 caves are closed to recreational use.

Management Class 2 caves may be visited with a guide or approved Trip Leader. To allow more people to visit Management Class 2 caves, a Trip Leader program was developed. Cavers become approved Trip Leaders when they participate in restoration projects within a certain cave, or when they complete in-cave Trip Leader training.

A Cave Steward program is being considered. Cave Stewards would work under Volunteer Agreements and receive in-depth training to protect cave resources while leading visitors on recreational trips.

CONSERVATION AND RESTORATION

TOURISTS AND ENTREPRENEURS: CAVE PRESERVATION IN THE 19TH CENTURY UNITED STATES

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The first impulse toward preserving underground natural spaces came from visitors who feared that the aesthetic qualities of caves were jeopardized by vandalism and other threats to these important cultural spaces. This anxiety led to informal efforts to create new behavioral norms for tourists and, in the remarkable case of Horace Martin, a call for government protection of America's most important cave, Mammoth Cave of Kentucky. A second group, cave entrepreneurs, also supported cave preservation, though they were motivated by overriding pecuniary interests and implemented an approach based on regulating the behavior of tourists. Neither visitors nor proprietors recognized other threats to caves, such as extractive mining or industrialization of karstlands. Aesthetic preservation, still the dominant thrust of cave conservation today, was the primary basis for nascent efforts at protection, while biological, geologic, and historic preservation were non-existent. Compared to other environments, cave preservation was late in arriving and generally ineffective until the 20th century.

GEOLOGY AND GEOGRAPHY

APPLICATIONS OF CAVE DEPOSITS TO TEMPORAL HYDROLOGIC AND ENVIRONMENTAL CHANGE

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Cave deposits can preserve physical, biologic, and chemical records of the temporal and spatial scales of the processes involved in the development of aquifers and landscapes. Studies of growth rates, trace elements, and isotopes illustrate uncertainties involved and the novel advances that can be made with these methods. In central Texas karst (CTK), stalagmite growth rates correspond to glacial periods over the past 70 ka, as determined by 2 independent U-series dating methods. These results are consistent with wetter climates during glacial periods in this region. Based on faunal successions in cave sediments, a hypothesized major CTK soil erosion episode starting in the early Holocene is supported by a new application of Sr isotopes to estimate changes in ancient soil thickness. Paleoclimate studies infer temporal changes in drip water temperature and rainfall composition, using the temperature dependence of trace element and stable isotope partitioning into calcite. This approach assumes that equilibrium precipitation of calcite occurs and that other processes do not significantly affect trace element variations. These assumptions are tested in CTK by examining Mg and Sr variations in modern water samples from soil, vadose, and phreatic environments, reflecting increasing reaction with aquifer limestone. Geochemical variability in soils exerts a first-order control on regional and local water compositions. These effects are much larger than estimates of temperature control. Isotopic equilibrium is being tested by analysis of coexisting water and calcite pairs in CTK and Barbados aquifers. Modern aquifer systems provide important constraints for interpretation of paleo-environmental records derived from cave deposits.

USING CONTINUOUS DYE INJECTION TO SIMULATE CONTAMINANT TRANSPORT DURING PRECIPITATION EVENTS IN A KARST AQUIFER, FORT KNOX, KENTUCKY

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Traditional single-pulse dye injections effectively simulate the movement of a contaminant mass released immediately into a groundwater system. However, they do not address the movement of long-term, slow-release point source contaminants to the environment (e.g., leaking underground storage tanks). Accounting for both release modes would help develop a more effective groundwater monitoring program. This project developed a continuous dye injection program to simulate a potential long-term contaminant release to groundwater. Methodology included the continuous injection of dye, at a constant rate and concentration, over several weeks to establish baseline concentrations of dye at resurgent springs. Once the baseline was established, changes in dye concentration caused by precipitation events could be observed. Two trials were conducted in separate drainage basins under different hydrologic conditions. Dye concentrations showed similar behavior during the initial response to storm events; however, concentrations during post-storm monitoring varied significantly between the 2 trials. In trial 1, the dye returned to its baseline concentration as discharge returned to pre-storm volumes, suggesting uniform transport through the system with minimal residence time. Trial 2 concentrations did not return to baseline values but increased 5-fold and remained elevated for long periods, indicating that a majority of the dye was stored in the aquifer until mobilized by a storm event. Using dye as an analog for contaminant transport through a karst aquifer, the variations in dye concentration from this study demonstrate a need to develop more detailed groundwater sampling protocols to account for slow-release contaminants.

ROME TROUGH TECTONICS IN PULASKI COUNTY, KENTUCKY: KARST INDICATORS

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Karstification of Mississippian carbonates in southern Pulaski County, Kentucky, is extensive. The location and orientation of the passages and flow paths of several major karst conduits within the study area are independent of surface drainage patterns, suggesting a dependence on geologic structure. Geologic, geomorphic, speleogenetic, and statistical evidence gathered from within Jugornot, Coral, and other regional caves, as well as nearby surface features, represents probable faulting below the study area. Further evidence suggests this faulting is related to the Rome Trough structure formed during Iapetan rifting in the Late Precambrian to Middle Cambrian. Fractures and lineaments generated by minor reactivation of this fault system have propagated upward through Mississippian and Pennsylvanian strata as fracture swarms. To date, 5.4 km of passages have been mapped in Jugornot Cave, with a vertical span of 81 m. The nearby Coral Cave System has a current total length of 42 km (36 km connected), with a vertical span of 100 m. Evidence gathered from this study compared with seismic data provided by the Kentucky Geological Survey confirms the presence of a basement fault with a maximum offset of 880 m. This fault was previously hypothesized from magnetic and gravity-anomaly data. The surface expression of this fault is a lineament, mapped using surface and subsurface data, ~3 km wide, 20 km long, and oriented at ~065°. Structural, depositional, and geophysical evidence points toward 3 subparallel, right-lateral, oblique-slip faults in the Precambrian and Cambrian strata of Pulaski County related to Rome Trough tectonism.

SANNUR CAVERN, EGYPT, AND FORMATION CAVE, IDAHO, AS ROOFED GOURS

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Depositional carbonate caves ("travertine caves") are a neglected part of speleology. A considerable variety of morphologies is evident. One interesting type is represented by Sannur Cavern, in the Eastern Desert of Egypt, and by Formation Cave, in southeastern Idaho, USA. Although enormously different in size and in geomorphic settings, both caves are characterized by a half-moon horizontal section with a nearly horizontal floor, a near-vertical inner wall, and a backward-curved outer wall, which forms the roof as part of its curve. Thus, both appear to be large roofed gours. Additional studies are needed of depositional carbonate caves, in general, and of any additional roofed gour caverns that can be identified.

REGIONAL KARST MAPPING OF VIRGINIA'S VALLEY AND RIDGE PROVINCE COMPLETED

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The last regional karst maps of Virginia's Valley and Ridge physiographic province is published. The 1:250,000 scale maps include carbonate outcrop areas for 254 different 7.5-minute quadrangles, and were mapped from 1980 through 2001. All three maps include sinkhole and cave entrance locations plotted on a cultural base with geologic map units of limestones, interbedded limestones and dolostones, and non-carbonate rocks. The southern map, the third in the series, includes spring and insurgence features. The mapping of specific features conveys a sense of the relative degree of karst development throughout the province, but on a scale that minimizes their inappropriate use as site specific data. Sinkholes, springs, and insurgences were remotely sensed by stereographic viewing of leaf-off, low altitude (~3600 m), panchromatic aerial photography. Sinkholes (includes all karst depressions) range from a minimum size of 9 m to the 6.8 km long Dungannon polje. A total of 31,239 sinkholes are located on the southern map; the series map includes 48,807 sinkholes. Cave locations were provided as proprietary data for disclosure only at this regional map scale by Virginia Speleological Survey. Karst development increases markedly from north to south. By quadrangle, the maximum number of sinkholes observed for the three maps were: 501 on the Harrisonburg quadrangle, 776 on the Radford North quadrangle, and 1350 on the Crockett quadrangle for the northern, central, and southern maps, respectively. These maps define the extent of karst in the province and convey a relative degree of karst hazard potential.

VERMICULATIONS AND ASSOCIATED DEPOSITS IN SNEDEGARS CAVE, WEST VIRGINIA

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Vermiculations are deposits of incoherent materials made primarily of clays and silts. In Snedegars Cave, vermiculations are unusually abundant on walls of canyons in the Saltpetre Maze and on the ceiling of the Trunk Continuation passage. The vermiculations and associated deposits take a variety of forms. These include relatively uniform ceiling, wall, and ledge coatings, elongated spots and patches, isolated spots and stringers with well-developed haloes, interconnected stringers that locally resemble dendritic vermiculations, ledge undercut deposits, and rill coatings deposited in rill trails associated with descending condensation waters. Many vermiculations undergo annual wetting and drying cycles associated with abundant summer condensation and winter drying. However, detailed observations and repeated photography at selected locations have failed to detect active growth of vermiculations or major changes in vermiculation patterns since 1986.

At least four types of materials form the vermiculations. Red/brown clayey silts may be derived from similar deposits found on ledges, in plugged ceiling tubes, in anastomoses, as crack infillings on canyon walls, and on the surface in sinkholes. Brown/black clayey silts and clays occur primarily near the Saltpetre maze entrance and may be derived in part from forest soils and from the red/brown clayey silts. Gray/tan clays may include aeolian material plating out on surfaces moistened by condensation. Brown/red clayey silts may have coated the ceiling of the Trunk Continuation during waning stages of floods and may be derived from both the red/brown clayey silts and more recent suspended fluvial sediments carried by Cove Run into the cave.

INFLUENCE OF SOILS ON CAVE DRIPWATER GEOCHEMISTRY IN THE EDWARDS AQUIFER OF CENTRAL TEXAS

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Systematic differences in the geochemistry of cave dripwaters in the Edwards aquifer of central Texas are traceable to local soil variability. The Edwards aquifer is developed in karstified Cretaceous limestone and is well-suited to examination of groundwater evolution processes using vadose groundwaters (i.e., cave dripwaters), phreatic groundwaters, and soil leachates. Variations in Sr isotopes and Mg/Ca and Sr/Ca ratios offer insight into the influence of soils on groundwater geochemistry, sources of dissolved constituents in groundwater, water-rock interaction processes, and groundwater residence time. Samples from multiple caves across the region provide the potential to distinguish between local (e.g., within a single cave) versus regional effects.

Variations in Sr isotope values likely reflect changes in the relative Sr flux from soils versus carbonate host rocks, which varies in response to residence time and the corresponding extent of water-rock interaction. Strontium isotope values for cave dripwaters correlate inversely with both Mg/Ca and Sr/Ca ratios. Mass-balance modeling suggests that variations in fluid compositions are regionally controlled by groundwater residence times and water-rock interaction with overlying soils and host aquifer carbonate rocks. Local geochemical differences in dripwaters between individual caves are similar to differences in leachates of soils overlying the caves. These differences in the soils determine the starting point of a fluid evolution model, in which waters evolve along a compositional pathway from soil water, to vadose dripwaters, to phreatic groundwaters. Although soils affect local dripwater variability, the controlling processes on dripwater geochemistry and groundwater evolution are regionally extensive.

SUBAERIAL BEDROCK ALTERATION IN HIGH-CO_2 CAVE ENVIRONMENTS

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Subaerial dissolution of bedrock in a high-CO_2 environment produces pasty or fluffy material, which falls to the floor and onto ledges as irregular layers under smooth, corroded ceilings. Such deposits are most common in caves in dry climates, where through-flow of meteoric water is limited. These deposits and their mineral assemblages can help define past chemical and hydrologic conditions. Most of this material eventually solidifies into a hard rocky material, which can be misidentified as flowstone or bedrock. In many places the unconsolidated paste has flowed down the walls before solidifying. Where the weathered paste falls into wet areas, evaporation forces calcite and aragonite to precipitate, concentrating other ions such as magnesium. The carbonate ion activity also rises, because evaporative enrichment offsets its loss to the precipitating minerals. As evaporation proceeds, fractionation causes rarer minerals such as huntite, hydromagnesite, magnesite, and dolomite to crystallize. The exact assemblage depends on the initial magnesium concentration and the extent of evaporation. Solidified paste is often recognizable as opaque, white, very finely crystalline material. It provides evidence for intense condensation corrosion in the past, even in caves that no longer support such an environment.

HYDROLOGIC, LAND USE, AND HISTORIC CONCERNS RELATIVE TO THE ROSENDALE MINING INDUSTRY

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The Rosendale and Kingston district in southeastern New York State, USA, was the natural cement capital of the world from 1825 to about 1950. It is important to document the world-class historic value of this major economic industry before significant industrial artifacts are lost. Relict features remaining today include vast mines, kilns used to produce high grade hydraulic cement, and a canal and transportation network. The limestone belt worked by early miners is riddled with abandoned limestone mines. There is no comprehensive inventory of these features.

Limestone (i.e., karst) aquifers are particularly vulnerable to contaminant inputs because no natural cleansing occurs. Formerly discrete karst aquifer systems were often integrated when mining operations discordantly cut across them. Today, extensive water-filled portions of these mines, strategically situated near or at the furthest downstream end of Rosendale and Kingston area karst aquifers, represent vast untapped groundwater reservoirs. Consideration of both mine and hydrologic features are important first steps in natural resource protection. Tracer investigations have been initiated.

Our research strives to document and portray these features via a GIS data base. Work being conducted includes a field-based GPS inventory of mines, mills, kilns, springs, caves, and karst features. Aerial photography is also being used to locate vertically bedded mines. Digitized mine maps, a digital photography library, and GIS maps are being produced to graphically depict information and make it accessible to the community. We envision that this information will be useful as a tool to further community planning, to enhance ecotourism, and to protect groundwater resources.

GROUNDWATER FLOW VELOCITIES FOR THE DEEP ARTESIAN PORTION OF THE EDWARDS AQUIFER, NEAR COMAL SPRINGS, TEXAS

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Two tracer tests assessed groundwater flow velocities and flowpath relationships between the deep artesian and recharge zones of the Edwards Aquifer at Comal Springs, TX. Results of the tests will help calibrate flow models of the Edwards, design an improved ambient water quality monitoring program, and improve response to hazardous material spills. Comal Springs, the largest in the southwestern United States, with an average discharge of 8.5 m^3/s, emerge from hundreds of individual locations and form the 1.2-km-long Landa Lake in New Braunfels, TX. The Comal Springs "complex" is located on the 250-m-displacement Comal Springs Fault, which juxtaposes the aquifer's recharge and deep artesian zones.

Over 80 participants, representing 4 countries and >15 public and private entities, monitored 30 surface sites and 3 municipal wells and collected and analyzed over 1600 water samples. A trace from the 200 m deep flowing artesian well (with a head about 5 m above ground level) yielded flow velocities of 290 m/d to springs 350-750 m away, and demonstrated conduit flow in the deep artesian zone. The dye emerged from rise points in a 400 m stretch of the middle of Landa Lake in an "underground delta" pattern. Dye was also detected in a municipal well 300 m from the dye-injection point. A second dye, simultaneously injected into a 25-m-deep well on the up thrown side of the fault, moved at 1400 m/d to a separate set of rise points at the springs.

ESTIMATING THE EFFECTS OF SEEDING-INDUCED RAINFALL ON KARST AQUIFERS

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Texas has one of the fastest-growing populations in the nation. With much of the state located in arid to semi-arid climates, cloud seeding is examined for its potential to replenish surface and groundwater supplies. Satellite interpretation of cloud structure is used in this study to identify clouds most suited for seeding, and probable seeding-induced rainfall (SIR) is calculated, based on limited ground calibration. The effects of SIR versus unseeded rainfall on groundwater were calculated primarily from mean recharge rates. However, most published recharge rates for Texas karst aquifers probably underestimate recharge, in some cases by nearly an order of magnitude. Recharge rates are better estimated by water balance calculations than by general permeability and porosity values that often do not account for karstic conditions. SIR was found to have high potential to significantly recharge karst aquifers. Due to the rapid discharge and flow-through rates in karst, SIR would be most effective in artesian aquifers with slower mean velocities and greater potential residence times through fracture and diffuse storage. Broad, aerially extensive unconfined karst aquifers with long distances to springs may also benefit from SIR. Small, narrow unconfined aquifers would probably rapidly discharge the enhanced recharge and not appreciably benefit from SIR. A comparison of SIR-enhanced Edwards Aquifer recharge versus diminished groundwater pumping following SIR over the city of San Antonio showed that the volume in pumping reduction would be 6 to 13 times less than the hypothetical volume of recharge from an equal size portion of the aquifer's recharge zone.

QUADRANGLES AS PIXELS: A PROPOSED TECHNIQUE FOR MAPPING CAVE DEVELOPMENT AT SMALL SCALES

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Preparing small-scale maps of karst areas at the State scale of 1:500,000 or a national scale of 1:7,500,000, poses unique challenges to the map maker's art. Existing karst maps typically display the outcrop pattern of karstic rocks-limestones, dolostones, and gypsum. One of the most important measures of karst development is the extent of cave development. Although cave maps can be prepared at scales in the range of 1:100 to 1:1000 and "stick maps" can represent large caves at scales of 1:10,000 and below, representation at still smaller scales is difficult. The scheme of representing each cave by a dot fails to account for cave lengths. There may also be objections to maps that show exact locations of caves.

The overall cave length per unit area is a better indicator of cave development than the number of caves per unit area. The USGS 7.5' quadrangle map is a useful, fundamental unit of area. Pennsylvania, a roughly rectangular, medium-sized state, is 40 quads east to west and 18 quads north to south. The total surveyed cave length within each quadrangle can be color coded on a logarithmic scale. A state map of cave length distribution is then shown as a mosaic of colored rectangles. Such a cave length representation lends itself to computer manipulation of database information and is adaptable to GIS formats. The colored quadrangle display gives a good sense of cave length distribution, but no indication of how many individual caves are present or where they are located.

CAPTURE ZONE ASSESSMENT FOR CONTAMINATED MUNICIPAL WELLS IN A CARBONATE AQUIFER

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Seven people died and about 2300 people became ill at Walkerton, Ontario, in May 2000 from contamination of the municipal water supply by pathogenic bacteria. Hydrogeological investigations have since sought to establish potential source areas, pathways, and travel times for this contamination.

A major hydrogeological investigation was conducted on behalf of the town of Walkerton in the summer of 2000. A numerical model of flow, incorporating the results of this investigation (assuming an equivalent porous medium and using MODFLOW), indicated that the 30-day time-of-travel capture zones extended up to 300 m from each of the 3 municipal wells. In February 2001, the hydrogeologic results obtained by the town of Walkerton were presented to a judicial inquiry. The author of this paper suggested that the carbonate aquifer at Walkerton was in fact karstified, implying that groundwater velocities could be far greater than the MODFLOW results indicated. This hypothesis was tested by convergent flow tracer testing to 1 well, which showed that groundwater velocities were about 80x faster than indicated by the MODFLOW simulation.

These rapid groundwater velocities show that the potential source area for the pathogenic bacteria extended far beyond the one farm initially implicated as the source of bacteria. These results vividly demonstrate both the importance of a precautionary approach in carbonate aquifers, in which karstic conduits may be present, as well as the usefulness of actually measuring groundwater velocities by means of tracer testing.

GEOLOGY - SPECIAL SYMPOSIUM ON PSEUDOKARST

THE ANVIL POINTS CLAYSTONE CAVE COMPLEX: WORLD'S LONGEST DRYLANDS PIPING CAVE?

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In recent years, a number of significant pseudokarstic piping caves have been documented in badland areas of northwestern Colorado. These typically occur in mixed claystone/sandstone debris-flow material along contacts with bedrock and resemble vadose solution caves in pattern and morphology. Their development is facilitated by high porosity in the matrix, a considerable content of shrinking/swelling clay, and high exchangeable sodium percentage. The Anvil Points claystone cave complex in Garfield County, in the Eocene Wahsatch Formation, is the most extensive thus far surveyed. It includes 3 genetically related caves, of which the longest is 625 m, 55 m of vertical relief, and 166 m maximum linear extent. The system is dendritic; a complicated sinkhole terrain feeds intermittent influx into several tributaries that converge into a discharge trunk. Passages are well-defined, with up to 12 m of overburden and with widely varying cross-sections, from crawlways to 6-m-high tubes and winding canyons. Breakdown chambers up to 9 m wide occur at 2 passage junctions. Internal piracy has diverted flow from some conduits. In one respect, these caves resemble ice and snow thermokarst: the roofs slowly sag, cycling surface material into the drains. In the process, bubble-like breakdown chambers may be formed above the stream level and migrate surfaceward. Such piping caves may exist on extraterrestrial planets like Mars, where weathering and intermittent water flow have occurred, but which have not necessarily been hospitable to carbonate solution cycles.

PSEUDOKARST: AN HISTORICAL OVERVIEW

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Pseudokarstic forms in loess were observed and described in China perhaps 2300 years ago. Roman writings mentioned lava tube caves on Mt. Etna. The presence of large talus, crevice, and glacier caves must have been known locally from early times.

During the early 20th Century, the specific terms “pseudokarst” and “pseudokarstification” originated several times, in several languages, and for several types of features. This created controversies that are still not completely resolved. Most of these pioneer reports described features remote from centers of learning, and their writers were not academics. They were commonly in obscure publications, and many were in languages that were not widely read, thus creating gaps in communications.

The German geologist von Knebel (1908) was apparently the first to use any of these specific terms. Beginning around 1927, Russian geologists pioneered the study of karst-like features in permafrost and poorly soluble rocks. In 1941, the title of a significant Italian paper used the term “fenomeno pseudokarsico,” and Malaurie used the term in French in 1948.

In the 1950s, the term became commonplace in speleological publications in central European languages and began to appear in the American geological and speleological literatures. Late in the 20th Century, symposia on pseudokarst developed independently in central Europe and in the USA, and a IUS Commission for Pseudokarst now correlates advances in this rapidly growing branch of speleology.

CAROLINA PSEUDOKARST: AN OVERVIEW OF ITS MULTIFACETED SPELEOLOGICAL SIGNIFICANCE

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As of January, 2002, the files of the Carolina Cave Survey listed ~1525 caves. The vast majority of these North and South Carolina caves are pseudokarstic. These non-solutional caves in the Carolinas include such features as large stream-worn potholes, rock shelters, and waterfall alcoves formed by erosion and breakdown. Also of interest are small tafoni caves created by honeycomb weathering. There are numerous soil pipes and suffosion caves formed by the piping of underground water along weak zones of decomposing granite. The most extensive caves include mechanically produced talus and tectonic caves formed by joint enlargement through frost action, block creep due to exfoliation, cliff spalling, and more massive gravity sliding phenomena. The most prevalent rock types include sand- and siltstones, quartzites, granites, schists, and gneisses.

ROCK-CITY CAVES: DISTRIBUTION, MORPHOLOGY, AND GENESIS

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There are several categories of pseudokarstic caves, formed largely by processes other than dissolution of bedrock. These include ‘accidental caves’ those formed through the juxtaposition of rocks, such as the accumulation of talus or the falling away of a lower section of a cliff, leaving an overhang or a shelter cave. Rock-city caves result from the displacement of blocks of rock that have separated from bedrock. Rock-city caves differ from most other accidental caves because of their systematic movement of blocks in a uniform direction.

Geomorphologists describe rock cities as blocks that have become detached from the bedrock and separated by sliding, so that a network of avenues, often in two mutually orthogonal sets, forms spaces among the blocks. The result is the appearance of a ‘city’ composed of blocks (buildings) that have canyons (streets) surrounding them. Block gliding is typically facilitated by lithological differences between the moving blocks and the material on which they glide, for example, blocks of sandstone that have slid on an underlying shale. Rock-city caves require that some of the blocks form roofs. This occurs by differential sliding among superimposed strata, by toppling of some blocks, or where separated blocks have become lodged between glided blocks.

Rock-city caves are found in areas where the process of block gliding is common. Some noteworthy examples are found in the eastern states, including New York, Ohio, Pennsylvania, Virginia, and Tennessee. Several rock cities have been developed as tourist attractions or parks.

SEA CAVES OF RHODE ISLAND, USA

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Rhode Island, “The Ocean State,” has at least 12 sea caves. Pirate and Conrads Caves in Newport were Victorian-era tourist attractions. The Boston Grotto recently discovered other sea caves; it is very likely that more will be found. In Newport, 2 smaller sea caves are adjacent to the original Pirate Cave near Brenton Point. In Middletown, there is one sea cave within Purgatory Chasm, a Victorian attraction. In Jamestown, caves are located on Taylor Point, Fort Weatherill, and Lion Head.

Two factors control the location of the sea caves. The primary influence is a high-energy shoreline. Most of the sea caves are on or within 1 km of the Atlantic Ocean. Two small sea caves on Taylor Point, Narragansett Bay, are the furthest (7 km) from the ocean. The second factor that controls sea cave locations is the local structural geology. Faults allow sea caves to form in some of the most resistant rock in Rhode Island. The sea cave in Purgatory Chasm is in the Purgatory Conglomerate, a very tough, cliff-forming metaconglomerate, where a high-angle fault intersects the chasm-forming joint set. The sea cave at Fort Weatherill is in a fault zone within the porphyritic Lily Pond Granite. Better sea cave development occurs where faults and joints further weaken the less-tough meta-siltstones and phyllites of the Newport Neck, Fort Burnside, and Jamestown Formations. At Taylor Point, where the sea caves are 7 km from the ocean, phyllite of the Jamestown Formation contains sea caves at weaknesses related to joints and kink folds.

EROSIONAL AND SOLUTIONAL SEA CAVES OF NAHANT, MASSACHUSETTS, USA

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Nahant, a rock island connected to the mainland by a sand tombolo, has erosional and solutional sea caves. The cave area is on the Atlantic Ocean and 5.5 km from the mainland. It is a southeast-facing, high-energy shore with dramatic rocky cliffs. The cave area has complex geology with structural blocks and hundreds of black mafic intrusions that imprinted colorful contact metamorphism on faulted gray Cambrian strata.

There are 3 erosional caves (Swallows, Devils Cove, and Slime) in Nahant. Swallows Cave, known in colonial times and included in Hauer's Caves of Massachusetts, developed by erosion of a forked basalt dike in the Nahant Gabbro lopolith. The other caves are in the Pulpit Rock structural block. Devils Cove Cave formed in a shattered tholeiitic dolerite sill. Slime Cave, barely worth noting, is in folded and faulted Weymouth Formation meta-sediments.

Three solutional sea caves in Weymouth Formation limestone are unique to New England. The Weymouth is often contact-metamorphosed into colorful, insoluble rocks, but the portion with caves is a 3.6-m-thick unit of unmetamorphosed cherty limestone. The caves, which have oval or rectangular cross-sections, formed because of seawater dissolution of the limestone along joints. Devils Maze is on the north side of Devils Bridge chasm. Devils Chin and Devils Mouth Caves, on the south side of the chasm, go through a rock point. The caves are at different elevations above current sea level. Devils Mouth and Devils Maze are emerged sea caves, while Devils Chin is just above the current high-tide mark.

PSEUDOKARST DEVELOPMENT NEAR BARSTOW, CALIFORNIA

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An area near Barstow, California, which includes Rainbow Basin National Natural Landmark, contains numerous pseudokarst features and several sizable caves. The area is dominated by Tertiary lake-bed deposits and includes other sedimentary and volcanic ash layers. A fault system related to the San Andreas Fault has caused extensive folding and tilting of these layers, resulting in textbook examples of unconformities, anticlines, and synclines.

Runoff has been channelized by numerous faults and folds, and erosion occurs naturally along fractures and weaker beds. Heavy dissection of these sedimentary deposits in some areas has created significant gradients that have further channelized and concentrated runoff, resulting in tunneling and piping. Some areas are dominated by sinkhole-like structures, pits, and numerous small caves. Weathering of less consolidated layers also contributes to the development of small caves. Although the region is arid, seasonal rainfall contributes to these processes today.

CAVES FORMED IN SALT-BEARING ROCKS BY LARGE ANIMAL CONSUMPTION

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In their quest for salt, large animals are known to create cavities or caves in salt-bearing rock formations. Several examples of such caves are described in various publications. An example in Mississippi, Rock House Cave, was visited by the authors in 1999. It seems to have been formed by deer. Perhaps the most spectacular example is Kitum Cave in Kenya. This cave has been excavated to a length >100 m by elephants. An ancient example is La Cuerva Milodon in Chile, which is reported to have been used by the now extinct Milodon. The several natural caves formed by this animal process constitute a unique class of pseudokarst features.

BRAINERDS CAVE: AN UNUSUAL PSEUDOKARST CAVERN

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Brainerds Cave in Jersey County, Illinois, is probably developed in the Edgewood Limestone of Silurian age. It is a relatively recent geologic addition to the landscape; the crack that formed the cave likely began to widen only a few thousand years ago. The cave is the only example of a "block-creep" cavern known to this author in the Midwest. It was created when a massive block of limestone separated from the high bluff above the Illinois River and began slowly sliding down the talus slope. A spacious cavern 3 m wide, 12 m deep, and 21 m long was formed between the downwardly advancing block and the main limestone massif. Small side passages exist along secondary cracks. The process is still continuing. No solution processes were involved in the genesis of this cave, but water seeping down the walls of the cavity from above adorned the cave with a few small flowstone deposits. Pounded chert nodules hint that prehistoric American Indians explored the cave.

The cave can be entered through a tight opening at the top of the bluff. The caver can chimney down to the bottom of the cave. Use of a handline is advised. Once the haunt of local children, Brainerds Cave is now owned and managed by Pere Marquette State Park. It is the home of a well established colony of little brown bats and numerous other cavern dwelling creatures. Entrance to the cave is currently allowed only with a research permit.

SUFFOSIONAL PSEUDOKARST, GRANITIC WEATHERING, AND SOME IMPERTINENT QUESTIONS CONCERNING THE UNIQUENESS OF KARST LANDFORMS

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Pseudokarst features have the appearance of karst landforms but are formed by processes other than bedrock dissolution. Volcanic landforms are pseudokarst only because of the interest in cave exploration common to karst caves and lava tubes. Glacial caves and surface features are either karst or pseudokarst depending on whether or not one considers the melting of ice to be equivalent to the dissolution of rock. Development of karst requires a pronounced differential dissolution to bring out the relief of sinkhole or pinnacled surface karst or the creation of large cave passages in otherwise solid bedrock. Very rarely is the development of karst a purely dissolutional process. In nearly all karstic rocks, there is a residue to clay, sand, and chert that must be removed by mechanical processes. This, in turn, requires flow velocities much greater than those found in granular aquifers.

Consider two traditional types of pseudokarst: granitic weathering and suffosional pseudokarst. Weathering in fractured granites and occasionally in fractured sandstones can result in pinnacle landforms not visually distinct from karst pinnacles. The differential weathering is dominated by the chemical breakdown of feldspar minerals, with concurrent transport of quartz and other insoluble minerals. Suffosional pseudokarst, which includes caves of substantial size, is found in insoluble but poorly consolidated sediments. Transport is by particles held in suspension by the development of turbulence along certain flow paths. Suffosional pseudokarst also requires high flow velocities and channelized flow. There is no clear-cut boundary between karst and many categories of pseudokarst.

HUMAN SCIENCES

BEEN THERE, GOT THE BUTTON

Steven J. Stokowski, Jr., Stephen Hulbert, John Evans, Anne Fletcher, Morrie Gasser, John Hannon, Gary Lau, Joanne Pacheco, Karen Potter, Sybille Rex, and Chris Taylor, c/o Boston Grotto, P.O. Box 380304, Harvard Square Station, Cambridge, MA 02138-0304 USA, caversteve@aol.com

In 2001, the Boston Grotto helped the Boston Museum of Science market the IMAX film, *Journey into Amazing Caves*. The museum's goals were to increase attendance and interest in the film. The grotto's goals were to support the museum, to attract local individuals in the caving community who are not in the grotto, and to increase club camaraderie. We were specifically not interested in attracting new people to caving or appealing to thrill seekers.

To achieve the goals, the Boston Grotto contributed the following:

- A display of eight large photographs of caves by grotto members
- A display of caving equipment on a mannequin
- Two posters of grotto activities in speleology and caving
- Grotto member attendance in cave suits, gear, and with the BG posters at the Press Preview with Michael Ray Taylor, at the official Saturday opening with Hazel Barton, and at two Saturday "Meet the Cavers" events

We met all the goals. The movie had an extended run of three months beyond the scheduled six. Grotto participants had a good time, showed their cave photographs in a public venue, had a party, met many cavers visiting Boston from other areas, saw the movie, and received a prized Amazing Caves button. All grotto members learned the grotto's achievements. No large numbers of people contacted the grotto to go caving, but we did present our caving message to the public.

INTERNATIONAL EXPLORATION

2002 RÍO DE LA CIDRA EXPEDITION

Barbara Anne am Ende, 12801 Climbing Ivy Dr., Germantown, MD 20874 USA; Keith Christenson, Unit 5542, APO AA 34041-5542

The 2002 Río de la Cidra Expedition to the Dominican Republic started a little early on December 29, 2001. We surveyed a maze cave 479 m long, which extended from a hole in the side of the rock shelter that we used as base camp. Several new pictographs were found in the cave. Across the river, we resurveyed another cave, 882 m long, which also contained pictographs. A new pit entrance was discovered. Another 307 m virgin cave containing a large population of bats was surveyed. A rock shelter, not previously known to researchers, was discovered 250 m from base camp and contained 43 pictographs. The biology of the area was studied, and 9 species of bats were verified. Several nasty climbing leads remain in the caves. The extensive karst area, of 5-10 m high jagged pinnacles, lies above the resurgences and remains nearly unchecked. Two obvious entrances beckoned on a distant hillside, but the locals reported that the caves were small. The 14 km return hike to civilization was more difficult than the hike in, due to muddy conditions from earlier rains. Where the trail went through shady forest, the mud was calf-deep. The fog changed to rain, we lost 3 of our group, and it got dark. The challenging adventure worked out in the end, and by 3 AM, everyone was safe, dry, and fed by local farm family.

CAVES OF HOG CAY, SAN SALVADOR, BAHAMAS: SETTING THE BAHAMIAN DRY CAVE DEPTH RECORD

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Majors Cave is a flank-margin cave mapped in 1998 on Hog Cay, San Salvador, Bahamas. Flank-margin caves form at the margin of the freshwater lens on the flanks of eolianite ridges as mixing chambers, not conduits. Their morphologies are large globular chambers with concave dissolution surfaces and undulating ceilings and floors, vertically restricted and clustered like beads on a string. Investigations in 1999, 2000, and 2001 on Hog Cay revealed that many pit caves exist above Majors Cave. Pit caves on carbonate islands develop as vadose fast-flow routes to conduct meteoric recharge from the epikarst of the land surface to the freshwater lens. They are believed to form independently of phreatic features in the lens, such as flank margin caves. Pit caves developed in eolianites can occur in concentrations of over 100/km^2. They rarely exceed 10 m in depth, but may cross-connect to produce caves with over 50 m of horizontal extent. They have 2 main morphologies: simple vertical shafts, and complex features with horizontal components controlled by subtle changes in lithology. In late December 2001 and early January 2002, an effort was made to map several karst features on Hog Cay. CK1, a complex pit cave, was mapped and connected to Majors Cave, producing the only known pit cave/flank margin connection. This connection produced the deepest known dry cave in the Bahaman Archipelago, at 17.8 m.

SEARCHING FOR TEMPLE CAVES IN THAILAND

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Caves are an integral part of life for many of the peoples of southeast Asia. Consequently, they have modified caves in many ways. Religious shrines are particularly common, especially where Buddhism is the dominant religion, as in Thailand, Laos, and nearby areas. The beauty of Thai architecture has led to the construction of especially notable shrines in its caves. At least two, however, predate the coming of the Thai people. So many shrines exist that no reasonably complete list is known to exist. *Caves of Thailand* lists many of them throughout the country, but is far from complete. *Sacred Rocks and Temple Caves*, the sole book on the subject, considers even fewer. The contents and fame of these temple caves vary greatly. Perhaps the best known are at Phetchaburi and north to northeast of Chiang Mai. Others near Ratchaburi and Kanchanaburi are less famous. Most are known only locally. Thailand is strongly emphasizing caves as ecotourism sites, and some are targets of other special interest tours. In the Ao Luk-Phangna area, and probably in many other regions, local publications and publicity handouts are a good source for information on such caves. In addition to their interest as architectural gems, points of worship and speleological pilgrimage, some are of special interest for lengthy karstic conduits that extend far beyond the areas of religious shrines.

MULTIYEAR PROJECT TO MAP CAVES FOR THE BELIZE DEPARTMENT OF ARCHEOLOGY

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In February and March 2002, a group of 15 cavers from all over the US returned to Belize to resume mapping Barton Creek Cave. The project is under the auspices of the Western Belize Regional Cave Project, directed by Jaime Awe for the Belize Department of Archeology. Dye tracing was done to identify the sources of water in Barton Creek Cave. Slate Creek was determined to be the major source of water in the cave, with two other sources of water identified. A total of 6400 m of passage, some beautifully decorated, has been mapped in Barton Creek Cave. The cave currently ends at 3 sumps that are 3 km from the entrance. Dye tracing has shown that there are potentially 6 km of passage beyond one of the sumps. Small caves near the insurgences were located and mapped. Offering Cave, which like Barton Creek Cave was used by the Maya 1000 years ago, was mapped during the 3 weeks we were in Belize.

CLOSE TO THE EDGE, 2001

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Close to the Edge was discovered from the air in 1985. It is at the top of a cliff east of Prince George, British Columbia. The 255-m entrance pit was not expected, so it took several trips before enough rope was up the mountain. By late 1986, the cave had been explored down a second pit of 32 m to an impassable crack with strong air flow. In 1994, after blasting, exploration continued down short drops to a depth of ~440 m in tight wet passage. Trips in 1995 and 1998 improved the survey and found a drier route into the cave. The 1999 push ended at a depth of 421 m, part way down a large pit named The Abyss. Ice in the entrance prevented a trip in 2000. In September 2001, exploration continued. The rigging from the entrance to The Abyss was improved, and the crack was enlarged to give it a minor axis of ~23 cm. The Abyss was bottomed (68 m), and a 9-m pit was descended to a sump at a depth of 472 m. Horizontal passages discovered below The Abyss included a canyon carrying a stream much larger than any other seen in the cave. This stream flows into the sump, and the passage goes upstream. A number of possible cave entrances were also found on the surface and checked, and GPS readings revealed that the water from the cave resurges ~610 m below the entrance.

PALEONTOLOGY AND CAVE ARCHAEOLOGY

THE PALEONTOLOGICAL RESOURCE INVENTORY OF VIRGINIA CAVES (PRIOVAC): A NEW NSS PROJECT

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The Paleontological Resource Inventory of Virginia Caves (PRIOVAC) is one of the newest NSS Projects, but our initiative dates from 1995. Recognition of how few caves with noteworthy paleontological resources were included in the Virginia Significant Cave List prompted a 1995 convention talk to stimulate awareness of cave paleontological resources. A few interesting fossil records had been discovered in Virginia caves, but the Virginia

Cave Protection law, designed to protect cave resources, also made scientific collections from caves difficult. Before 1995, the Commonwealth of Virginia had issued only one fossil collection permit, which was the result of a lengthy process and our joint efforts. Our solution was a blanket permit that, with owner permission, would allow immediate legal collection status, so caver reports of potentially significant exposed animal remains could be investigated, examined, and collected without a lengthy delay between discovery and laboratory analysis. The first of a series of blanket permits took nine months from application to receipt. The context of the remains is at least as important as the fossils, because it helps us decipher how they came to be in the cave and other information about their nature. Many of Virginia's past cave fossil finds were collected without regard to context. PRIOVAC investigators, working forensically to recover clues to the nature of fossil occurrences, have included studies of many of the known Virginia cave fossil discovery sites and investigations of the new cave finds.

FROM THE PORTALS OF XIBALBA THROUGH THE DOORS OF PERCEPTION: "ENLIGHTENED" INTERPRETATIONS OF ANCIENT MAYA CAVE ART

Cameron Griffith, Indiana University, Bloomington, IN USA

Recent investigations by the Western Belize Regional Cave Project revealed a new class of ancient Maya cave art, termed Modified Speleothem Sculpture. This genre of speleothem modification is far more elaborate than the simple petroglyphs previously identified by Maya cave scholars.

PHOTOGRAPHY

MAKING A MULTIMEDIA DISSOLVE PROGRAM FOR THE COMPUTER

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Multi-projector dissolve (MPD) shows are an impressive way to present cave images, usually combined with an audio track. The dark regions inherent in cave images can be used creatively in overlays. But MPDs are incredibly time-consuming to produce and require lots of equipment to show. With the advent of digital projectors, building such a show on the computer is an attractive alternative. Many software packages are designed to present multimedia images, but few seem to offer control of transitions and duration timing on a slide-by-slide basis or the precise mating of audio with the images. Surprisingly few provide a smooth-looking digital dissolve. I discovered a simple yet powerful $15 shareware program, Slide Show to Go, that allowed me to migrate an existing MPD show to the computer. Useful PhotoShop techniques help prepare images for the show, such as aligning images for overlays.

HOW TO KEEP A CROWD AWAKE IN A QUIET, DARK AND WARM ROOM: SLIDE PRESENTATIONS FOR AN AUDIENCE

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The most important thing one must consider is your audience-who they are and what they will expect of you. This may even dictate the topic of your presentation. Next you must determine how long you have and how long you want the picture portion of your show to be. Now you may consider your selection of media and the use of various "show and tell" objects. Then you will be ready to make the selection of what pictures you want to show. Pay particular attention to beginning your show, and keep it varied, lively and moving along, but do not fear silences. Use humor when you can. Be sure to go through your show ahead of time to get out the kinks, and arrive early enough to be set up and ready to go before the audience arrives. Determine when you want to take questions, and let the audience know this before you are well launched. You can always find a way to mix in a safety and conservation message with your show. Do this. Common pitfalls to avoid include apologies, reading of the text, reversing slides, and inappropriate use of scale.

SAVING AND MANAGING CAVE LANDS WITH NONPROFIT CONSERVANCIES WORKSHOP

CORPORATE STANDARDS AND PRACTICES OF THE LAND TRUST ALLIANCE

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Incorporated cave and karst conservancies arose from the desire of cavers and cave scientists to ensure access to caves and to protect the natural features of caves. The conservancies have the knowledge and enthusiasm necessary to set reasonable protective policies for management of caves owned, leased, or only managed. However, they seldom start with knowledge and experience in incorporating and managing a non-profit, charitable corporation. The foremost source of support and guidance in those respects is the Land Trust Alliance (LTA, www.lta.org), an umbrella organization for over 1200 conservancies nationwide. In order to ensure a high standard of corporate responsibility and management, which helps to maintain the corporate health, effectiveness and reputations of land trusts everywhere, LTA recommends the adoption of corporate Standards and Practices (S&P). LTA S&Ps concern such topics as incorporation, board development and board member training, financial and asset management, fundraising, training and recognizing volunteers, and much more.

VOLUNTEERS AND CONSERVATION: A VALUABLE PARTNERSHIP

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Non-profit conservation organizations are often faced with financial limitations when planning and implementing protection projects. Volunteer help is essential to the success of conservation efforts, often "making or breaking" a project. The Nature Conservancy has long relied on volunteers for many functions, including cave and karst protection projects. In a general capacity, volunteers routinely offer help with office and fundraising event functions. Volunteer groups, such as Boy or Girl Scouts and corporate volunteer programs, are critical to larger projects. These activities might include trail development and maintenance at preserves, removing exotic plants, or reforesting riparian areas. In Tennessee, volunteers from the caving community have given countless hours in a variety of ways to support conservation of the state's magnificent cave resources. Projects such as sinkhole and cave cleanups and entrance barrier construction require much volunteer labor. These projects can be incredibly time-consuming, financially draining, and physically exhausting and would be virtually impossible to accomplish without the many members of Tennessee's caving community volunteering their time. The caving community in Tennessee also provides assistance with both the management of biologically significant caves and with biological surveys at these sites. Partnerships between volunteer groups and The Nature Conservancy play an important role in the conservation.

SURVEY AND CARTOGRAPHY

USING A DISTO LASER RANGE FINDER TO SURVEY CAVES IN BELIZE

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The 2002 Barton Creek Cave Mapping Project used 2 different models of Leica Disto rangefinders to measure distances in Barton Creek Cave and other caves in the Cayo District in Belize. By using the Distos, we could accurately measure distances between stations and make left, right, up, and down measurements. These measurements, which would have taken hours or been impossible using a tape, took only minutes with the Distos. In one room of Barton Creek Cave, the ceiling height measured 55 m, and we only had a 30-m-long tape. The sketchers were given accurate measurements from spray shots to the walls and speleothems, rather than estimates of distance. Many of the station-to-station distances exceeded 30 m. Ceiling heights varied from 3 to 55 m. Left and right measurements exceeded 30 m in places. The data from the Disto, plus direction and inclination data, were entered into a laptop computer running Walls, a cave mapping program, to produce an outline map of the cave. At the end of the trip we found another cave. In 90 minutes, we were able to collect survey data for 400 m of cave. It would have taken all day if we had been using a tape to measure the distances.

U.S. EXPLORATION

EXPLORATION OF SCOTT HOLLOW CAVE

Michael Dore, Scott Hollow Project, P.O. Box 7, Sinks Grove, WV 24976 USA

Scott Hollow Cave is a 40 km cave system in Monroe County, WV. The cave has been explored for the last 18 years, and in that time several significant discoveries have been made. These discoveries include Mystic River, Scoop City, prehistoric animal bones, and a large portion of cave that comes close to Windy Mouth Cave, another nearby long cave. Exploration in 2001 and early 2002 focused on the far upstream portions of the cave. The most current exploration has occurred at the opposite end of the system (downstream), in an attempt to find a connection to Windy Mouth Cave. Microblasting and aluminum extension ladders have been effective tools for this exploration.

THE MAINE CAVE SURVEY

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Maine caves can be found in limestone, granite, and sandstone. Although one does not connect caving with Maine, the state does have some very nice small caves of various origins. The Maine Cave Survey gives an in-depth look at the Maine caves that have reached publication and the Maine Cave Protection Act. This survey and the law have been primarily the result of the work of Presque Isle High School students. For years, only a handful of caves were known, with most of these dating back to the 1800s and the Charles Jackson geological survey. Recently, there has been a systematic search to rediscover these historical coastal sea caves and ice caves once used by sailors and loggers. Maine's hiking trails were then searched, resulting in the discovery of many new caves, including sections of the Appalachian Trail that pass through talus caves. Maine's rocky coast has many sea caves with interesting histories. With the increased awareness of Maine's geologic heritage, many new caves have been discovered, including emerged sea caves caused in part by the weight of glacial ice depressing the land near coastal areas, and talus caves formed by the movement of glacial ice causing large rock falls in the granite regions. As the search continues, there are currently just over 200 caves reported in the literature, with the number growing yearly. With increased recreational caving and further systematic exploration of the region, the number of caves in Maine should continue to grow rapidly.

CAVES OF TAYLOR RUN

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The Taylor Run cave survey project has been an ongoing effort since 1994 to explore and map the caves of the Taylor Run region in Randolph County, WV. Meeting monthly, cavers from around the Virginia Region have explored and mapped caves within a 600 hectare parcel of limestone spanning the eastern flanks of Middle Mountain, above Gandy Creek. Accomplishments of the survey include discovery and mapping of 5 large caves with a combined extent of 8 km. The longest single cave exceeds 3.2 km long and spans ~1.5 km of lateral distance. Cumulative depth of all these caves exceeds 107 m.

PEELING THE "ONION": CONTINUED DISCOVERIES IN UNION CAVE, MONROE COUNTY, WEST VIRGINIA

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Before March of 2001, Union Cave in Monroe County, WV, was only known to be ~300 m long. Under the auspices of the Monroe County Cave Survey, a dig was started in 1997, but suspended after the discovery of Hurricane Ridge Cave. The dig was continued in early 2001, yielding major discoveries in March of that year. Many passages of various characteristics were then surveyed, including one containing a large stream that represents a major portion of Dickson Spring, the county's largest spring. The cave is now 7.3 km long.

RECENT EXTENSIONS TO KNOX CAVE

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Located in Albany County, New York, Knox Cave has been known since at least 1787, being shown on a map made that year by Will Cockburn, then the Surveyor-General of New York State. The definitive map of the cave dates back to 1963. The cave has been very popular with cave explorers for perhaps 50 years and is one of the more frequently visited wild caves in New York. Despite those years of visitation and exploration, during a trip in 1995 a mere 20 minutes of relocating rock by hand was all that was required to extend the northern limits of the cave, yielding entry to a previously undiscovered room ~6 by 18 m, but only 30 cm high. A return trip extended the cave into yet another room, and a stream that leaves that room by a low passage ending in a sump after 240 m. Besides the relative significance of extending the cave length by nearly one-third, the stream passage is geologically significant for having formed in the Brayman Dolomite, which is shaly and not typically known as a cave-forming rock. All other known cave passages located in the Brayman Dolomite have originated in the overlying limestone before cutting down into the Brayman. The second room also contains an unusual formation, of the type informally known as a "dribbler." During periods of adequate water flow, perhaps 10 mL of water collects at the tip of the formation before draining abruptly and then repeating the process.

RUMBLING FALLS CAVE

Marion O. Smith, Rt. 1 Box 461A, Bone Cave Rd., Rock Island, TN 38581 USA

In 1983, 2 Western Kentucky University students did several dye traces near Spencer, Tennessee. One trace was to Swamp Spring, 9.7 km to the north, presenting alluring possibilities of then unknown cave passages. In 1991 and 1995 Nashville cavers found segments of the system near the resurgence, yielding the 2-km Thunder Run Cave and 6.4-km Swamp River Cave. They were prevented from continuing south by a sump and massive breakdown.

In 1997, a lone caver found an entrance with a 20-m pit. Returning with a friend, they dropped the pit and explored the passage 150 m updip, stopping below a waterfall. The discovery was named Rumbling Falls Cave and was recorded by the Tennessee Cave Survey. In July 1998, another caver climbed the waterfall and explored 425 m of virgin passage. Instigating a survey, he returned and on the third trip discovered a 60-m drop into a huge breakdown chamber. This led to a major segment of the hydrologic puzzle, consisting of 24 km of cave. The project remained secret until a conservation issue forced disclosure. Resulting media attention, including a great picture by a Kentucky caver, has made the 1.6+-hectare Rumble Room, and the cave, famous.

MOTHER MAY I SPRING CAVE

Kelly Utana Norwood, Dogwood City Grotto, 1858 Robin Hill Court, Tucker, GA 30084 USA

Several cavers found Mother May I Spring Cave while ridgewalking on Mothers Day weekend in 2000. The exploration of this cave was awesome, having just enough of everything: stream crawls, pits, domes, canyons, waterfalls, climbups, and climbdowns. There's even a beautiful side passage 200 m long with one rimstone pool after another. Currently the cave has an estimated total length of ~1 km and a total depth just over 30 m.

Surveying began on the third visit to the cave. During the survey, several archaeologically significant torches were found. Paying more careful attention to the surroundings, the first of several bare human footprints were found in the cave floor. The prints had obviously been there a while. The explorers were then alarmed after finding a mud ball with ancient hand/finger prints mere centimeters away from the fresh boot print of one of the explorers.

Finding and exploring virgin cave is an exciting experience, and it's often tempting to rush through the new discovery to see what has been found, but some aspects of the discovery may be less obvious than others. The moral of this story is that things like this do exist and are likely more abundant than we think. Watch your step!

VIDEO

USING UNCONVENTIONAL LIGHT SOURCES FOR CAVE VIDEO ILLUMINATION

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As part of the 2002 Barton Creek Cave Mapping Project in Belize, I used fluorescent work lights to illuminate the cave passage while shooting video from a canoe. The lights were powered by a 12V battery and 110V inverter. The 3 lights used 125W of power and produced a light intensity equal to a 500W incandescent flood light. The light provided an even illumination of the passage. I was able to light the ceiling at a height of 25 m. Another advantage of the fluorescent lights was that the color temperature was close to daylight, so the white balance did not need to be adjusted going from bright shadow, outside the cave, to the dark zone of the cave, where the only light was supplied by the fluorescent lights. The use of fluorescent lights eliminated the need to carry a generator into the cave.

In another cave, I used torches made from modified propane plumber's torches to illuminate the cave. This light allowed one to see figures that the Maya had carved into flowstone formations. The figures disappear when illuminated with a helmet light or flashlight.

INDEX TO VOLUME 64 OF THE *JOURNAL OF CAVE AND KARST STUDIES*

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This index covers all articles and abstracts published in volume 64 parts 1, 2, and 3. Selected abstracts from the 2002 Society meeting in Camden, Maine, are included.

The index has three sections. The first is a **Keyword** index, containing general and specific terms from the title and body of an article, including cave names, geographic names, etc. Numerical keywords (such as 1814) are indexed according to alphabetic spelling (Eighteen fourteen). The second section is a **Biological** 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, and 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.

KEYWORD INDEX

BIOLOGICAL NAMES INDEX

AUTHOR INDEX

STALACTITE

CARLOS DE OLIVEIRA (TRANSLATION BY ALEXIS LEVITIN)

I
The limestone sky
of the hollow hill,
where sullen drops
of water or of stone
will fall
a few millennia from now
and waken
tenuous flowers
in calcified corollas
so close to me
I think I hear, filtering
through the tunnel
of time, and of this hill,
the garden's dew.

II
To imagine
the sound of dew,
the slow contraction
of petals, the weight of
water
at such a distance,
to register
in that inverted
memory
the rhythm of dissolving
stone
as it settles
drop by drop
on those anticipated flowers.

V
Space
so that
drops of water
or of stone may fall
carried
by their weight,
smooth angularities
of the silent
hill
so limestone
may flower
in this calligraphy
of petals
and of letters.

VIII
They fall
from a limestone sky,
they will waken flowers
millennia from now,
they roll
from line
to line
closed
like droplets,
and at the end
of the page
one hears
dew-laden
murmurings.

IX
The image
the sound of dew,
to transmit it
from flower to flower,
to guide it
gradually thickening
through space
where now
it moves
[water → limestone],
and to capture it as if
it were born
only
as it is written.

XI
The weight
of the water
at such a distance
is almost
imperceptible,
and yet it weighs,
hovers,
settles on the page,
a past
of stone
[limestone ← hill]
that burns
as it
falls.

These poems are taken from a 24-poem sequence called Stalactite that will be published in its entirety in fall 2002 by Metamorphoses, *a journal of literary translation, and in the book* Guernica and Other Poems *by Carlos de Oliveira, which is to be published in December 2002.*

ABOUT THE AUTHOR: Carlos de Oliveira (1921-1981) was a Brazilian novelist, poet, and painter. His poetry reveals neo-realist, symbolist, surrealist, and cubist tendencies.

ABOUT THE TRANSLATOR: Alexis Levitin of SUNY-Plattsburgh received an undergraduate degree in zoology from Columbia University and did graduate work in biology at Northwestern University. He lived for several years in Brazil while setting up a graduate program in English.

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