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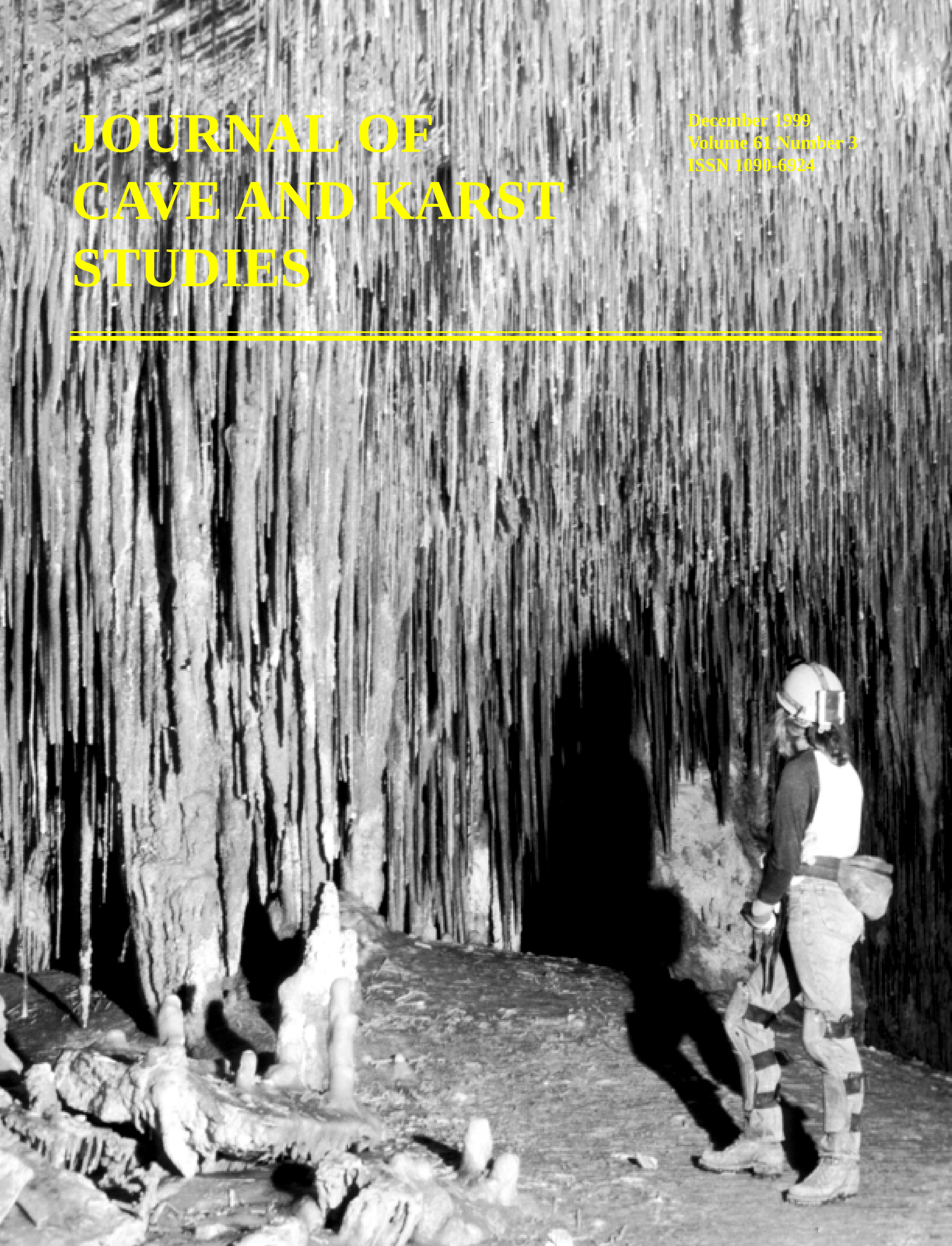

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Cover: Sodastraw Forest in Carlsbad Cavern, New Mexico by Marc Ohms. The *Journal of Cave and Karst Studies* will feature the Guadalupe Mountains, New Mexico Symposium in volume 62 issue 2 next summer. This symposium issue is organized by Harvey R. DuChene and Carol A. Hill and will be edited by Louise D. Hose and James A. Pisarowicz.

SPATIAL AND TEMPORAL VARIATION OF GROUNDWATER CHEMISTRY IN PETTYJOHNS CAVE, NORTHWEST GEORGIA, USA

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A longitudinal study of water chemistry in Pettyjohns Cave, Georgia, reveals a wide range of major ion water chemistry at different sampling points within the cave, and pronounced seasonal water-chemistry variations at some locations. The cave occurs in the Mississippian Bangor Limestone on the east side of Pigeon Mountain in the Appalachian Plateaus physiographic province of northwest Georgia, USA. Four sampling points within the cave were monitored at approximately 2- to 3-month intervals for 22 months: a major conduit stream; a small conduit tributary; water dripping into the cave through a small fracture; and water dripping from active speleothems. Other waters, including surface water, were sampled as available. Samples were analyzed for temperature, pH, specific conductance, alkalinity, and major ions. Most spatial water chemistry trends within the cave appear to be the result of rock-water interaction along distinct subsurface flowpaths. Temporal variations, most pronounced in conduit streams, result primarily from mixing of distinct waters in varying ratios, although seasonal changes in CO_2 partial pressure may account for some variation. Results illustrate the inherent spatial and temporal variability of water chemistry in karst aquifers and point to the need to design sampling programs carefully.

Karst aquifers are difficult to characterize because of their inherent heterogeneity. Water chemistry, for example, can vary tremendously over very short distances depending upon whether a sample is drawn from an actively flowing conduit or from rock matrix (Quinlan & Ewers 1985). Water chemistry also varies over time in response to seasonal changes in recharge and dilution effects of individual storms (Hess & White 1988). Along subsurface flowpaths, waters can be modified by CO_2 outgassing, mineral dissolution and/or precipitation, and mixing (Dreybrodt, 1981; Herman & Lorah, 1986; Holland *et al.* 1964;). Finally, karst aquifers typically possess several chemically distinct recharge sources including internal runoff, sinking streams that originate in adjacent borderlands, and diffuse infiltration (Drake & Harmon 1973). Much karst water variability results from mixing among these recharge sources and from rock-water interaction.

This study demonstrates spatial and temporal variability of groundwater chemistry within a relatively small portion of a karst aquifer, and identifies mechanisms responsible for the observed variation. These results provide a detailed look at karst aquifer flowpaths and water types that are not normally resolved separately. Understanding such small-scale variability of karst water is important for understanding sources of larger scale water chemistry variability in karst systems. The study highlights the complexity of karst aquifers and underscores the importance of designing karst water sampling programs carefully.

Waters analyzed in this study were collected in and around Pettyjohns Cave, northwest Georgia, USA. They are derived from surface and subsurface water sources and many apparently distinct flowpaths. Water samples were collected over a 22-month period and, thus, also capture seasonal water-chemistry fluctuations. The study was prompted by observations of the many and varied water sources within Pettyjohns Cave, and the obvious role of the cave as a capture and mixing zone for these waters. As is the case in many caves, it is possible in Pettyjohns Cave to stand ankle-deep in one conduit stream within sight of one or more tributary streams, while watching water trickle into the cave through fractures, vertical shafts, and/or ceiling formations. Within the cave, chemically distinct waters from these varied sources mix and ultimately discharge via springs at the conduit terminus. The amount and proportion of different waters entering the cave varies with seasonal precipitation. Thus, waters that owe their composition to mixing of different input sources will reflect these changes. An initial hypothesis was that most temporal and spatial trends in the cave, especially those in the main conduit, could be explained by mixing of two endmember waters. During times of low flow, water composition appeared to shift toward a slowly infiltrating, concentrated endmember; during times of high flow, waters appeared to be diluted by a rapidly-infiltrating, fresh-water endmember. Although this scenario appears to be true for conduit waters, there are important deviations from a simple mixing model.

Objectives of the study are to characterize major-ion water chemistry within Pettyjohns Cave and to identify spatial and temporal trends in water composition. Questions addressed include: 1) To what extent does mixing of chemically distinct input waters control water chemistry variations within Pettyjohns Cave? 2) If mixing is important, what endmember waters are involved? 3) In addition to mixing, what other processes control chemical composition of cave waters? 4) Are there significant temporal variations in water chemistry? The main hypotheses argued in this paper are: 1) most observed

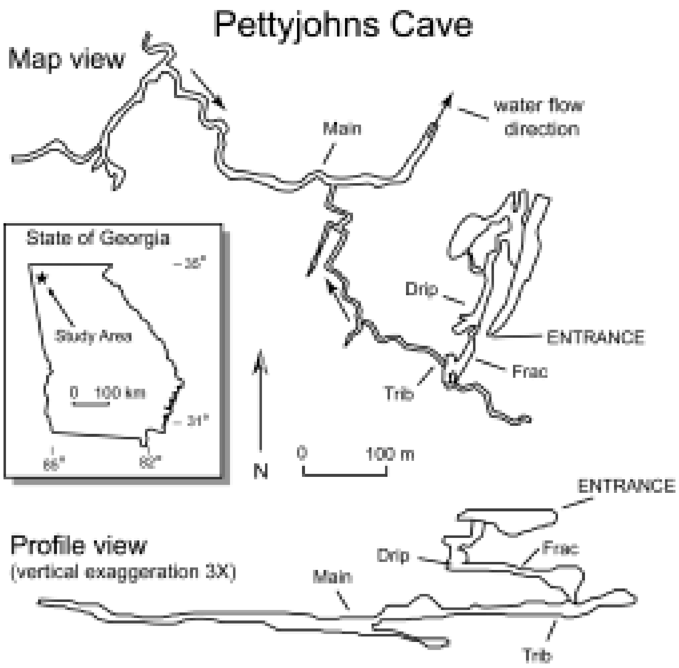


Figure 1. Map and profile of studied portion of Pettyjohns Cave (map after Schreiber, 1985; profile after Crowell, 1993).

spatial water chemistry trends within the cave are the result of rock-water interaction along distinct subsurface flowpaths (some separated only by a few meters); and 2) temporal variations result primarily from mixing of chemically distinct waters.

LOCATION

Pettyjohns Cave (Fig. 1) is on the southeastern margin of the Appalachian Plateaus physiographic province of northwest Georgia (Hack 1986) and contains more than 9750 m of surveyed passage (Schreiber *et al.* 1985). The cave lies on the east side of Pigeon Mountain within the Mississippian Bangor Limestone, and is overlain by Mississippian and Pennsylvanian shale and sandstone (Cressler 1964). Pettyjohns Cave is an excellent setting in which to study karst water chemistry because of the many and varied water sources within the cave. Several trunk passages possess perennial streams that converge within the cave, along with countless smaller rivulets derived from small conduits and shafts; slowly infiltrating water drips into the cave from numerous small fractures and actively growing speleothems. There appear to be two major sources of recharge to the cave. One is a series of surface streams that originate on sandstones and shales atop Pigeon Mountain, and infiltrate through streambed fractures where streams cross from clastic rock units onto underlying limestone rocks. The second source is diffuse infiltration that falls as precipitation both on sandstone-capped uplands and on limestone and alluvium of valley bottoms. There is little or no direct surface runoff into the cave through large conduits or sinkholes. Thus, water levels in the cave do not fluctuate rapidly, and all water entering the cave undergoes at least moderate rock-water interaction in the subsurface. The discharge point for cave waters is Dickson Spring, a large conduit spring ~1600 m south of the cave entrance (A. Padgett, personal communication, 1999).

METHODS

Major-ion water chemistry was assessed at numerous points within the cave and in surface streams above the cave. In the field, samples were analyzed for pH, temperature, and specific conductance. Samples collected in the cave in 250 ml polyethylene bottles were transferred to a cooler at the surface and transported to the laboratory. Subsamples for major ion analysis were filtered through 0.45 µm membrane filters. Cation samples were acidified to pH <2.0 with trace-metal grade nitric acid. Processed samples were stored in polyethylene bottles and refrigerated. Bicarbonate concentration was determined by alkalinity titration of unfiltered sample with 0.1 N HCl to an assumed bicarbonate endpoint of pH 4.5. Titrations were completed within 24 hours of sample collection. Alkalinity was also determined with potentiometric titration on a sample subset. However, titration to a fixed endpoint yielded results within experimental error and was used for routine alkalinity determination in this study. Major cation composition was determined by inductively coupled plasma-atomic emission spectrometry. Major anion composition was determined by ion chromatography. Total dissolved ion (TDI) concentration was determined by summing concentrations of major ions reported in Table 1. Carbon dioxide partial pressure and calcite saturation indices were calculated using the computer code WATEQF (Plummer *et al.* 1976). Analysis and quality control procedures followed standard methods (American Public Health Association 1995). Analyses for which charge-balance error exceeded 5% were eliminated from the dataset.

Waters were analyzed on an approximately bimonthly basis from January 1997 through October 1998. Conditions permitting, three sites within the cave were sampled on each visit (Fig. 1): water dripping from a small fracture (frac); a tributary to the main cave conduit stream (trib); the main cave conduit stream (main) upstream from confluence with tributary. In addition, numerous other points were sampled as available according to flow conditions and accessibility, including other points along cave streams, water infiltrating rapidly into the cave through large fractures and shafts, water dripping from actively growing speleothems (drip), and surface waters above the cave (sfc).

RESULTS

MAJOR ION CHEMISTRY

Cave waters are very similar in overall composition (Fig. 2;

Table 1. Water chemistry data used in this study.

Date	Station	T (°C)	pH	HCO_3 (mg/L)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Si (mg/L)	Cl (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	TDI (mg/L)	log pCO2	log SI Cal
01/20/97	main	10.4	7.4	27.30	0.75	8.80	0.51	*	2.32	1.26	*	3.38	44.32	-3.03	-1.75
01/20/97	trib	13.6	7.7	88.14	1.64	30.22	0.76	0.74	2.96	1.49	1.22	3.13	124.47	-2.82	-0.41
01/20/97	wall	11.2	7.7	72.96	1.63	26.31	0.61	0.62	1.89	1.18	0.08	8.72	114.01	-2.91	-0.58
01/20/97	frac	13.0	7.8	142.13	2.35	45.70	0.82	0.38	3.44	2.68	*	3.47	201.00	-2.67	-0.01
070/1/97	trib	**	7.4	93.60	1.62	30.33	0.57	0.30	2.81	1.71	*	2.04	132.98	-2.50	-0.68
07/01/97	main	**	7.4	57.60	1.30	17.06	0.64	0.40	2.96	1.35	0.12	3.03	84.46	-2.69	-1.11
09/16/97	frac	13.6	7.6	122.80	1.98	40.80	0.82	0.16	3.67	2.31	*	3.18	175.72	-2.58	-0.25
09/16/97	trib	13.8	7.5	101.30	1.89	33.04	0.57	0.16	2.89	1.65	1.41	1.95	144.86	-2.56	-0.51
09/16/97	main	14.1	7.7	94.90	2.44	29.87	1.00	*	3.22	1.92	0.41	3.72	137.56	-2.78	-0.38
11/08/97	trib	13.5	7.2	106.90	1.99	34.64	0.54	0.11	2.90	1.67	2.14	2.24	153.14	-2.23	-0.77
11/08/97	main	13.9	7.5	73.40	1.96	22.87	0.82	*	3.02	1.23	*	3.51	106.88	-2.69	-0.79
11/08/97	frac	13.0	7.9	122.00	1.99	39.20	0.54	*	3.53	2.15	*	3.52	172.96	-2.88	0.01
01/03/98	frac	13.0	7.7	162.50	2.63	51.80	0.70	0.46	3.54	2.58	1.15	3.80	229.16	-2.56	0.04
01/03/98	trib	13.0	7.9	103.70	1.84	34.54	0.54	0.52	2.96	1.60	1.54	2.80	150.05	-2.95	-0.10
01/03/98	main	12.0	7.6	35.60	1.10	11.50	0.64	0.38	2.66	1.17	*	3.33	56.38	-3.11	-1.30
01/03/98	infilt	12.5	7.6	92.70	2.29	34.36	0.61	0.58	2.04	1.32	0.32	13.05	147.27	-2.70	-0.46
01/03/98	conduit	11.5	7.2	30.50	0.97	10.18	0.54	0.42	2.056	1.55	*	4.55	51.28	-2.78	-1.83
02/15/98	drip C	12.0	8.2	204.50	2.19	70.69	0.61	0.38	2.26	2.59	1.24	13.50	297.96	-2.98	0.73
02/15/98	frac	13.0	8.2	133.20	2.01	43.86	0.61	0.51	3.44	2.52	*	3.04	189.19	-3.15	0.39
02/15/98	trib	10.0	7.2	22.70	0.67	8.83	0.42	0.40	1.93	1.20	0.10	3.29	39.54	-2.91	-2.03
02/15/98	main	10.5	7.4	29.50	0.80	10.51	0.51	0.40	2.23	1.11	*	3.17	48.23	-3.00	-1.64
02/15/98	drip A	13.0	8.2	153.70	2.42	49.01	0.70	0.45	2.57	2.26	0.46	6.97	218.54	-3.09	0.48
02/15/98	sfc lower	9.0	2.9	0.49	0.43	1.05	0.39	*	1.85	1.04	0.03	3.45	8.81	-3.27	-5.90
02/15/98	sfc upper	7.0	5.7	0.25	0.44	0.62	0.42	0.39	1.96	1.26	*	3.17	8.51	-3.38	-6.68
04/07/98	frac	13.0	7.5	135.00	1.92	42.28	0.64	0.13	3.31	2.28	0.51	2.56	188.63	-2.44	-0.31
04/07/98	trib	11.0	7.0	20.30	0.57	6.96	0.39	*	2.05	0.97	0.26	3.06	34.64	-2.75	-2.36
04/07/98	trib B	11.0	6.8	13.40	0.55	4.58	0.42	*	1.91	0.93	0.11	3.34	25.24		
04/07/98	drip A	13.0	7.8	164.10	2.56	54.78	0.73	0.17	2.81	2.14	0.39	6.39	234.07	-2.66	0.16
05/31/98	frac	12.9	7.4	118.40	1.73	38.11	0.57	*	3.30	2.26	0.88	3.12	168.37	-2.39	-0.50
05/31/98	trib	12.5	7.4	95.20	1.56	30.42	0.51	*	2.74	1.76	1.85	1.52	135.60	-2.49	-0.69
05/31/98	main	13.2	7.6	69.60	1.54	21.66	0.76	0.13	2.78	1.20	0.48	2.67	100.82	-2.82	-0.75
09/20/98	frac	13.0	7.3	123.30	1.98	39.62	0.57	0.32	4.01	2.22	1.36	3.10	176.61	-2.28	-0.57
09/20/98	trib	13.0	7.3	97.90	1.83	31.42	0.54	0.56	2.73	1.60	1.95	2.20	140.76	-2.37	-0.76
09/20/98	wall	12.5	7.3	83.5	1.41	26.50	0.54	0.48	3.15	1.34	0.99	2.34	120.25		
09/20/98	main	13.0	7.4	96.70	2.41	29.49	0.94	0.60	3.19	1.35	0.99	3.37	139.04	-2.48	-0.69
09/20/98	drip B	13.0	7.5	141.10	2.25	45.77	0.70	0.79	3.02	1.98	3.43	4.95	203.99	-2.42	-0.26
10/04/98	frac	13.0	7.1	122.80	1.90	39.11	0.54	0.32	3.67	2.12	1.04	2.87	174.41	-2.08	-0.78
10/04/98	trib	13.0	7.1	102.50	1.79	30.83	0.54	0.55	2.83	1.50	1.99	2.19	144.77	-2.15	-0.95
10/04/98	main	13.0	7.0	98.10	2.40	29.40	0.97	0.43	3.14	1.37	1.19	3.33	140.33	-2.07	-1.08
10/04/98	drip B	13.0	7.4	143.50	2.13	44.15	0.76	0.65	3.02	1.90	4.16	4.81	205.08	-2.31	-0.37

* below detection limit ** not recorded due to equipment malfunction

Table 1). Dominant ions are calcium and bicarbonate; magnesium, sulfate, chloride, sodium, silica and potassium are also present above detection limits in most waters. Most variation among cave waters consists of differences in TDI concentrations—ion relative abundances are similar. Cave conduit streams are generally lower in TDI concentration than other cave waters, especially during winter months. Cave streams during periods of high flow are significantly more dilute than other cave waters, but always contain much higher TDI concentrations, and significantly more calcium and bicarbonate than surface waters. Surface waters, as well as being much lower in TDI concentrations than cave waters, are also deficient in calcium, magnesium and bicarbonate.

TOTAL DISSOLVED ION CONCENTRATION

Although the entire sample suite spans a large range of TDI concentration, samples collected from individual locations are fairly consistent (Fig 3; Table 1). Surface waters range from 8.5-8.8 mg/L TDI. The main cave stream shows more variability than other locations, ranging from 40-140 mg/L TDI. The tributary stream also varies widely, but it does so in a strongly bimodal fashion. During the late summer and fall when rainfall, surface stream flow, and cave stream flow are at their lowest levels, TDI concentration ranges from 124-153 mg/L. During exceptionally high flows after prolonged winter and spring rains, TDI concentration ranges from 34-40 mg/L. Fracture water ranges from 168-230 mg/L TDI. Drip water varies between 204 and 298 mg/L TDI.

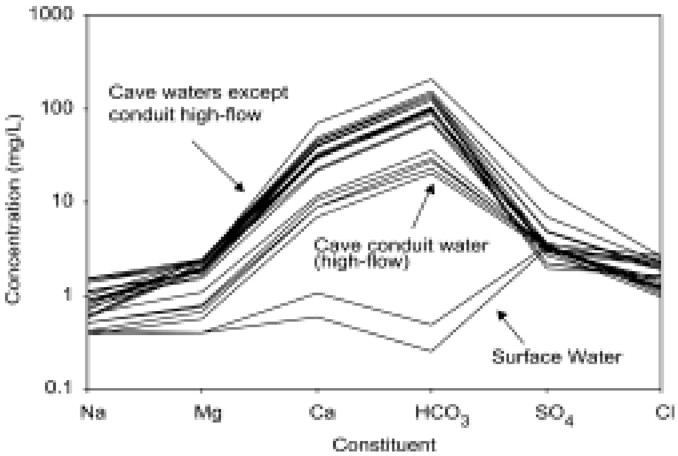


Figure 2. Major ion chemistry of cave and surface waters. Surface waters are very dilute and relatively deficient in calcium, magnesium and bicarbonate compared to cave waters. Cave conduit waters are more dilute than other cave waters but maintain similar ionic composition.

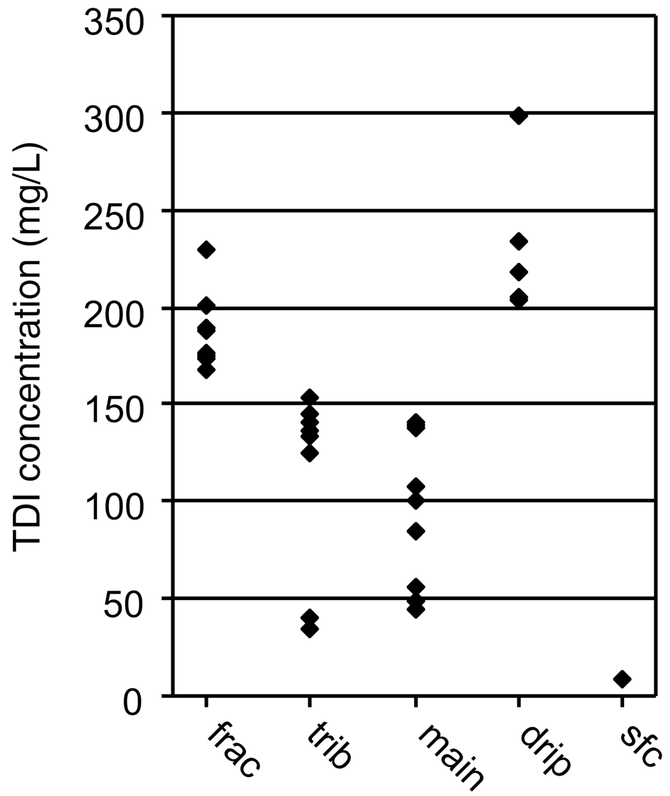


Figure 3. Total dissolved ion (TDI) concentrations of major water types in this study. Surface waters are the most dilute, drip waters most concentrated. Conduit and conduit tributary waters show most variability. TDI is defined as the sum of major ions analyzed in this study as reported in Table 1. Key: frac=fracture seep, trib=conduit tributary, main=main conduit stream, drip=soda straw drip, sfc=surface stream.

SCATTER PLOTS

Figure 4 shows plots of magnesium, sodium, sulfate and chloride vs. TDI. Total dissolved ion concentration is assumed to indicate extent of reaction with bedrock minerals and, thus, is a rough indicator of aquifer residence time. The extent to which points diverge with increasing TDI concentration reflects the extent to which flow histories of waters differ. Figure 4 reveals subtle differences in major-ion composition between sample sites, and underscores the consistency of water chemistry from individual subsurface sources. Using one or more of the plotted ions, it is possible to distinguish between all of the major water sources of this study. For example, main stream waters during low-flow conditions, when they are most concentrated, are similar in ionic composition and TDI concentration to tributary conduit waters. However, main stream waters are distinguishable from other waters based on their higher concentrations of magnesium and sodium. Similarly, there is significant TDI overlap between fracture and drip waters, but they are easily distinguishable based on sulfate and chloride concentrations.

CALCITE SATURATION INDEX, pCO_2

Surface waters are strongly undersaturated with respect to calcite. Conduit waters are undersaturated but span a wide range of SI values. Fracture and drip waters range from slightly undersaturated to slightly oversaturated with respect to calcite (Fig. 5). There is a weak positive correlation between calculated pCO_2 and TDI with considerable data scatter. Carbon dioxide partial pressure varies from $10^{-2.1}$ to $10^{-3.4}$ atm and individual sample locations show relatively large variations in pCO_2. Distinguishing between samples based on pCO_2 is difficult or impossible. However, at least some of the pCO_2 variation apparent in Figure 5 is probably an artifact of sample collection techniques, as outlined in the discussion section below.

TEMPORAL TRENDS

Water chemistry variability reflected in the scatter plots of figure 4 is not random. Rather, there are clear temporal trends. In figure 6, TDI concentrations are plotted as a function of time for three cave waters: main conduit, tributary conduit, and fracture drip waters. Temporal variations of TDI concentration in main stream water follow seasonal flow volume variations. Although flow volume was not quantified, relative streamflow estimates clearly show that the main stream reaches maximum discharge during winter and spring months, declines through the summer, and reaches a minimum during the late summer or autumn. TDI concentration varies inversely with this trend, reaching a maximum during low-flow periods. Individual ions show clear temporal trends similar to TDI concentration trends.

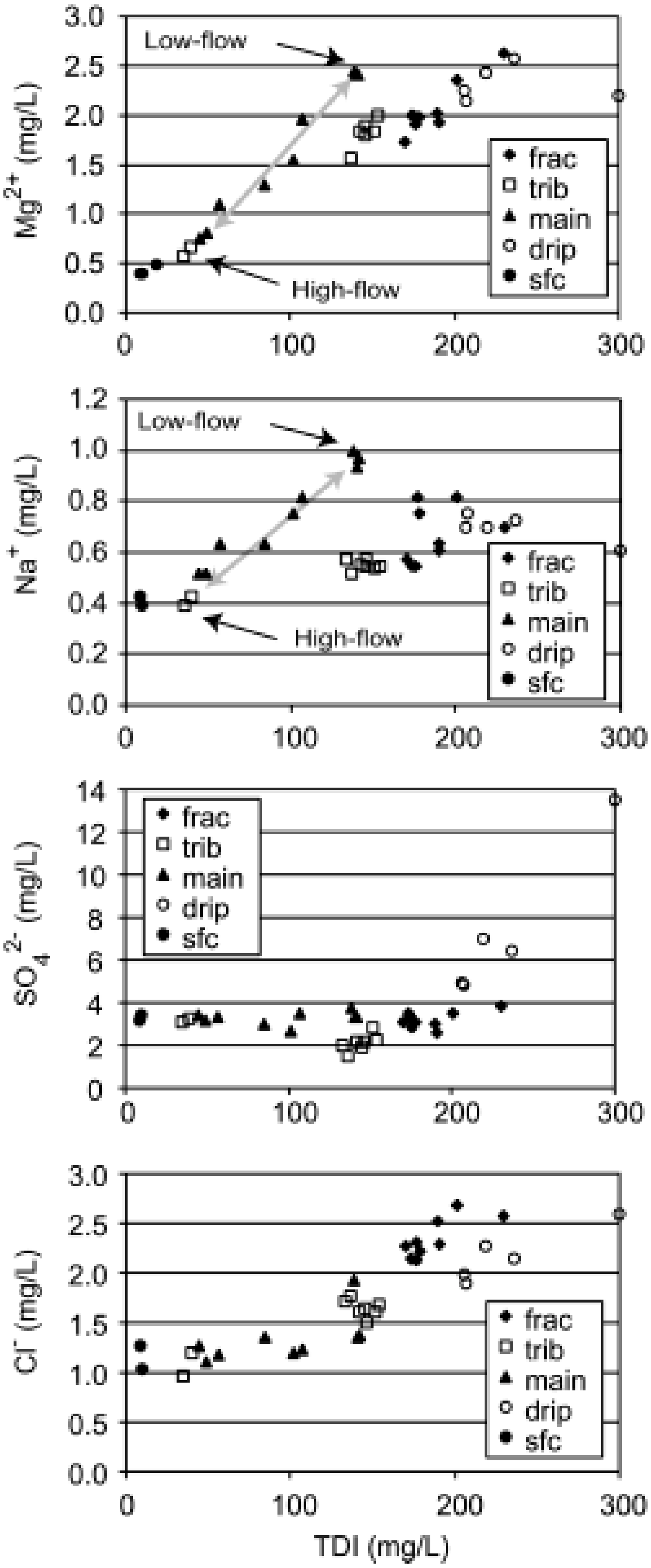
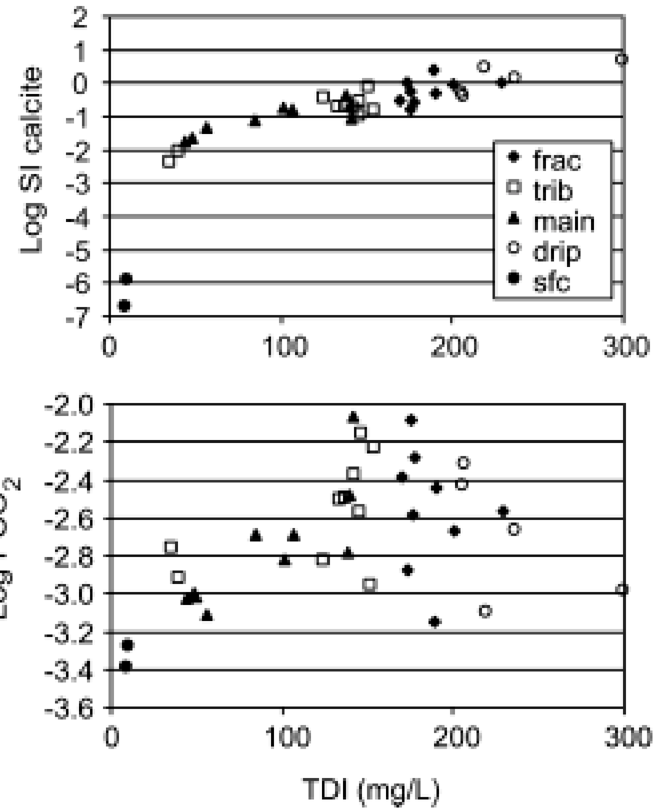


Figure 4 (left). Mg^{2+}**,** Na^{+}**,** SO_4^{2-}**, and** Cl^{-} **concentrations vs. TDI concentration. Plots illustrate consistency of individual water sources and subtle differences among different water sources. See text for explanation of figure annotation.**

Figure 5 (below). Calcite saturation index and calculated carbon dioxide partial pressure vs. TDI concentration.



Also apparent in figure 6 is the bimodal behavior of the tributary conduit stream (trib). It is generally intermediate in composition between main conduit and fracture water. However, during months of exceptionally high flow volume (late winter, early spring) it is nearly indistinguishable from main conduit waters.

DISCUSSION

WATER CHEMISTRY CONTROLS

Spatial variation of groundwater composition in Pettyjohns Cave is controlled primarily by rock-water interaction along distinct subsurface flowpaths. Temporal variation is controlled by mixing—primarily dilution during wet periods. It is possible that seasonal variations of pCO_2 also play a role in temporal variation. Calcium, bicarbonate, and magnesium are derived from carbonate dissolution. The relatively low concentrations of magnesium indicate dissolution of very magnesium-poor calcite. Silica is derived either from dissolution of siliceous microfossils that are abundant within carbonate rocks surrounding the cave, or from weathering of silicates in overlying soils and clastic units. Sodium and potassium are prob-

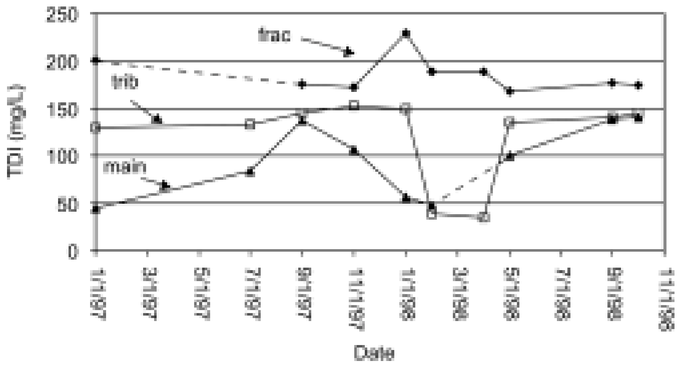


Figure 6. Temporal water chemistry variation of fracture (frac), conduit tributary (trib), and main conduit (main) waters. Main stream water was inaccessible on the April 1998 trip due to high water levels. Fracture water from the July 1997 trip was not sampled due to logistical problems.

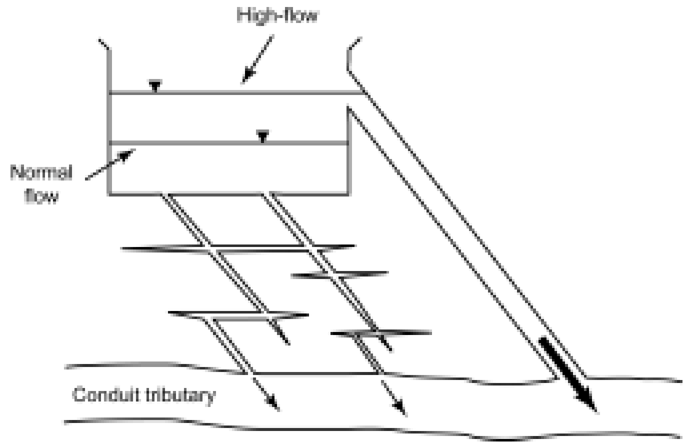


Figure 7. Conceptual model to explain bimodal behavior of conduit tributary stream. During normal flow conditions, water reaches the conduit only after significant contact with bedrock in narrow fracture network. During high flows, water reaches the conduit by a much more direct route and much less bedrock contact.

ably derived from atmospheric inputs plus ion-exchange in soils and clastic rock units. Chloride is probably derived solely from atmospheric inputs. Sulfate is likely derived from atmospheric inputs, pyrite oxidation, or dissolution of minor gypsum fracture fillings that occur in drier parts of Pettyjohns Cave and presumably in similar settings throughout the aquifer. Nitrate is likely derived from human and animal wastes deposited in and above the cave. Because the cave and associated groundwater recharge area lie mostly on undeveloped land of a wildlife preserve, local pollution is probably not a significant source of other ions.

SPATIAL WATER CHEMISTRY VARIATION

Waters sampled in this study can be distinguished from each other based on TDI concentration and subtle differences in major ion composition. Fracture and drip waters show remarkably little variation over the course of the study. Conduit waters vary in composition over well-defined ranges that do not significantly overlap with other water types. For a calcite-undersaturated water in contact with a predominantly limestone aquifer, concentrations of calcium and bicarbonate will tend to increase through time as the water approaches thermodynamic equilibrium (Jacobson & Langmuir 1970). Therefore, differences in TDI concentration in a karst aquifer are due largely to differences in residence time within the aquifer. Furthermore, residence time is primarily a function of flowpath—waters entering the cave through large fractures and conduits flow faster and have much shorter residence times than waters percolating through small fractures or limestone matrix. Thus, the persistent differences in water composition between different locations in Pettyjohns Cave are likely caused by differences in aquifer residence time, which in turn result from different subsurface flowpaths. This is also suggested by casual observation of cave hydrology: rapidly flowing conduit waters contain low TDI concentrations and are strongly undersaturated with respect to calcite; slowly percolating drip water is saturated with respect to calcite, and contains the highest concentrations of dissolved ions.

TEMPORAL WATER CHEMISTRY VARIATION

Water chemistry of the main conduit stream is controlled largely by mixing of two endmember waters: a rapidly infiltrating, dilute endmember that dominates conduit water chemistry during high-flow conditions of winter and spring, and a slowly infiltrating, concentrated endmember that dominates during low-flow conditions of late summer and autumn. Mixing of two endmember waters is indicated by the linear trend of main conduit data points on scatter plots of figure 4 (Mazor 1997, p. 115). Note in particular the magnesium and sodium vs. TDI plots. These plots clearly show the linear mixing trend between concentrated and dilute endmembers and key differences in water chemistry between conduit waters and other cave and surface waters. In particular, as TDI concentration increases, magnesium and sodium concentrations increase much more in conduit waters than in other waters. Preliminary results had suggested that the dilute conduit water endmember was surface water and that the concentrated endmember was drip water. Total dissolved ion concentrations and casual observation of mixing within the cave supported this hypothesis. However, further analysis showed both of these proposed endmembers to be incorrect. Surface water lies significantly off of the mixing lines identified in figure 4. Therefore, the dilute endmember is not unaltered surface water. Instead, the dilute endmember is probably surface water that dissolves a moderate amount of carbonate rock as it percolates through fractures connecting surface streams to the cave. This is suggested by a significantly higher TDI concentration and elevated concentrations of calcium and bicarbonate in the dilute endmember relative to surface water. The dilute conduit endmember appears to be represented by the most dilute conduit tributary samples, which lie at the low-concentration end of mixing lines defined by main conduit waters.

The concentrated endmember of the conduit mixing system has a slightly lower TDI concentration than fracture drip waters and approximately the same TDI concentration as most conduit tributary waters. Subtle differences in major ion composition, however, show that main conduit waters are distinct from other cave waters. Most notably, they are relatively enriched in magnesium and sodium (Fig. 4). Thus, the source of main conduit baseflow is different from that of conduit tributary and drip waters. There are two obvious source possibilities for this endmember. It may originate well upstream from sample points within the cave, or it may react with different stratigraphic horizons than other cave waters. In either case this would allow interaction with different strata and subsequent evolution of distinct water chemistry.

The strongly bimodal behavior exhibited by the conduit tributary stream suggests different water sources in wet versus dry periods. During high-flow, tributary waters are very similar in composition to the most dilute main conduit waters. Conduit tributary behavior can be grossly conceptualized as in figure 7. During all but the highest flows, water percolates through a network of small fractures to eventually emerge in the conduit tributary. Such a flowpath would allow significant contact with carbonate bedrock and subsequent carbonate dissolution. During times of high recharge rates, however, the fracture system cannot transmit all available water and some bypasses the fractures by a more direct route to reach the conduit after significantly less contact with bedrock. Many other plumbing arrangements could also lead to the observed bimodal behavior. The important point is that there is a separate infiltration mechanism during high-flow conditions.

Carbon dioxide is an important control of carbonate dissolution. Some of the variation apparent in TDI concentration in this study may result from seasonal variations of soil CO_2 concentration. The rough positive correlation between calculated pCO_2 and TDI concentration in figure 5 may be, in part, due to the increased availability of CO_2 during summer months and a corresponding increase in the ability of summer infiltration to dissolve carbonate rock. However, much of the variation in pCO_2 shown by fracture and drip water is likely an artifact of sample collection techniques. For example, fracture water was withdrawn from a small depression at the base of a narrow fracture on the cave wall. During summer and autumn—times during which pCO_2 would be expected to be at a maximum—flow rates reach their minimum levels. Water issuing from the fracture therefore remains in the depression for a relatively much longer time, where it might equilibrate with cave atmospheric CO_2. Likewise, soda straw drip water hangs exposed to cave air at the cave ceiling much longer during low-flow periods than during high-flow periods, and probably loses much CO_2 to the cave atmosphere. Thus, some of the relatively low pCO_2 values for fracture and drip water of figure 5 probably do not accurately reflect aquifer conditions, but rather are caused by CO_2 outgassing during low-flow conditions.

CONCLUSION

Water chemistry trends within Pettyjohns Cave, Georgia and in adjacent surface streams reveal a wide range of water chemistry. Depending on which water source is sampled, and when it is sampled, cave waters range from 34-298 mg/L TDI and are dominated by calcium and bicarbonate. Surface streams vary between 8 and 9 mg/L TDI and are very deficient in calcium and bicarbonate compared to cave waters. In general, water composition from a given source is remarkably consistent. As may be expected, conduit waters exhibit the most temporal variability.

Important processes that control groundwater chemistry in Pettyjohns Cave include evolution via carbonate dissolution along subsurface flowpaths, mixing, and seasonal variations in pCO_2 in overlying soil. Although all processes contribute to a certain degree to each water source, it appears that a subsurface flowpath is by far the most important factor. The importance of a subsurface flowpath is demonstrated by the persistent, subtle differences in water chemistry documented at numerous cave sampling points at all times of the year and under a wide range of flow conditions. Even conduit water, which is also strongly influenced by mixing of two endmember waters, is discernible from other cave water sources at all times of the year, regardless of which endmember dominates.

The greatest variation in water chemistry occurs in the main cave stream. This variation appears to be the result of mixing between two endmember waters: a baseflow component that is diluted during wet periods with a rapidly infiltrating, dilute water. The dilute endmember is most likely surface water that has reacted with limestone bedrock during infiltration from losing streams. Interestingly, the relatively high-TDI baseflow endmember is not composed of the high-TDI waters identified in this study: fracture and drip waters. The baseflow component is relatively enriched in magnesium and sodium compared to other high-TDI cave waters and may originate in the upstream reaches of the conduit system or in a different stratigraphic horizon. Results illustrate the fine-scale complexity of karst aquifers and reinforce the notion that karst water sampling programs must be carefully designed and executed.

The most pronounced seasonal variations in water chemistry occur in conduits and appear to be the result of mixing between two endmembers—a dilute, rapidly infiltrating water, and a more concentrated, slowly infiltrating water. The dilute endmember appears to be surface stream water that has experienced moderate rock-water interaction. The concentrated endmember is distinct from local fracture and drip infiltration and may originate in the upstream portion of the main conduit stream. Some seasonal water-chemistry variation may also result from seasonal variations in soil CO_2 partial pressure.

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David C. Culver, Horton H. Hobbs III, Mary C. Christman and Lawrence L. Master - Distribution Map of Caves and Cave Animals in the United States. *Journal of Cave and Karst Studies 61*(3): 139-140.

DISTRIBUTION MAP OF CAVES AND CAVE ANIMALS IN THE UNITED STATES

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The distributions of nearly 45,000 caves and 924 obligate cave species and subspecies (stygobites and troglobites) in the 48 contiguous states of the United States were mapped by county. Both maps show a highly clumped distribution. Approximately one-half of the variance in the number of species in a county is explained by variance in the number of caves per county.

While several maps of karst and pseudo-karst areas of the 48 contiguous states are available, most notably that of Davies *et al.* (1986) and its variants (Culver 1999), we know of no similar map of cave locations. We have a special interest in the distribution of caves since we have compiled a list of the obligate cave-dwelling species by county for each of the 3100 counties in the 48 contiguous states (available at www.karstwaters.org). In particular, we were interested in the explanatory power the distribution of caves has in accounting for the distribution of obligate cave-dwelling species. Therefore, we have assembled data on the number of caves by county, based on information in the National Speleological Society cave files and from records of state cave surveys. The list includes not only solution caves, but lava tubes, sea caves, etc.

The purpose of this brief communication is to present dot maps of the distribution of caves by county and the distribution of obligate cave species by county, and briefly to compare the two. A more complete analysis of the spatial distribution of cave species will appear elsewhere at a later date.

The maps presented below were generated using the Geographic Information System software package, MapView™. Each cave (or species) in a county is represented by a dot so that, for example, a county with 10 caves has 10 dots. The position of the dot within the county is assigned at random by MapView™. While this produces some loss of accuracy, it also ensures that no precise location information can be determined from the maps. For some counties, the number of caves is so great that the dots completely fill the county, and individual dots are indistinguishable and superimposed.

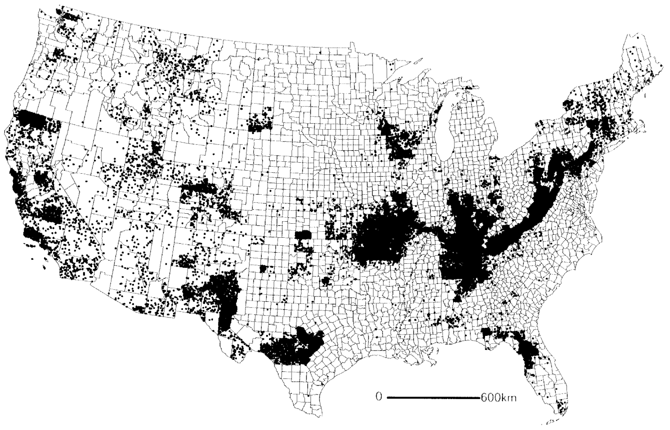

Figure 1. Dot map of the number of caves per county. Each dot represents one cave.

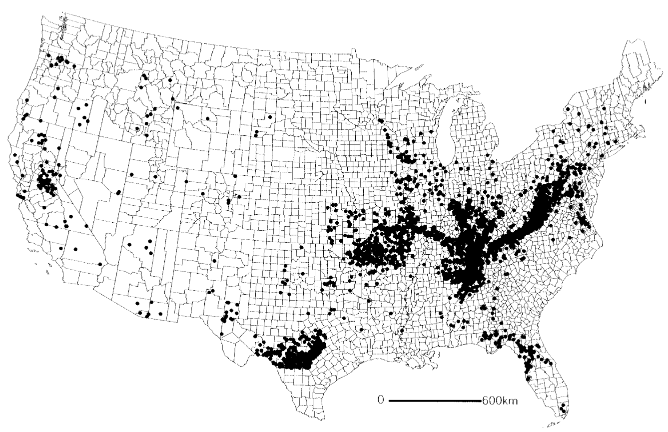

Figure 2. Dot map of the number of stygobites and troglobites per county. Each dot represents one county record of a stygobite or troglobite.

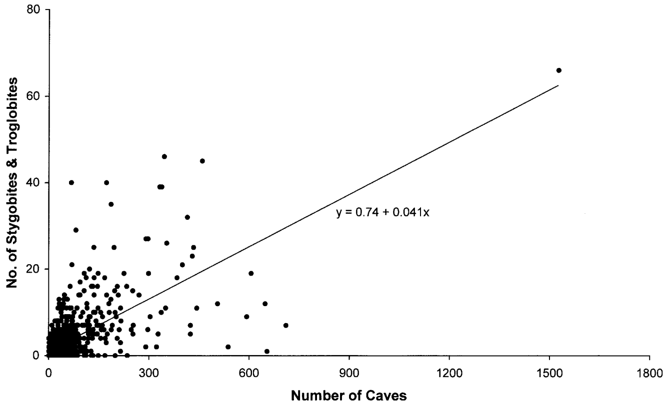

Figure. 3. Scatter plot of number of stygobites and troglobites versus number of caves for counties with one or more caves. The line is the least squares linear regression.

Figure 1, a dot map of cave locations, shows the county distribution of 44,681 caves in our database. Over one-third of the counties in the U.S. (1144 of 3211) have at least one cave. The major karst regions in the U.S. are apparent—the Appalachians, the Interior Low Plateau and associated areas immediately to the west, the Florida Lime Sinks, the Ozarks, the Driftless Area (Iowa, Illinois, and Wisconsin), the Edwards Plateau and Balcones Escarpment, the Guadalupe Mountains, the Black Hills, and a scattering of caves throughout the western U.S. The large number of caves in the West, especially in California and Colorado, may come as a surprise to some who think of caves as primarily an eastern and midwestern phenomenon.

Figure 2, a dot map of obligate cave animals, shows the county distribution for the number of species and subspecies of obligate aquatic organisms (stygobites) and terrestrial organisms (troglobites), based on a total of 924 species and subspecies. This map shows a combined total of 2774 records. Each dot in this map represents a county record for a stygobite or troglobite, and each dot is 4 times the area of the dots in figure 1, in order to facilitate comparison. Some of the same cave regions shown in figure 1 are apparent in the stygobite and troglobite distribution map: the Appalachians, the Interior Low Plateau and Cumberland Front, the Florida Lime Sinks, the Ozarks, and the Edwards Plateau and Balcones Escarpment. Cave areas to the north (Driftless Area) and west (Guadalupe Mountains and Black Hills) are not well represented by stygobites and troglobites. Another way of putting it is that, relative to figure 1, the density of dots in figure 2 is less to the west and to the north. The exception is a small cluster of records from Calaveras County, California.

The number of caves in a county is a surprisingly good predictor of the number of stygobites and troglobites. We considered those 1144 counties with one or more caves, and did a simple least squares linear regression of the number of species of stygobites and troglobites (S) on the number of caves (C), with the resulting equation (Fig. 3):

$$S = 0.74 + 0.041C$$

This relationship accounted for 47% of the variance in the number of stygobites and troglobites, and was highly significant (t=31.62, p<.00001). The intercept was also significant (t=5.69, p<.00001). There is considerable scatter (Fig. 3) and other variables, such as the number of caves in adjoining counties or latitude, are likely important. The one extreme is Jackson County, Alabama with more than 1500 caves and 66 species, nearly twice the number of caves and half again as many species as any other county. Excluding this county from the regression analysis has little influence on the estimated regression relationship, implying that the results and conclusions are not due to this single county. The analysis does not look at the level of individual cave, which would require a much more detailed analysis. However, this simple regression does demonstrate the important link between number of caves reported and number of species reported.

ACKNOWLEDGMENTS

We are grateful to the many cavers who provided us with up to date information on the number of caves per county. Richard Blenz, Chair of the NSS Cave Files Committee, and William Torode, NSS Librarian, were especially helpful in this regard. The compilation of the species list was supported by a contract from The Nature Conservancy to DCC and HHH.

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A SPELEOGENIC ORIGIN FOR FIVE-COLUMN ROCK, WISCONSIN?

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Five-Column Rock is among the most impressive of several notable fragile rock formations in southwestern Wisconsin's unglaciated Driftless Area. Consisting of a basal sandstone plinth, a set of columns enclosing "windows", and a tabular dolostone summit, the entire structure is over 6 m high. The Rock has not been previously studied in detail, and its origin has only generally been ascribed to weathering and eolian processes. Closer examination suggests that the feature originated as a phreatic cave developed in carbonate rocks transitional between the underlying Cambrian sandstone and the overlying Ordovician dolostones. The morphology of the feature, its stratigraphic context and its relationship to extant cave passage in the adjoining interfluvial ridge all point to a speleogenic origin, which may have broader significance for the development of similar features throughout the region.

Five-Column Rock (Fig. 1), a tabular prominence on the western flank of the Kickapoo River Valley in Vernon County, is an enduring icon of the Driftless Area of southwestern Wisconsin—a fragile rock formation in a unique region of some 39000km² that was spared the ravages of Pleistocene glaciation. It was featured in Lawrence Martin's classic treatise on the geomorphology of Wisconsin (three editions: 1916, 1932, 1965) and also appeared in an early 20th Century edition of the State of Wisconsin Blue Book, the official arbiter of state significance (Larson 1991). Moreover, it is the subject of a 1991 limited (135) edition pencil print series by the local artist Brian L. Larson, whose family once owned the land on which the Rock is situated (Fig. 2), and it is a well-known, if unadvertised spot for regional sightseers.

Five-Column Rock has been the subject of little geomorphological attention. It was attributed by Martin (1965) to "...weathering and wind work..." but our investigations suggest that its origin may be speleogenic, at least in part.

Figure 1. Five-Column Rock, looking northeast; main ridge to right of photograph.

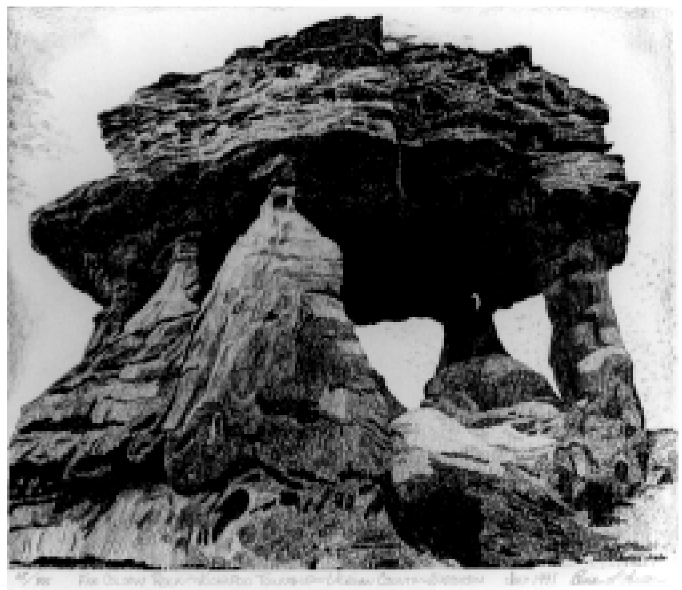

Figure 2. Five-Column Rock, pencil print, Larson (1991).

LOCATION AND DESCRIPTION

Five-Column Rock, also known locally as Table Rock, is located ~3 km west of Readstown, Vernon County, Wisconsin (Fig. 3). It is the northernmost remnant of a promontory or residual interfluvial ridge extending into the southern margins of the valley of Sherry Creek, a west bank tributary of the Kickapoo River (Fig. 3). The Rock is separated from the main body of the ridge by a downward-tapering defile, which presumably reflects the location of a broadly east-west trending structural discontinuity such as a joint or fault.

The interfluvial ridge and Five-Column Rock itself are aligned near north-south (340°). Ridge side slopes on either side of the rock are roughly 32° (west) and 36° (east) degrees, with the northern extremity of the ridge declining to 7° beyond

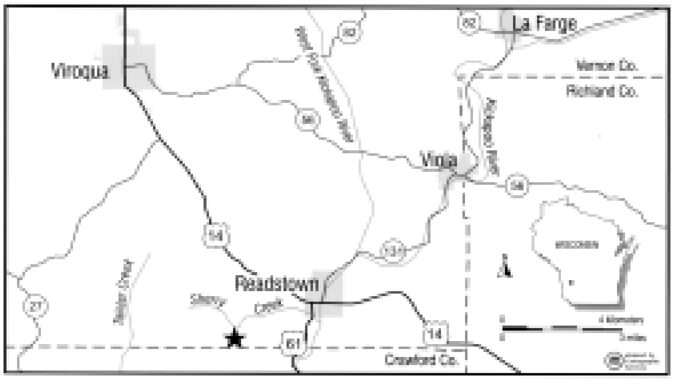

Figure 3. Location of Five-Column Rock.

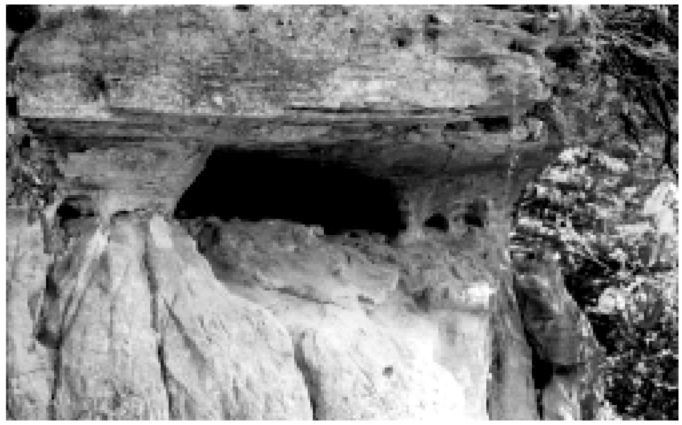

Figure 4. Adjacent cave from Five-Column Rock, looking south.

the rock itself. The elevation of the base of the rock is at 262m above msl.

The rock has three distinct components: a basal plinth, a set of columns enclosing "windows", and an entablature, or tabular summit (Fig. 1 & 2). The basal plinth tapers upwards, is ~2.0 m tall, 8.8 m long, 4.0 m wide and 21.0 m in circumference. It is an extension of the main ridge rock mass, here about 3.4 m wide and 3.2 m thick, and it extends northward beyond Five Column Rock for another 7.5m. By contrast, the entablature is ~ 3.0 m thick, also tapering upwards from 7.1 to 6.8 m long and from 4.7 to 2.0 m in width. The Rock is separated from the main mass of the interfluvial ridge to the south by a distance of ~0.2 m at plinth level and 2.4 m at table level.

The interior dimensions of the space described by the columns between the base and the table are ~1.3 m high, and a maximum of 5.0 m long and 2.5 m wide, giving an enclosed volume of ~16 m³. The name Five Column Rock is actually a misnomer, since there are currently seven columns, with heights ranging from 0.7 m to 1.8 m (Table 1). The columns themselves are vase- or hourglass-shaped, tapering inward from their extremities (points A & C) to a minimal circumference (B) at an elevation describing a northeastward-dipping (035° orientation) plane inclined at ~3° (Table 1). The seven "windows" described by the columns range from 0.25 m to 2.7 m high and from 0.2 m to 2.65 m wide, each individual window being of similar height and width (Table 1).

Table 1. Column and Window Measurements (in meters).

Column	Aspect	Circumference Basal A	Circumference Minimum B	Circumference Upper C	Total Height	Height A to B	Height B to C
1	180°S	3.3	0.8	1.3	1.5	1.3	0.2
2	232°SW	3.5	1.3	2.4	0.7	0.5	0.2
3	322°NW	1.0	0.8	0.9	0.7	0.5	0.2
4	0°N	2.5	2.3	2.6	0.7	0.6	0.1
5	70°NE	5.5	2.9	4.0	1.7	0.6	1.1
6	128°SE	5.5	1.6	2.6	1.8	1.5	0.3
7	178°SE	3.2	1.9	2.7	1.7	1.1	0.6

Window	Apect	Width	Height
1	South	2.7	2.65
2	West	1.2	1.2
3	West	0.6	0.6
4	Northwest	0.25	0.2
5	Northeast	0.4	0.35
6	East	1.85	1.8
7	Southeast	0.62	1.6

Aspect is from base of column or window facing outward.

Vegetation on the slopes below the rock consists of mixed hardwood tree species together with assorted shrubs and grasses. The basal plinth itself is essentially unvegetated, but the upper table surface supports a limited assemblage of mosses, lichens, grasses and stunted shrubs of Eastern Red Cedar (*Juniperus virginiana*).

GEOLOGICAL AND GEOMORPHOLOGICAL CONTEXT

Five-Column Rock formed within the transitional strata between the Upper Cambrian Jordan Sandstone and the Oneota Formation of the Lower Ordovician Prairie du Chien Group (Paull & Paull 1977; Wisconsin Geological & Natural History Survey 1970).

The basal plinth is composed of cross-bedded, well-sorted, medium-grained, white- to buff-colored sandstone of the Jordan Formation. By contrast, the tabular summit is formed in medium-textured, light gray-colored, sandy dolostone of the Oneota Formation. The columns are transitional, formed in calcareous sandstones and glauconitic siltstones, probably representing the Sunset Point Member of the lower Prairie du Chien Group. This transition represents the marine transgression between the Jordan and the Oneota, and the sequence within the Rock is characteristic (Davis 1970; Raash 1935).

The Jordan Formation is typically composed of quartz sandstones, locally dolomitic and hosting some small caves (Cronon 1980). The Oneota Formation, in which many southwestern Wisconsin caves are developed (Day *et al.* 1989), is typically composed of dolostones, which are of variable color and locally sandy, cherty and shaley (Clayton & Attig, 1990; Day 1979, 1984; Wisconsin Geological & Natural History Survey 1970). The transitional Sunset Point Member, largely a calcareous sandstone, has not previously been identified as a locus of cave development.

Karst is a significant component of the landscape of southwestern Wisconsin's Driftless Area, with a wide array of dry valleys, sinkholes, caves and springs (Day *et al.* 1989). Although dissolution of the dolostone is sluggish (Day 1984), the absence of direct Pleistocene glaciation (Mickelson *et al.* 1982) has permitted the continued existence of residual karst and other landscape features including such fragile formations as Five-Column Rock itself.

The geomorphic landscape of the Five-Column Rock area is dominated by a mature dendritic drainage system dissecting a series of gently-dipping cuestas (Paull & Paull 1977). Relative relief varies generally between 50 and 100 m, with relatively narrow and steep-sided interfluvial ridges separating valleys whose bases have been infilled with successive sequences of alluvial sediment. For a more complete discussion of this fluvial landscape, the reader is referred to Faulkner (1998).

A SPELEOGENIC ORIGIN?

The overall morphology of Five-Column Rock is entirely consistent with a speleogenic origin. The space between the plinth and the entablature appears to be a remnant portion, albeit subsequently modified, of a cave as defined by recognized authorities (Ford & Williams 1989; Gillieson 1996; White 1988). Geologically, the Rock is formed within a carbonate formation transitional between the underlying Jordan sandstone and the overlying Oneota dolostone, and, geomorphologically, other caves in southwestern Wisconsin have developed adjacent to carbonate-sandstone transitional contacts (Cronon 1980; Day *et al.* 1989). Regionally, many of the springs that characterize southwestern Wisconsin debouch close to the Prairie du Chien-Jordan contact (Day *et al.* 1989; Kemp & Day 1998).

Speleologically, the interior confines of the Rock are very similar to those in other regional caves, with a broadly tubular cross profile, suggestive of initial development under phreatic conditions, and a corbelled ceiling, indicative of upward-tapering breakdown of thin carbonate beds.

Perhaps the most convincing evidence for a speleogenic origin is the relationship between Five-Column Rock itself and the rest of the interfluvial ridge of which it is an extension. The west flank of the ridge proper in the immediate vicinity actually contains a small cave passage, some 8.6 m long with average height and width of 0.4 m and 1.5 m (Fig. 4). Moreover, this cave is at approximately the same elevation as the interior of the Rock and generally follows the same 340° orientation. The orientation of the cave and of the Rock itself are generally consistent with the regional pattern of cave passage orientations (Terlau & Day 1997) which are suggestive of a regional underground karst plumbing system draining towards the south and west (P. Day, 1998, personal communication). Where the cave abuts the near-vertical western rock face of the ridge, "windows" into the cave have developed between intact rock pedestals, providing a striking similarity to the windows and columns of Five-Column Rock itself.

DISCUSSION AND CONCLUSIONS

Five-Column Rock has a speleogenic origin. The void within Five-Column Rock is essentially a modified northern, possibly "upstream" extension of the cave passage in the interfluvial ridge, now dismembered by the defile between the Rock and the main body of the ridge. Following exposure as a result of fluvial dissection of the landscape surface, the Prairie du Chien dolostone has provided a durable cap rock to preserve this speleogenic feature. Eolian and fluvial processes have subsequently modified the original remnant cave passage, particularly the former passage floor, which shows evidence of spalling and has clearly been severely degraded by visitors climbing up the sandstone plinth.

Fragile rock formations such as Five-Column Rock are not uncommon features in southwestern Wisconsin's Driftless Area (Martin 1965; Paull & Paull 1977) and the probable speleogenic origin of the Rock suggests that other of these features may also have developed from cave remnants. Like the Rock itself, the origin of these features has previously been ascribed to fluvial, aeolian and/or periglacial processes, but speleogenesis may well have been involved. Two significant natural bridges in the area may also have a similar origin (Paull & Paull 1977).

The probable speleogenic origin of Five-Column Rock may also relate to the development of other sandstone and sandstone-carbonate contact caves in southwestern Wisconsin (Deckert 1980). Of the over 250 caves catalogued in the state "A high percentage...are small erosional caves in sandstone..." (Cronon 1980: 106). This study suggests that these caves, hitherto largely ignored, may actually be of true speleogenic origin, and may be of wider geomorphological and hydrological significance than previously recognized. Although caves in the Oneota Formation are widespread, and caves within the Jordan sandstone have been recorded, there has been little recognition of cave development within the transitional Sunset Point Member, which may be an important locus of speleogenesis.

ACKNOWLEDGMENTS

We are particularly grateful to the Peterson family for granting us access to Five-Column Rock, which is located on private property and should not be visited without permission. Jean Olson and Julie Kaim assisted with field measurements, and figure 3 was prepared by staff of the UWM Cartographic Services. Figure 2 is reproduced by permission of Brian Larson. We appreciate the comments and suggestions by the two reviewers.

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Thomas M. Kaiser - New Pleistocene Vertebrate Assemblages in the Breitscheid-Erdbach Cave System (Iberg Limestone, Dill Basin, Germany). *Journal of Cave and Karst Studies 61*(3): 145-149.

NEW PLEISTOCENE VERTEBRATE ASSEMBLAGES IN THE BREITSCHEID-ERDBACH CAVE SYSTEM (IBERG LIMESTONE, DILL BASIN, GERMANY)

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A substantial cave system developed in Devonian reef carbonates at the eastern foothills of the Westerwald Mountains (Hessen, Germany) was first opened in 1993 by limestone quarrying. The system is split into 4 karst levels that appear to represent stages of cyclic karst formation. All accessible levels are presently in the vadose state. Clastic sediments filling fossil voids have preserved two rich Pleistocene vertebrate assemblages. Most specimens are identified as bats or the cave bear Ursus spelaeus*. The assemblages are at least partly allochthonous. The significance of the accumulations lies in the preservation of an undisturbed surface assemblage, which most likely has not been disturbed since the late Pleistocene.*

During quarrying activities under the so-called "Hohes Feld", the entrances of the Breitscheid-Erdbach Cave system (also called Herbstlabyrinth-Adventhöhle-System; KNr: 5315/51; Hülsmann 1996) were blasted open in the fall of 1993. Initial investigations by cavers from the Speleologische Arbeitsgemeinschaft Hessen e.V. (SAH) (Grubert 1996a, b, c; Hülsmann 1996), revealed a system divided into different karst levels. In the upper levels of this system, rich fossil vertebrate faunas are preserved. Due to the early recognition, the unique fossil inventory was subject to only a little modern alteration. These assemblages offer the rare opportunity to study the formation process of fossil accumulations in central European caves in a protected environment. They further provide the rare opportunity to document and study a undisturbed Pleistocene cave-floor thanatocoenosis (death assemblage) by applying non-contact methods of documentation. The current research program therefore has the character of a pilot study, introducing non-contact methods into cave paleontology.

GEOLOGIC SETTING

Speleogenous carbonates are common in the Dill Basin (Kayser 1907; Lippert *et al*. 1970). The cave system is developed in the Iberg Limestone, a complex of Late Devonian, predominantly biogenetic reef carbonates, exposed in the vicinity of Breitscheid-Erdbach (central Hessen). The outcropping carbonates belong to a formerly extensive reef complex, outcrops of which now are restricted to an area of only 3 km² (Fig. 1). Despite its limited extent, the carbonate complex of Bereitscheid demonstrates all the characteristics of deep karstification (Becker 1925; Böhm *et al*. 1985; Kayser 1907; Stein 1995; Stengel-Rutkowski 1968). Since the complex is bordered and partly overlain by non-speleogenous volcanics and slates (Lippert *et al*. 1970; Nesbor *et al*. 1993), it probably has to be considered as a "karst barré", *sensu* Pfeffer (1984).

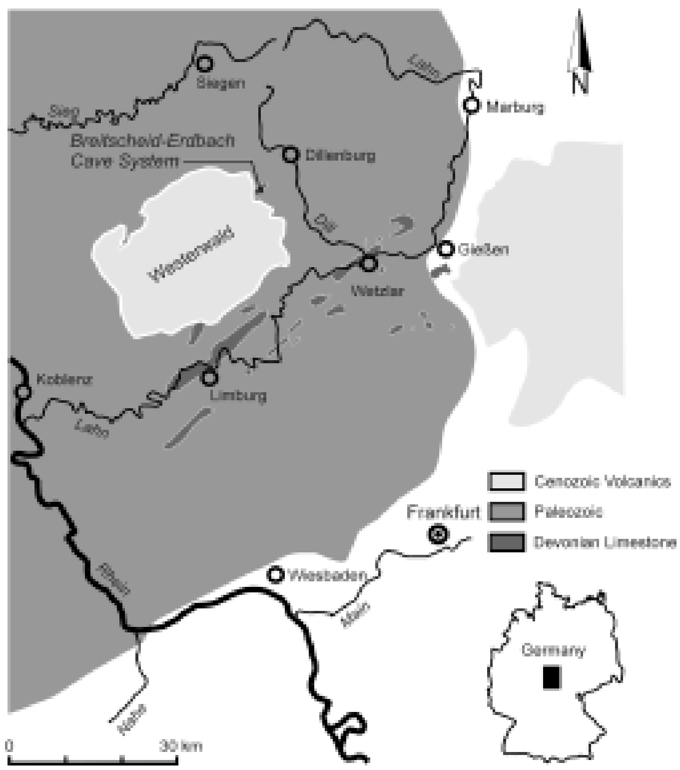

Figure 1. Location of the Breitscheid-Erdbach Cave System, at the north-eastern foothills of the Westerwald Mountains (after Kaiser et al. 1999).

Exposures in the Breitscheid Limestone complex are presently restricted to some dolines and limestone quarries operated by the Kalksteinwerk Medenbach Co. (Bachwinkel 1979).

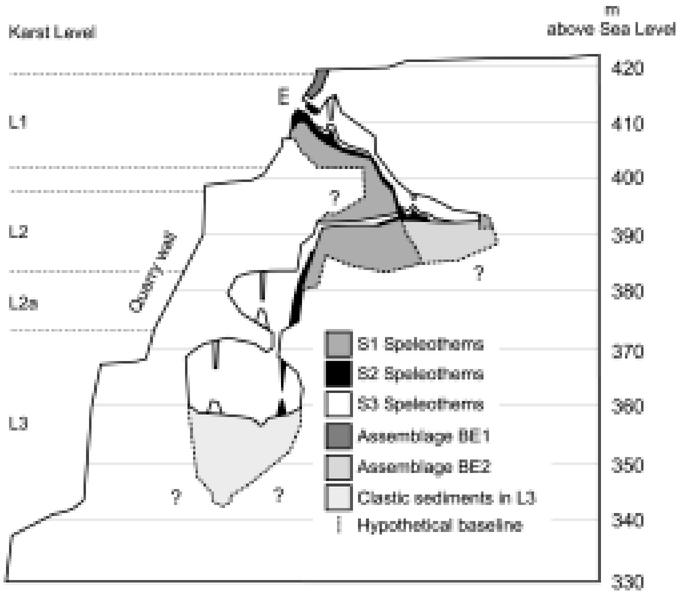

Figure 2. Generalized cross-section of the known parts of the Breitscheid-Erdbach Cave System (altitudes with kind permission of Barbara Rohstoffbetriebe Co.) showing karst levels, speleothem generations, fossil assemblages and clastic sediment bodies.

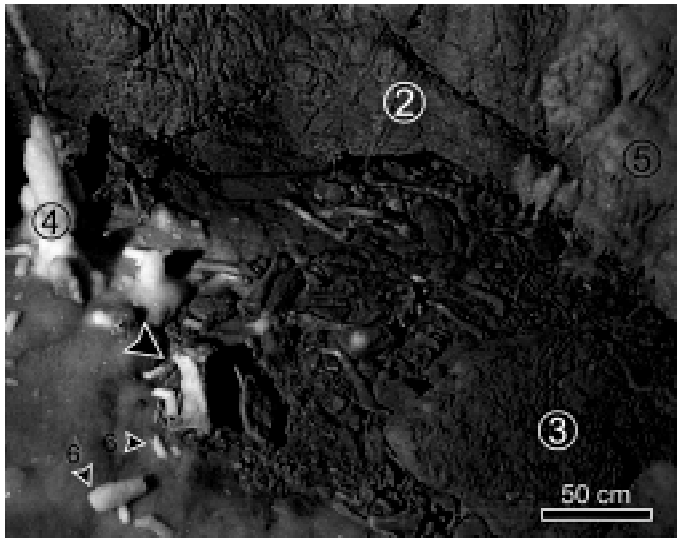

Figure 3. Surface exposure in the BE2 assemblage. A skull of *Ursus spelaeus* (1) and isolated cranial and post-cranial skeletal elements of a Pleistocene vertebrate fauna exposed in close proximity of the southern cave wall (2). (3) Collapsed boulder of S1 sinter; (4) S2-S3 stalagmite; (5) S3 sinter crust; (6) S3 stalactites fallen due to blasting activities in the quarry.

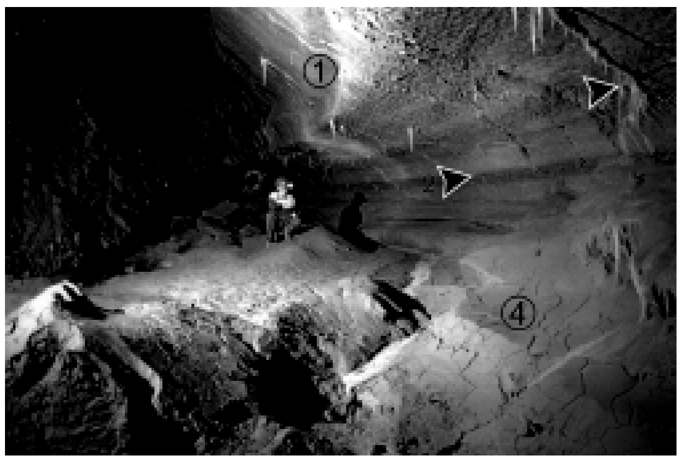

Figure 4. Principal gallery in L3, showing well preserved phreatic ceiling (1). Vadose features are water-level marks (2). Thick bodies of fine grained clastic sediment form the basal deposits (4). Some S3 speleothems are developed (3).

METHODS

Surveys for karst level correlation were conducted using a Leica-DistoMemo handheld lasermeter. Speleothem generations are distinguished morphologically. The vertebrate assemblage contained by L2 is considered unique in Europe due to its undisturbed preservation. Investigators therefore agreed to ensure maximum site protection. Fossil sampling was restricted to a small area previously disturbed. A fossil assemblage outcropping in the quarry wall was sampled, providing isolated blocks of fossiliferous deposits. From this assemblage, fossils embedded in flowstone were prepared with 5% acetic acid. The acid was changed daily and isolated specimens were subsequently hardened following Wadewitz (1977).

STRUCTURE OF THE CAVE SYSTEM

The Breitscheid-Erdbach Cave System extends over several levels that are in different stages of speleogenesis. Four levels (L1, L2, L2a, & L3) are distinguished in the presently known part of the cave. These levels (Fig. 2) are all in the vadose state (Kaiser *et al*. 1999).

L1 is the highest complex of preserved air-filled voids, which provides the present cave entrances. The voids show vadose features and are severely altered by collapse. L1 cavities, therefore, are fossil voids partly filled with clastic sediments. This level is cut by the present surface and entirely collapsed and blocked in places.

L2 voids show pronounced phreatic features, which are superimposed by vadose features. Collapse is of little importance. Coarse grained clastic sediment fills the basal part of the level and probably obscures many vadose features (Fig. 3). L2a is topographically intermediate between L2 and L3. The speleogenetic state corresponds to L2. L3 cavities show phreatic features with only a little vadose alteration. Thick bodies of fine-grained clastic sediment form the basal deposits (Fig. 4). A temporary cave creek is evident in this part of the system.

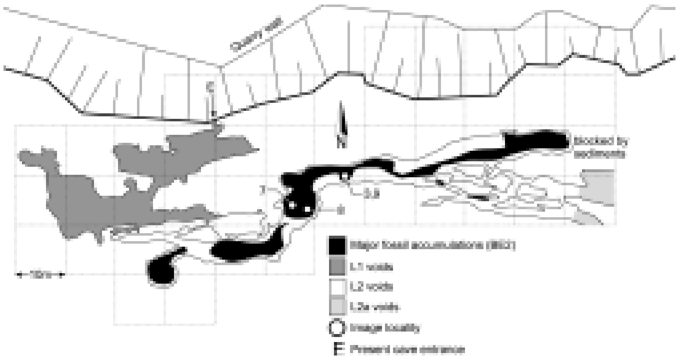

Figure 5. Plan view of cave levels L1-L2 and L2a, containing the BE2 fossil assemblage (cave topography after Thomas Hülsmann, unpublished map, and Barbara Rohstoffbetriebe Co., unpublished map). Spots indicate image localities of figures 3,7,8,9.

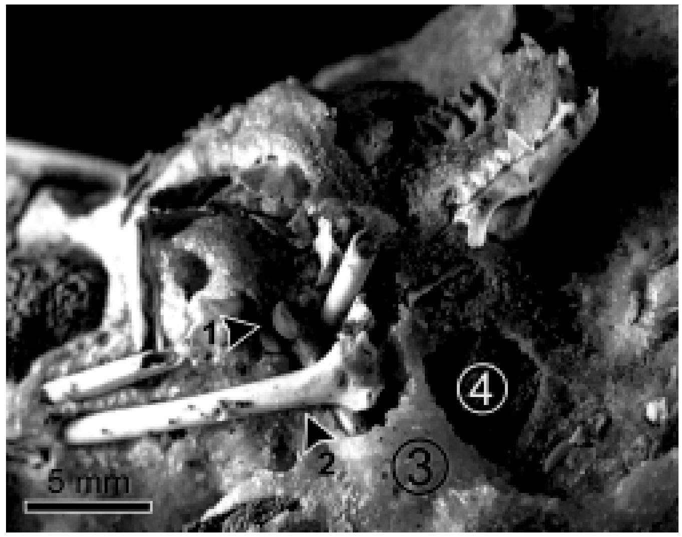

Figure 6. Bat remains predominate in BE1. Skull and long bones of *Myotis* sp., distal femoral (1) and ulna fragment (2), are embedded in calcitic matrix (3), which is intercalated with fine grained clastic material (4).

The Vertebrate Assemblages

Rich accumulations of vertebrate fossils are preserved in voids attributed to levels L1, L2, and L2a. The occurrence of these assemblages is bound to these karst levels. The uppermost complex of fossil accumulations BE1 (Breitscheid-Erdbach 1) crops out in the quarry wall. It is associated with sediment bodies attributed to the fossil level L1 (Fig. 2). The fossil accumulations in levels L2 and L2a are summarised as thanatocoenosis BE2 (Breitscheid-Erdbach 2). The BE2 complex is not exposed in the quarry. The faunal remains are components of a clastic sediment body, which forms the cave floor in a 105 m section of a principal gallery in L2 (Fig. 5). BE1 and BE2 have an average vertical spacing of 25 m. No fossils are yet recorded from L3.

Breitscheid-Erdbach 1 (BE1)

The BE1 complex of fossil assemblages is exposed at an absolute altitude between 400 m and 420 m. Alternating bands of sinter and clastic facies composed of boulders, pebbles and vertebrate bones occur in a fine to coarse grained matrix, which in places is dominated by pelites. Incasion masses and surface detritus from the overlying units predominate. Fossils are enclosed in sinter bands and in the finer clastic lithofacies. Vertebrate fossils so far recorded are not yet identified fish vertebrae, several species of the Genus Myotis (Chiroptera), the lagomorph *Ochotona pusilla*, the rodent *Apodemus* sp., the marten *Martes* cf. *vetus* (Michael Morlo, pers. comm.; Anderson 1970), and the ursid *Ursus* sp. Bat remains (Fig. 6) predominate as well as individuals and also in species diversity. The bat assemblages are considered to represent a fragment of hibernating communities. Since the faunal record so far is considered to be fragmentary, a detailed faunal and taphonomic analysis will be dedicated to a later contribution.

Breitscheid-Erdbach 2 (BE2)

The underlying limestone floor is not accessible in any part of the gallery containing BE2 (Fig. 3,7,8). Thickness and volume of the sediment body is thus largely unknown. The clastic lithofacies is clay bound and contains inclusions of sinter fragments, limestone gravel, and collapsed boulders. Mammalian fossils are exposed covering the cave floor in large masses, partly lacking sedimentary cover (Fig. 3,7,8,9). Fossil inclusions are bone fragments and complete skeletal elements which predominantly are identified as *Ursus spelaeus* Rosenmüller. *Equus* sp., a rhinocerotid, and a large bovid recorded by isolated foot bones.

An initial sampling of bone specimens was undertaken in an previously disturbed area of assemblage BE2. It yielded the first evidence of a middle Würmian date for part of BE2 (Gernot Rabeder, pers. comm.). The superficially exposed fossils are in a state of preservation that is characterized by extensive loss of the organic bone matrix. Speleothems grow on superficially exposed bone specimens in a wide variety of forms (Fig. 5,6,8).

Strongly rounded limestone clasts are common in the surface exposures of BE2 (Fig. 9). Edge rounding is further evident in many fossil bone specimens. With the exception of isolated bat remains, no macroscopic postglacial components are recorded from the surface assemblage of BE2. This also applies to evidence for hominid presence or artifacts.

Relative chronology of speleothem generations and vertebrate assemblages

A minimum of three sinter generations (S1-S3) of different ages are proposed from the known parts of the system. Massive bodies of brown clay-encrusted speleothems block

Figure 7. Panoramic image of principal gallery in L2 containing the BE2 fossil accumulation. Dashed lines are match lines of the 360° panorama. SW extension of gallery (5); NE extension (4). Prominent S1 and S2 sinter masses are covered with white S3 sinter crusts (1). S2 (2) and S3 speleothems (3).

substantial galleries in places (Fig. 7). These speleothems are inactive, partly corroded, and form collapse masses (Fig. 3). They are regarded as the oldest speleothem generation (S1). S1 speleothems are common in L1-L2, but not yet identified in levels L2a and L3 (Fig. 2). A younger sinter population assigned to S2 superimposes S1. S2 sinter is white or yellowish. It forms massive stalagmites (Fig. 7), sinter columns, and massive flowstone formations. S2 speleothems are recorded from all known levels (L1-L3). The youngest speleothems of the system (population S3) are mostly clear white. They superimpose S1 and S2 speleothems as well as all clastic bodies in the system (Fig. 3,4,7,8). S3 is the presently active sinter population, which is recorded as soda straws, sinter draperies, helictites, slender stalagmites, and flowstone crusts. Speleothems grown on fossil specimens from BE2 probably belong to the generations S2 and S3 (Fig. 3, 8). S2 was probably already active when BE2 fossils were finally embedded. Recent sinter damage, mainly suffered by S3 soda straws and slender stalagmites (Fig. 3,8,9) is due to quarry blasting in the close vicinity of the cave.

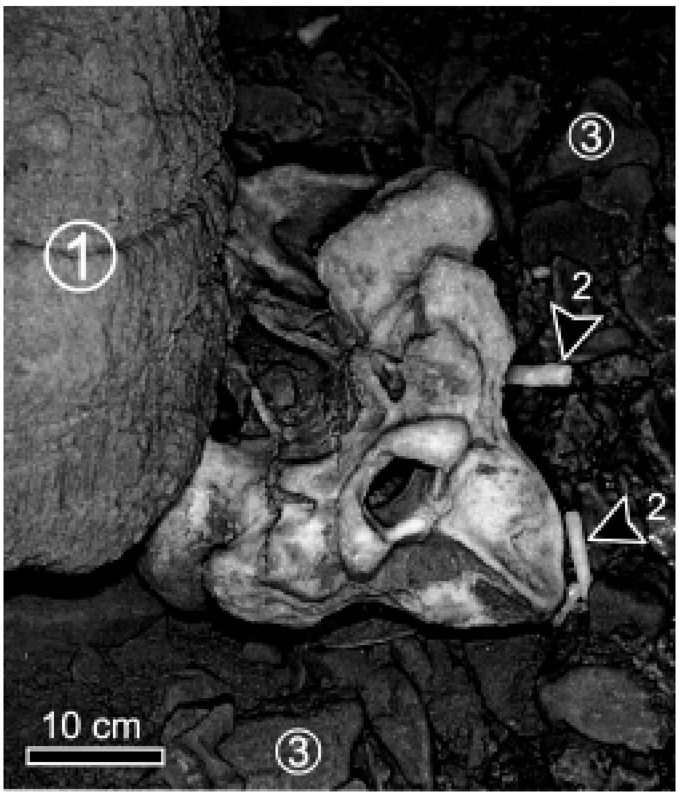

Figure 8. (1) Cranium of *Ursus spelaeus* underneath a collapsed boulder of S1 speleothems; (2) fallen S3 stalactites; (3) edge- rounded clasts of the BE2 sediment body.

The BE1 complex and the associated sediment body is interpreted as representing the infill of the collapsed and partly eroded karst level L1. Because BE1 and BE2 have a mean vertical distance of 25 m, it is likely that the related paleovoids are part of different karst levels (L1 and L2). It is thus regarded likely that these voids represent different stages of cyclic karst formation in the sense of Sawicki (1909). The voids associated with BE1, representing level L1, would then be older then L2 and L2a voids containing BE2.

Intense edge rounding of clastic inclusions and fossils in complex BE1 may evidence transport and resedimentation of clasts and fossils. Also in BE2, clasts with severe edge rounding suggest impact during transport prior to final emplacement.

Figure 9. Postcranial elements of *U. spelaeus* (1: femur), superimposed by S3 stalagmites (2). The stalagmites grow on the stumps of older fallen stalagmites (3). (4) S1 sinter mass; (5) bone specimen covered by S3 sinter crust; (6) S3 stalactites that fell due to blasting.

BE1 and BE2 are, therefore, interpreted as at least partly allochthonous complexes.

The primary depositional environment of part of the BE2 fossil assemblage may be located in level L1 or an even higher, hypothetical level L0. Horizontal fluviatile transport within level L2, however, seems more likely.

The undisturbed preservation of the Pleistocene cave floor, and the lack of Holocene components in the surface assemblage suggests that L2 was no longer accessible for larger vertebrates after the deposition of BE2. Today, the gallery containing assemblage BE2 is only accessible by vertical passages. If the fossiliferous part of the cave acted as hibernating shelter for larger mammals, the Pleistocene entrances would not be identical with the present entrance passage.

The easterly extension of the gallery containing BE2 is blocked by massive deposits of speleothems and clastic sediment (Fig. 5). The proposed Pleistocene cave entrance is tentatively considered to relate to this proposed extension of the cave.

ACKNOWLEDGEMENTS

The author wishes to thank the Barbara Rohstoffbetriebe Co, especially Manfred Lang, for permission to work in the quarry area and for providing topographic data on the cave system. Thomas Hülsmann (Speläologische Arbeitsgemeinschaft Hessen e.V.) is acknowledged for permission to use data from an unpublished map for figure 5. Christina Seiffert (Forschungsinstitut Senckenberg), Walter Tanke (Museum für Naturkunde Dortmund), Thomas Keller (Landesamt für Denkmalpflege Hessen, Wiesbaden), and Roland Heuser (Speläologische Arbeitsgemeinschaft Hessen e.V.) are gratefully acknowledged for multiple support in the related field work. I further thank George W. Moore (Oregon State University) and an anonymous reviewer for their helpful comments and improvements to the manuscript.

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CAVE SCIENCE NEWS

Canon National Parks Science Scholars Program

The Canon National Parks Science Scholars Program will award scholarships to eight doctoral students in 2000. Each student selected will receive $25,000 per year for up to three years to conduct research in the national parks. The 2000 competition will focus on four research topics within the biological, physical, social, and cultural sciences. The research topics are of critical importance to the management of the National Park System and selected by the National Park Service. Students applying for 2000 scholarships must submit dissertation proposals that address these topics.

Visit http://www.nps.gov/socialscience/waso/acts.htm for an application and guidelines, or contact Dr. Gary Machlis, Program Coordinator, Canon National Parks Science Scholars Program, Natural Resource Stewardship and Science, National Park Service, 1849 C Street, NW (MIB 3127), Washington, DC 20240, mailto:gmachlis@uidaho.edu.

Applications are due 1 June 2000. Winners will be announced in early August 2000. Canon U.S.A., Inc. underwrites the program in collaboration with the National Park Service, National Park Foundation, and the American Association for the Advancement of Science.

Life Sciences Editor Needed by Journal

The *Journal of Cave and Karst Studies* is looking for a new Associate Editor of Life Sciences. The present Life Sciences Editor, Dr. David Ashley, would like to step down as soon as a replacement is identified. The responsibilities of Associate Editors are to solicit articles, arrange for appropriate reviews of papers in their fields of expertise, work with authors to prepare their manuscripts for publication, make recommendations concerning acceptance and rejection of submitted papers, and assist the Editor in gathering material for the non-refereed section of the *Journal*. Advice from the Associate Editors, along with the *Journal*'s Advisory Board, is commonly solicited on editorial policy decisions, making an Internet address highly desirable.

The *Journal* seeks a pro-active biospeleologist with contacts in the scientific community and experience in scholarly publishing. Interested candidates are asked to send a letter of interest by January 20, 2000 to the editor at: HoseL@jaynet.wcmo.edu.

New Cave Crayfish Species for Missouri

The Missouri Department of Conservation has determined that a stygobitic (aquatic, cave-adapted) crayfish from Ozark County is new to science. MDC cave biologist Bill Elliott, Ken Lister, and Melissa Shiver studied caves in the Caney Mountain Conservation Area, owned by MDC, on August 16, 1999. Their trip was part of a field project, funded by the U.S. Fish & Wildlife Service, in search of the Ozark big-eared bat and another rare cave crayfish, *Cambarus aculabrum* (neither was found in Missouri).

They followed up on an old report by visitors that crayfishes inhabit one of the caves at Caney Mountain. MDC found a small population of blind crayfish in a muddy stream passage, and Lister collected one adult male and one adult female for identification by an expert taxonomist (cave biologist Horton H. Hobbs III). Elliott extensively photographed the specimens and the "first form" (mature) male's gonopods (mating appendages), which are important in identifying different species. Tissue from the female was deep frozen for DNA work by a geneticist, and both specimens were preserved for study.

A small population of crayfish live in the cave, but they are difficult to census because of the muddy water. Biologists from the Shedd Aquarium had observed several adults and juveniles two years ago. For conservation reasons, the cave name will not be announced to the public and access will have to be restricted for scientific studies. Fortunately, the cave is inside a protected "Natural Area" inside the Conservation Area, and is far from any development or known pollution sources. It is not a pretty cave and will not be missed by most visitors.

Elliott suspected that the species would be new since no cave-adapted crayfish were known from Ozark County. He was thrilled when he studied his photos and realized that this was a species of the genus *Orconectes*, instead of one of the two known cave crayfishes in Missouri, which are *Cambarus hubrichti* (Salem cave crayfish) and Cambarus setosus (bristly cave crayfish from the Springfield Plateau). Ozark County was in a gap between the known ranges of these two species.

Five species of blind *Orconectes* inhabit caves from Indiana to Alabama. "Beep" Hobbs said he just about fell off his chair when he examined the specimens and realized that this was the first blind *Orconectes* from west of the Mississippi River. Missouri has 19 epigean (surface-dwelling) *Orconectes*, but had no cave species until this one. A photo of the new species may be seen on the Biospeleology web site at:

http://www.utexas.edu/depts/tnhc/.www/biospeleology.

Finding a new species of cave crayfish is a rare event. In Missouri *Cambarus setosus* was described in 1889 and *C. hubrichti* was described in 1952. The latest American cave crayfish, *Orconectes sheltae*, was described in 1997 from Shelta Cave, Alabama, but only after years of study by John Cooper. That species was found to have an extremely slow growth rate, low reproductive rate, and long life span; males mature after the age of 40, and individuals may live to 100 years. Other cave-adapted crayfish may have similar life histories, so it is important to carefully study and conserve cave crayfish populations.

Bill Elliott will be leading field studies of the new crayfish, and hopes to find other populations in the area. Cavers can help the scientific effort by reporting sightings of cave crayfish to Elliott. Some cave streams contain pale, but eyed, epigean crayfish. Either way, they are difficult to see when you are wading through streams and a cloud of mud is advancing in front of you. Please do not collect animals unless you have a MDC Wildlife Collector's Permit. Good macrophotos of crayfish may help, but they are of limited use because of the microscopic characters that must be examined.

It is still quite possible that other new cave species remain to be discovered in the Ozarks. The following Missouri karst counties have no identified populations of blind crayfish but are good candidates: Stone, Taney, Douglas, Webster, Wright, Texas, Polk, Dallas, and Laclede.

INDEX TO VOLUME 61 OF THE JOURNAL OF CAVE AND KARST STUDIES

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This index covers all articles and abstracts published in volume 61 parts 1, 2, and 3. Selected abstracts from the 1999 Society meeting in Filer, Idaho, and will be included in the next volume.

The index consists of three sections. The first is a **Keyword** index, containing general and specific terms from the title and body of an article. This includes cave names, geographic names, etc. The second section is a **Biologic** names index. These terms are Latin names of organisms discussed in articles. 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

BIOLOGIC NAMES INDEX

AUTHOR INDEX

JCKS REVIEWERS 1996-1999

The *Journal of Cave and Karst Studies* greatly appreciates the experts from many disciplines of speleology who review and comment on all of our articles. The decision to publish a paper in the *Journal* relies heavily on their comments and suggestions. A careful review typically takes several hours and many of our reviewers regularly donate their time to the *Journal*. As this issue concludes our fourth year of publishing under the revised name, The *Journal of Cave and Karst Studies*, the editors wish to acknowledge the professional scientists and cavers who provided reviews during the last four volumes (v. 58-61). Thanks, folks!

E. Calvin Alexander
Tom Aley
Enriqueta Barrera
Danny Brass
Jerry H. Carpente r
Arrigo Cigna
David Culver
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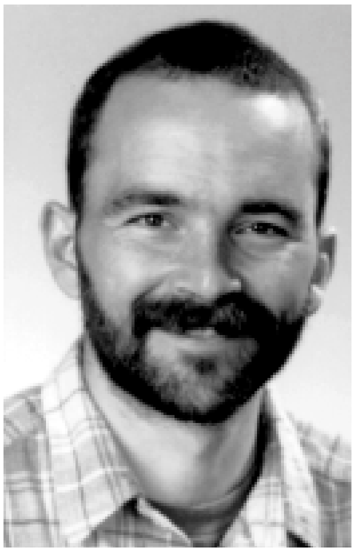


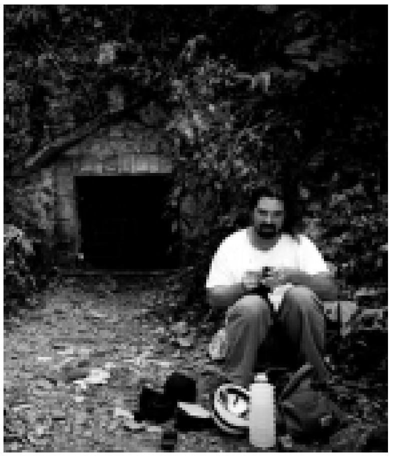
James Mayer is an assistant professor of geology at the State University of West Georgia in Carrollton Georgia. His main interests are karst water chemistry, sediment transport in karst systems, and crystalline rock hydrogeology.

David Culver received his undergraduate training at Grinnell College and his graduate training at Yale University. Thus, he had the great good fortune to study under two of the biospeleological masters—Kenneth Christiansen and Thomas Poulson. He is President of the Karst Waters Institute and an Honorary Life Member of the NSS. His current research interests focus on biogeography of cave faunas, conservation biology of cave faunas, and groundwater ecosystem services. Culver is Professor of Biology at American University.

Larry Master, PhD, has worked in the Network of Heritage Programs and Conservation Data Centers since 1980, when he started as Coordinator/Zoologist with the Michigan Natural Features Inventory. Since 1987, Master has been the Chief Zoologist for The Nature Conservancy and now for the Association for Biodiversity Information (ABI). Working out of the Boston satellite office of the Conservancy, he has overall responsibility for the integrity and development of the Natural Heritage Network's central zoological databases and files "http://www.abi.org/".

Mary C. Christman is an Assistant Professor in the Biometrics Program at the Department of Animal and Avian Sciences, University of Maryland, College Park, MD. She is active in developing sampling designs and statistical models for environmental studies and biological research. Her interests include modeling zoogeography and biodiversity, and estimating the abundance of rare, geographically clustered populations.

Mick Day is a Professor of Geography at the University of Wisconsin-Milwaukee, specializing in tropical karst geomorphology and conservation. He has undertaken research in karst areas of Europe, North America, the Caribbean, Central America, Southeast Asia and Australia. Originally from England, he has been conducting research and teaching in Wisconsin since 1977.



Jeff Kueny is a graduate student in the Department of Geography at the University of Wisconsin-Milwaukee. His research interests include karst, geomorphology and conservation. Since 1992 he has been carrying out research in Central America and the Caribbean, where he is currently assesssing the status of protected karst areas.

Dr. Thomas M. Kaiser is currently an Assistant Professor of Zoology at the University of Greifswald, Germany, where he teaches vertebrate anatomy and taphonomy. He received his Ph.D. (1997) from the University of Darmstadt. His research interests include the paleobiology of fossil herbivores and the taphonomy of Plio-Pleistocene fossil assemblages, including karst deposits.

WORLD DEEP AND LONG CAVE LIST

COMPILED BY: BOB GULDEN

Send all updates and/or corrections to: caverbob@aol.com

	Cave Name	Country	Depth Meters	Length Meters
1	Lamprechtsofen-Vogelshacht	Austria	1632	44000
2	gouffre Mirolda / Lucien Bouclier	France	1610	9379
3	Reseau Jean Bernard	France	1602	20000
4	Torca del Cerro (del Cuevon)	Spain	1589	2685
5	Shakta Vjacheslav Pantjukhina	Georgia	1508	5530
6	Sistema Huautla	Mexico	1475	55953
7	Sistema del Trave (La Laureola)	Spain	1441	9167
8	Boj-Bulok	Uzbekistan	1415	14270
9	(Il)laminako Aterneko Leizea (BU56)	Spain	1408	14500
10	Sustav Lukina jama - Trojama (Manual II)	Croatia	1393	?
11	Sistema Cheve (Cuicateco)	Mexico	1386	24300
12	Evren GUNAY sinkhole (Peynirlikonu dudeni)	Turkey	1377	?
13	Sniezhnaja-Mezhonnogo (Snezhaya)	Georgia	1370	19000
14	Ceki 2 (Cehi II)	Slovenia	1370	3959
15	reseau de la Pierre Saint Martin	France/Spain	1342	53950
16	Siebenhengste-hohgant Hohlensystem	Switzerland	1340	140000
17	Slovacka jama	Croatia	1295	4832
18	Cosanostraloch - Berger - Platteneck Hohle	Austria	1291	30000
19	gouffre Berger - Gouffre de la Fromagere	France	1278	31190
20	Pozo del Madejuno	Spain	1255	2852
21	Torca dos los Rebecos	Spain	1255	2228
22	Abisso Paolo Roversi	Italy	1249	4000
23	Vladimir V. Iljukhina System	Georgia	1240	5890
24	Sotano (Sistema) Akematl (Axematl)(Axemati)	Mexico	1226	4918
25	Schwerhohlensystem (Batmanhole)	Austria	1219	6101
26	Abisso Ulivifer (Olivifer)	Italy	1215	10000
27	Kihaje Xontjoa	Mexico	1209	25000
28	Gorgothakas	Greece	1208	?
29	Dachstein-Mammuthohle	Austria	1199	52944
30	Crnelsko brezno	Slovenia	1198	7580
31	Cukurpinar Dudeni	Turkey	1195	3550
32	Complesso del Monte Corchia (Fighiera,Farol.)	Italy	1190	52300
33	Vandima	Slovenia	1182	?
34	Sistema Aranonera (Sima S1-S2)	Spain	1179	34500
35	Jubilaumsschacht	Austria	1173	2380
36	g.de Bracas de Thurugne 6 (Reseau du Soudet)	France	1172	10340
37	Anou Ifflis	Algeria	1170	3800
38	Abisso Vive le Donne	Italy	1170	3800
39	Sima 56 de Andara(Torca Cueto de los Senderos	Spain	1169	5620
40	Torca Idoubeda	Spain	1167	?
41	Sistema Badalona/B15-B1 / Grota di Lombardia	Spain	1150	10970
42	Tanne des Pra d'Zeures (Reseau de la Tourne.)	France	1148	11200
43	Sistema del (Pozu) Xitu (Jitu)	Spain	1135	6100
44	Sistem Molicka Pec	Slovenia	1130	?
45	Neide - Muruk Cave	Papua NG	1123	17000

	Cave Name	Country	Length Meters	Depth Meters
1	Mammoth Cave System	U.S.A.	571317	115
2	Optimisticeskaja (Gypsum)	Ukraine	212000	15
3	Jewel Cave	U.S.A	195615	186
4	Holloch	Switzerland	175150	941
5	Lechuguilla Cave	U.S.A.	161900	477
6	Fisher Ridge Cave System	U.S.A.	144841	108
7	Siebenhengste-hohgant Hohlensystem	Switzerland	140000	1340
8	Wind Cave	U.S.A.	138621	199
9	Ozernaja	Ukraine	117000	8
10	Gua Air jernih-Lubang Batau Padeng	Malaysia	109000	355
11	Systeme de Ojo Guarena	Spain	100000	
12	reseau de la Coumo d'Hyouernedo(e)	France	94843	1018
13	Sistema Purificacion	Mexico	90470	957
14	Zolushka (Gypsum)	Moldova/Ukraine	90200	30
15	Hirlatzhohle	Austria	84992	1041
16	Toca da Boa Vista	Brazil	84000	
17	Friars Hole Cave System	U.S.A.	71052	188
18	Easegill System	United Kingdom	70500	211
19	Nohoch Nah Chichn (Under Water)	Mexico	68348	73
20	Raucherkarhohle	Austria	65000	725
21	Organ (Greenbrier) Cave System	U.S.A.	63569	148
22	Ogof Draenen	United Kingdom	62000	98
23	Kazumura Cave (Lava Tube)	U.S.A.	61420	1101
24	reseau de L'Alpe	France	60247	655
25	Red Del Rio Silencio	Spain	60000	502
26	Cenote Dos Ojos (Under Water)	Mexico	59436	?
27	Bullita Cave System (Burke's Back Yard)	Australia	57500	23
28	Kap-Kutan/Promezhutochnaja	Turkmenistan	57000	310
29	Sistema Huautla	Mexico	55953	1475
30	reseau de la Dent de Crolles	France	55250	608
31	Mamo Kananda	Papua NG	54800	528
32	reseau de la Pierre Saint Martin	France/Spain	53950	1342
33	Blue Spring Cave (Saltpeter)	U.S.A.	53108	61
34	Dachstein-Mammuthohle	Austria	52944	1199
35	Complesso del Monte Corchia	Italy	52300	1190
36	Martin Ridge System (Wig.,Jackpot,Martin)	U.S.A.	51884	96
37	Ogof Ffynnon Ddu	United Kingdom	50000	308
38	Carlsbad Cavern	U.S.A.	49680	316
39	Gr. Cacerna de Palmarito	Cuba	48000	?
40	Santo Tomas (gran caverna de)	Cuba	46000	?
41	Crevice Cave	U.S.A.	45546	?
42	Barenschacht	Switzerland	45400	946
43	sima del Hayal de Ponata (SI.44)	Spain	45000	220
44	Sistema Ox Bel Ha (Under Water)	Mexico	44501	?
45	Cumberland Caverns (Saltpeter)	U.S.A.	44444	61

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