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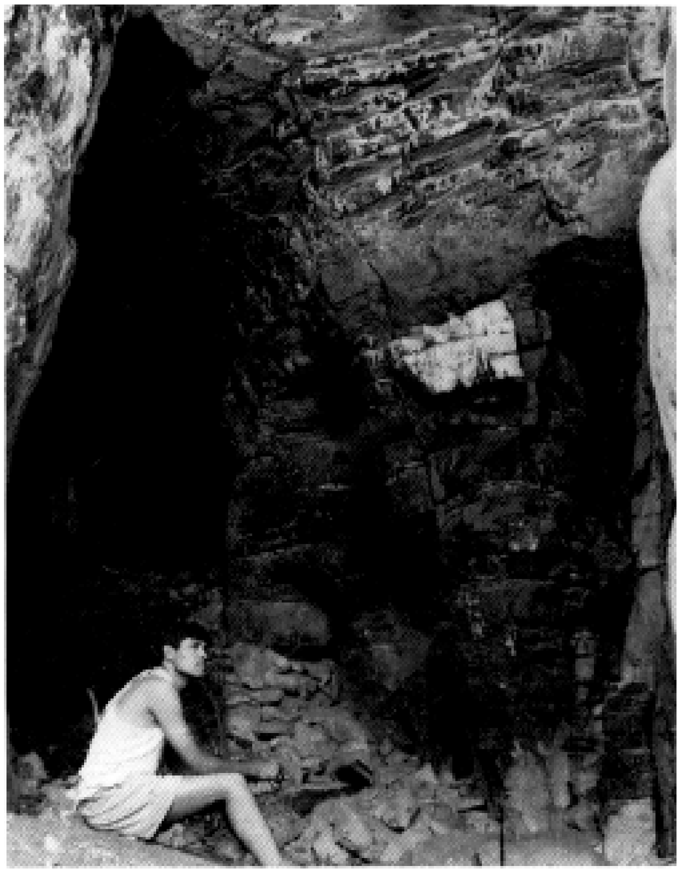

THIS ISSUE:

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Cover: Yerrazari Gavi (left) and Sanyasula Gavi (right). See Prasad, page 30.

A NEW BEGINNING: EDITOR'S COMMENTS

The National Speleological Society has demonstrated its dedication to the thorough exploration and study of caves by published refereed documentation of our activities in karst research in the *NSS Bulletin* for over 30 years. Throughout the years, leaders of the Society worried that the *Bulletin* was too esoteric to best serve the dues spent by most of our members. But, whenever the question was placed before the membership, you have strongly expressed your satisfaction and pride in our scientific journal. Many scientists in our Society cite the *Bulletin* as their main inspiration in pursuing professional careers in karst research.

NSS members have been great supporters of the scientific community within the Society and now we hope to expand the *Bulletin* to make it more interesting and valuable to all of our members. After a year of discussions, an editorial in the *NSS News*, and many letters from members, the NSS Board of Governors moved to make dramatic changes in our scientific publication. With the current volume, you can expect to see the following changes:

The name of the publication will change from *The NSS Bulletin: Journal of Caves and Karst Studies* to *Journal of Cave and Karst Studies: The National Speleological Society Bulletin*.

There will be three issues (formerly only two issues) per year which will typically be two regular issues and one theme issue.

Duties of the present editor will be split amongst two people in the future. The "Editor" will be responsible for controlling the refereeing process and general content of the publication. The "Production Editor" will be responsible for typesetting, proof-reading, and dealing with the printer and mailing.

Advertising for science-related products and publications will be solicited.

While the majority of the *Journal* will contain refereed articles similar to the previous content of the *Bulletin*, separate sections will include editorials, conference announcements, conference reports, news briefs, and the abstracts from the annual convention.

Brief biographies and photos of the primary author of publications will be included with each issue.

This issue also marks another transition. Andy Flurkey took over the editorship of the *NSS Bulletin* in 1987 and has served with distinction for nine years. At the time of his appointment, the *Bulletin* was over a year behind in its publication schedule. Andy has steadily and successfully worked to make the *Bulletin* both on time and a valued product. The dramatic changes we plan today are only possible because of the strong foundation Andy has built for the *Bulletin* during his tenure. The Society owes Dr. Flurkey a great debt of gratitude as he has chosen to retire after his many years of outstanding service.

Fred Wefer, the NSS Executive Vice President, asked me to serve as the Interim Editor for the first issue of the new *Journal*. I will continue as editor after this issue if the NSS-BOG chooses to confirm my appointment in March. Wefer also asked Dr. James A. Pisarowicz to act as the Production Editor. He also will continue if the position is confirmed by the board.

Louise D. Hose, Interim Editor

James A. Pisarowicz, Louise D. Hose, and Andrew Flurkey—left to right.

EDITOR - LOUISE D. HOSE, PH.D.

Louise D. Hose of Littleton, Colorado has been appointed Editor of the *Journal of Cave and Karst Studies* pending NSS Board of Governors approval in March. Hose recently retired after five years as editor of *Geo²*, the NSS Cave Geology and Geography Section tri-annual newsletter and as associate editor for exploration for the *NSS Bulletin*. She has a Ph.D. in geology and taught at the University of Colorado, Colorado Springs during the past seven years.

Hose is an active caver with an impressive record of exploration in Mexico, the western US, and elsewhere. Two articles by her on the Purificación system in northern Mexico, which passed through the refereeing process before her appointment, appear in this issue.

PRODUCTION EDITOR - JAMES A. PISAROWICZ, PH.D.

James A. Pisarowicz of Montrose, Colorado was appointed Production Editor of the *Journal of Cave and Karst Studies* pending NSS Board of Governors approval in March. Pisarowicz is the former Executive Director of the Death Valley Natural History Association and was the publisher of 16 books. He was the Guest Editor for a Special Topics issue of the *NSS Bulletin* on the Black Hills. Pisarowicz has a Ph.D. in psychology and currently teaches psychology for Mesa State College.

Pisarowicz has been honored with the Lew Bicking Award for his outstanding exploration efforts in Mexico, Papua New Guinea, Mystery Cave in Minnesota, and Wind Cave, South Dakota.

Palmer, A.N.—The Role of Cave Exploration in Karst Research. *Journal of Caves and Karst Studies 58*(1):4-5.

THE ROLE OF CAVE EXPLORATION IN KARST RESEARCH

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In the early years of mountaineering, it was customary for expedition members to haul up a variety of scientific instruments to give the impression that the climb was really just a way of pursuing serious research. Some climbers were indeed scientists with a bona fide interest in the data, but in many cases the science was simply a smokescreen to deflect any argument that exploration by itself was not a worthy endeavor. Of course none of the measurements amounted to much, but the feats of exploration stand today as major triumphs.

Today, in a similar way, many karst researchers downplay the importance of cave exploration in their work. They slice away any hint of sport from scientific papers, as though caves serve merely as gathering-grounds for scientific data and are not of interest by themselves. There are several good reasons to do so. First, there is a scientific pecking order in which theoretical and quantitative topics are considered more lofty than applied and qualitative studies. Those who aspire to the higher echelons must not soil their hands with field work (or so the current thinking would have it). Besides, the average scientist looks at cave studies merely as glorified spelunking. Why should karst researchers hobble their work with unnecessary references to muddy crawlways?

There is a second and more important reason to avoid describing caves in the professional literature—conservation. When writing for non-karst journals, I and many of my colleagues avoid unnecessary references to cave studies that involve sampling, to avoid sending the message that collecting in caves is justified, even for scientific purposes. A genuine speleologist cares more about the cave than about his or her research and will collect samples with caution and integrity, and only if no damage is done. Can we guarantee that the next person will be so conscientious? Even a small number of "outside" samplers can cause havoc, and have done so in some instances. This is not a case of wanting the entire playing field for ourselves. Unless a researcher has a comprehensive view of how caves relate to their geologic setting—which can be gained only by a lengthy study of the caves and their surrounding karst—the results are worthless.

However, among ourselves, we must recognize the importance of cave exploration. Without it, the various karst sciences would still be in the dark ages. Many scientists made the first steps toward their careers as cave explorers. Let's not abandon our roots. Karst researchers who disparage exploration have lost an important part of their heritage.

There is a growing tendency, particularly in the geosciences, to minimize field work. Industry and consulting firms realize that time is money, and there is no more time-consuming process than field work. As a result, employees are asked to solve problems with computer models, remote sensing, and legal maneuvers rather than by direct field observation. The quality of their work suffers enormously. This problem is most serious among traditional groundwater hydrologists, most of whom know appallingly little about karst, as a glance through any modern textbook on groundwater will show. One groundwater hydrologist acquired an international reputation as a karst specialist without ever visiting a cave! Needless to say, few of his contributions have stood the test of time. Caves control the development of a karst landscape, and without their service as underground drains, most surface karst features could not exist. A personal knowledge of cave patterns and their hydrologic function is essential to the full understanding of karst. And only by mapping and exploring (or working closely with explorers) can one appreciate the full significance of a cave's layout. Exploration of caves beyond their normally accessible limits has yielded some of the most scientifically important discoveries, such as Jewel, Lechuguilla, and Movile Caves. As a result, cave science is no longer restricted to improved trails in show caves. Microbiologists and geochemists are now buying wetsuits and honing their vertical skills in order to visit important field sites in caves.

But cave exploration and mapping are not real science, are they? Let's take a closer look. As we explore a cave, we must review the basic ideas of how the cave is put together. This does not always bear fruit, and on the other hand there are many examples of blind luck. But the process of thinking about where the cave might go — whether or not it actually cooperates —is one of the most fundamental kinds of scientific inquiry! It requires a synthesis and an understanding of what is already known, and a projection of that information into unknown territory. This requires fundamental ideas about how a cave forms. New discoveries demand new ideas to explain them. Such hypotheses are tested in the field, often at great labor. The success or failure of the explorer-researcher cannot be exaggerated or hidden by technical jargon. During my thesis field work in Indiana, I spent a great deal of time with local cave explorers who were still in high school. It was a memorable experience to hear them debate among themselves the developmental history of the caves they were exploring. Without realizing it, they were spontaneously turning into scientists. This is fairly simple science, to be sure; but can anyone deny that it lies at the heart of the scientific method?

Most scientists dwell at the cutting edge, where the action is. Unfortunately, public support for science has withered in recent decades, despite widespread alarm about diminishing standards in our schools, because the link between science and the common welfare is no longer clear. Ironically, the need for decisions based on scientifically sound reasoning has never been greater. The bridge between science and the public must be repaired, and the easiest way is to communicate the thrill that was so apparent in those Indiana teenagers.

One of the greatest problems in selling karst to the outside world is the remarkably poor public understanding of what caves are really like. There is plenty of cave information available, but most people cannot find it when it is needed. In an ideal world, those faced with a karst problem would simply turn to Speleologists in the Yellow Pages. Instead they try to solve the problem themselves simply because they are unaware that such talent even exists. Will they know enough to reach for the *Journal of Caves and Karst Studies*? That is unlikely. But if the *Journal* encourages even a few more explorers to take that extra step in the direction of science, there will be that many more voices of authority speaking up when decisions must be made about land use and environmental problems in karst.

I recommend the following. Give the *Journal* a greater focus on the basic description of caves and their setting. Imagine the value of articles that describe the basic layout, physical setting, and biology of the major caves of the US, written in language accessible to all readers. Aspects of cave exploration can be included if their link with science is clear, or if they provide significant historical perspective. In the same spirit, the dynamic aspects of science should be emphasized by opening the *Journal* to another kind of exploration — of controversial ideas, including debates of alternative viewpoints. This would require loosening the present format, but if such contributions are written authoritatively and submitted to peer review, they will actually increase the scientific value of the *Journal*. We can afford to do this, because the primary goal of the *Journal* is to benefit our own members. We may wish it to be widely recognized for its scientific content, but it is a specialized publication of limited circulation that can never attain the status of a mainstream professional journal. Instead, let it do what it is best equipped to do: bring science to the non-scientific public. Our members can help achieve this goal by contributing articles designed to appeal to a wide range or readers. The *Journal* will grow stronger as a result, and so will the link between cave exploration and research.

GEOLOGY OF A LARGE, HIGH-RELIEF, SUB-TROPICAL CAVE SYSTEM: SISTEMA PURIFICACION, TAMAULIPAS, MEXICO

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Sistema Purificación, a large cave system in the northern Sierra Madre Oriental of México, is developed in the middle Cretaceous Tamaulipas and overlying Tamabra Formations. The 400 m thick sequence of carbonates formed in a basinal to peri-platform environment north and northeast of the simultaneously developing, large carbonate Miquihuana Platform. The Tamaulipas Formation is stratigraphically underlain by shaly limestone, shale, sandstone, and conglomerate of the Early Cretaceous Taraises, the Late Jurassic La Caja, and the Late Jurassic La Joya Formations.

The cave system is within the west flank of the Huizachal-Peregrina anticlinorium, one of many large Laramide folds making up the Sierra Madre Oriental. Most of the lateral shortening within the carbonates was accommodated by slippage along décollement surfaces and abundant second-, third-, and fourth-order folds. Except along décollement surfaces, faults are rare and have separations of less than three meters. Steeply inclined joints mostly trend ~N5°W and represent axial plane cleavage resulting from Laramide folding.

The principal geologic factors controlling the development of the Sistema Purificación are the stratigraphy and structure of the area. Passages in the upper and lower cave commonly form along the intersection of joints and bedding planes, sub-parallel to the dip. The middle part of the cave is within a third-order, anticlinal-synclinal pair whose north-south trending axial surfaces are about 150 m apart. Passages are mostly developed sub-parallel to the axial surfaces where cleavage provides zones of permeability and enhanced conduit development.

The objective of this study was to determine the geologic controls on development of the Sistema Purificación, the longest known cave system in Mexico (Sprouse, 1992). Total surveyed length is 79.1 km, which places Sistema Purificación as the 6th longest known cave system in the Western Hemisphere and the 13th longest in the world (Gulden, 1992). The cave system has been described in numerous articles concerning the original exploration (Sprouse, 1977a, 1977b; Sprouse, Ubico, & Cavanaugh, 1977; Treacy, 1979, 1980) and in the annual journal, *Death Coral Caver*, which covers cave exploration activities in the area and is published by Proyecto Espeleológico Purificación. Sixty-seven other caves have been explored within the area of this investigation.

Sistema Purificación is developed in a thick carbonate section within the front range of the Sierra Madre Oriental. The rugged area, approximately 50 km northwest of Ciudad Victoria (Fig. 1), rises two kilometers above the coastal plain. Presently, the total mapped depth of 955 m makes this cave the seventh most vertically developed system in the Western Hemisphere.

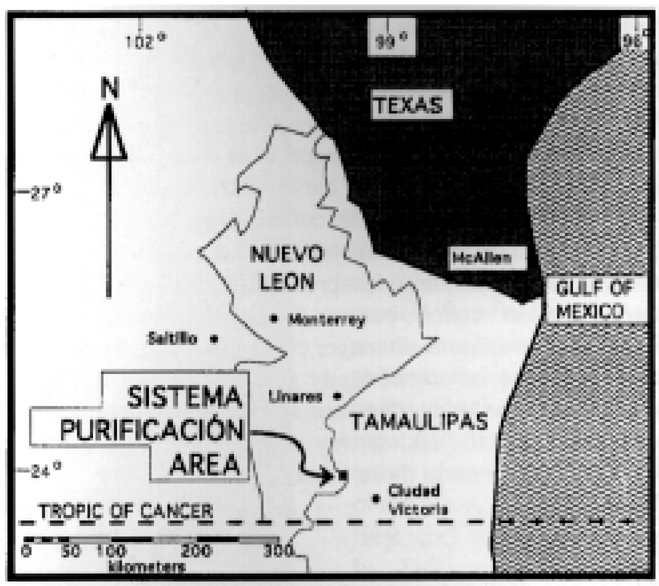

Figure 1. Location map of the Purificación Area.

STRATIGRAPHY

INTRODUCTION

The total stratigraphic section of the study area is approximately 800 m of marine sedimentary rocks, mostly carbonates. Shaly limestone, shale, sandstone, and conglomerate make up the oldest unit, the Upper Jurassic La Joya Formation. The Upper Jurassic La Caja and the Lower Cretaceous Taraises and Tamaulipas, consisting of basinal limestone and shale, overlie the Ja Joya. The youngest rocks are overbank deposits of the

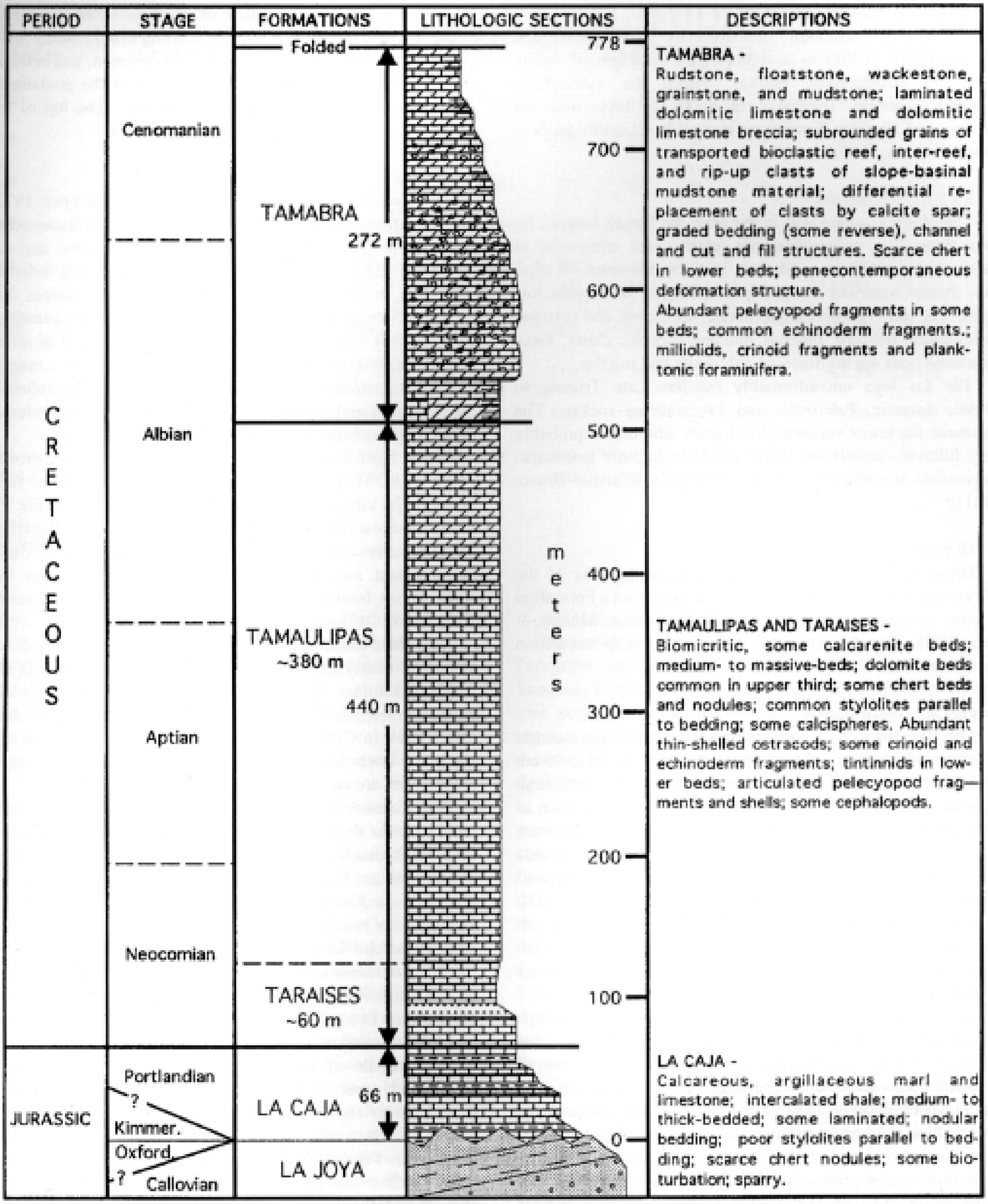

Figure 2. Generalized lithologic section and age boundaries near Conrado Castillo, Tamaulipas, México. Fossil identifications and stage divisions are based on work by Atkinson (1982).

middle Cretaceous Tamabra Formation (Fig. 2).

The Otates Formation, described by Enos (1974) and Carrillo-Bravo (1961) as a well-defined, widespread, easily mappable stratigraphic marker within the Tamaulipas sequence, is absent. The entire calcareous section between the Taraises and Tamabra Formations is considered in this paper to be the Tamaulipas Formation.

La Joya Formation

The oldest exposed unit in the area, the Upper Jurassic La Joya Formation, is a calcareous, clastic unit composed of shale, shaly limestone, sandstone, and conglomerate. It typically forms steep but not precipitous slopes, with some low cliffs. The red to purple conglomerate, sandstone, and siltstone beds contain siltstone, igneous, and metamorphic clasts. Gray limestone beds are argillaceous calcilutite and micrite.

The La Joya unconformably overlies Late Triassic to Middle Jurassic, Paleozoic, and Precambrian rocks. The sequence thickness varies and is locally absent. It probably only filled in depressions in the pre-Late Jurassic landscape. Deposition stopped early in the Oxfordian (Carrillo-Bravo, 1961).

Olvido and Zuloaga Formations

Upper Jurassic carbonate and evaporite deposits of the Olvido and Zuloaga Formations overlie the La Joya Formation in some canyons to the east and southeast (Mixon, Murray, & Diaz, 1959; Carrillo-Bravo, 1961) but do not crop out within the study area.

La Caja Formation

The 70 m thick, Upper Jurassic La Caja Formation consists of calcareous shale and shaly limestone. Beds are 10 to 50 cm thick with ubiquitous, poorly developed stylolites. Although the unit is similar to the age-equivalent La Casita Formation as described by Carrillo-Bravo (1961) in Cañones Esperanza, Rosario, and Olmo, it is called the La Caja Formation in this report because of its low clastic content, low-energy depositional characteristics, and basin facies fossils (Imlay, 1943). Tan to steel-gray micrites are commonly altered to pink or yellow. Vugs and fractures, largely filled by sparry calcite, are common. Pyrite grains and small, sparse nodules of chert are throughout the section. Iron from weathered pyrite probably causes the pink and yellow color of the altered rock. The calcium-magnesium ratio of 23:1 in one sample represents the presence of some dolomite (Table 1). Ferrous carbonate in solid solution with the dolomite is another potential source of iron. Approximately 17% of the sample was insoluble in hydrochloric acid and consisted of quartz, pyrite, chert fragments, and clay.

A broken topography of steep slopes and cliffs is formed by the alternating calcareous shale and limestone. Shale beds form slopes that are commonly covered by soil. A 20 cm thick bed of fissile, non-calcareous (probably bentonitic) shale is about six meters above the base of the unit. In the upper half of the formation, wavy to nodular bedding is moderately well-developed. Shale and stylolites are less common, and bedding is more clearly defined within five meters of the gradational upper contact with the Taraises Formation. The top of the highest wavy bed marks the top of the La Caja.

Taraises and Tamaulipas Formations

The Neocomian-Aptian Stage limestone (Gamper, 1977) between the La Caja and Tamabra Formations is discussed as one unit in this report. The Otates is not present and the Taraises and lower Tamaulipas Formations are mostly indistinguishable in the field. The 380 m thick Tamaulipas and Taraises Formations comprise limestone and minor quantities of shale that represent a long, uninterrupted period of quiet, basinal deposition. The limestone is predominantly a micrite with some calcilutite in the upper Tamaulipas. Microfossils are abundant and compose as much as 90% of the volume. Upper beds contain large fossils and fossil fragments.

Some beds in the lowest 50 m of the section are mostly black shale. They are best exposed and thickest on the road between the villages of Galindo and Conrado Castillo (Fig. 3). Laminated black shale and siltstone beds with a total thickness of eight meters also form a slope southeast of Galindo. Fossils are abundant, including bivalves and possible fish scales, but there is no bioturbation. This is apparently the Taraises Formation.

The shale interfingers with a sequence of alternating black shale and nearly pure limestone only three kilometers to the south of Galindo. To the northwest, the shale sequence is less than one meter thick west of La Curva and less than one-half meter thick in Cañon los Hervores. Common shale partings are in the lower half of the Tamaulipas Formation throughout the area but are rare in the upper half of the formation.

The Taraises Formation is a nearly pure carbonate unit, except for the shale beds. Samples contained only 5.2% insoluble (in hydrochloric acid) residue of chert, clay minerals, pyrite, rare quartz grains, and petroliferous material. Pyrite is ubiquitous and makes up between 1% and 2% of the volume. Petroliferous residue was present in all but one of the seven Tamaulipas and Taraises samples.

The calcium-magnesium ratio ranges from 140:1 to 100:1 in the Taraises and lower three-fourths of the Tamaulipas Formation. Two samples from near the top of the Tamaulipas had calcium-magnesium ratios of 8.5: 1 and 4.3:1.

The middle of the section locally contains calcarenite matrix with some rounded, micritic intra-clasts. The longest dimension of these intra-clasts is less than one centimeter. Large lithoclasts are reported in the middle section of the Tamaulipas Formation in Cañon de la Peregrina by Gamper (1977). She interpreted them as "evidence of a tectonic episode in the area". The isolated and apparently discontinuous distribution of these breccias along the edge of the developing reefs is more likely the distant products of turbidite

Table 1. Chemical Analysis of Rock Samples from the Sistema Purificación Area as Determined by Atomic Absorption.
(elements in ppm)

SAMPLE	LOCATION	Fe	Mg	Ca	Na	K	Mn	Al	Cu	% Insoluble	Ca/Mg
75aP	Tamabra calcarenite	650	33000	320000	210	140	45	4	3	6.5%	9.7:1
54P	Tamabra sand	590	64000	290000	330	180	83	4	5	7.7%	4.5:1
24P	Tamabra breccia	790	92000	240000	200	68	160	4	4	7.7%	2.6:1
66P	Tamabra breccia	930	110000	210000	240	110	170	4	3	9.0%	1.9:1
75P	Tamaulipas	550	2900	350000	230	50	63	4	4	9.7%	120:1
56p	Tamaulipas upper	470	34000	290000	160	48	100	4	4	13.5%	8.5:1
72aP	Tamaulipas breccia	6900	63000	270000	220	80	160	4	3	8.4%	4.3:1
79bP	Tamaulipas lower	1200	2700	270000	160	110	76	4	4	15.5%	100:1
26P	Tamaulipas lower	460	2600	370000	102	140	80	4	1	5.2%	140:1
40P	Taraises	3700	2500	350000	140	100	170	4	1	12.0%	140:1
PEP14	La Caja	3700	13000	310000	330	160	460	4	4	16.8%	23:1

Analytical technique - Atomic Absorption
Hydrochloric acid used to dissolve samples

flows derived from the incipient Miquihuana Platform (Fig. 4).

Bedding in the Tamaulipas ranges from thick to massive. Stylolites are well-developed, common, and have amplitudes up to ten centimeters. Most, though not all, stylolites are parallel to bedding. Vugs and fractures, particularly in the upper Tamaulipas, are commonly filled by sparry calcite cement. Depositional ripple marks on tops of beds are rare.

Chert nodules are common throughout the section. Most are black, although creamy white chert nodules are exposed in one bed near the middle of the formation south of the village of Desmontes. Near the top of the Tamaulipas, along the road between Galindo and La Canoa, there are ellipsoidal nodules of black and white, coarse-grained calcite about ten x seven x seven centimeters. One nodule has a small nucleus of black chert. The nodules of calcite are probably related to the development of chert nodules in the limestone. Similar occurrences have been interpreted by Lancelot (1973) and Waisley (1978) as forming by penecontemporaneous diagenetic replacement of calcite by silica and dolomite early in the burial history.

Rillenkarren, zanjones, solution pockets, and other karstic features are common in the middle and upper beds of the Tamaulipas Formation. They are prevalent in dolomitic beds near the top of the formation. However, there are no known cave entrances in the upper part of this Formation. Although much of Sistema Purificación is within the Tamaulipas Formation, the Cueva de Infiernillo is the only one of the system's twelve known entrances that is in the Tamaulipas. Two small caves with less than 100 m of passage each are the only other known caves within this formation (Hose, 1981).

Tamabra Formation

The middle Cretaceous limestone in the Huizachal-Peregrina anticlinorium has been called the Tamaulipas Superior, Tamaulipas, and Cuesta del Cura Formations by various workers. Although a breccia has been locally recognized between the El Abra Formation and the basinal limestone to the east, previous investigators have not identified this unit as the Tamabra Formation.

In the Purificación area, the youngest unit is a thick sequence of autochthonous mudstone, massive allochthonous channelized debris flow deposits, bedded allochthonous debris flow deposits, and turbidity current deposits composed of dolomite and limestone. These rocks are considered a part of the Tamabra Formation in this investigation. Modifying the definition provided by Barnetche and Illing (1956), the Tamabra Formation is defined as, "a dominantly bioclastic-lithoclastic limestone-dolomite sequence that underlies the Agua Nueva limestone and shale and laterally merges away from the Cretaceous platform into the basinal Tamaulipas Superior or Cuesta del Cura Formation."

The contact between the Tamaulipas and Tamabra Formations is always sharp, conformable, but slightly uneven. Channels, filled with clastic Tamabra carbonates, cut into the underlying limestone.

The top of the Tamabra Formation has been removed by erosion throughout the area making the original thickness indeterminable. A measured section in the village of Conrado Castillo is 272 m thick, probably close to the maximum thickness within the Purificación area (Atkinson, 1982). Lateral

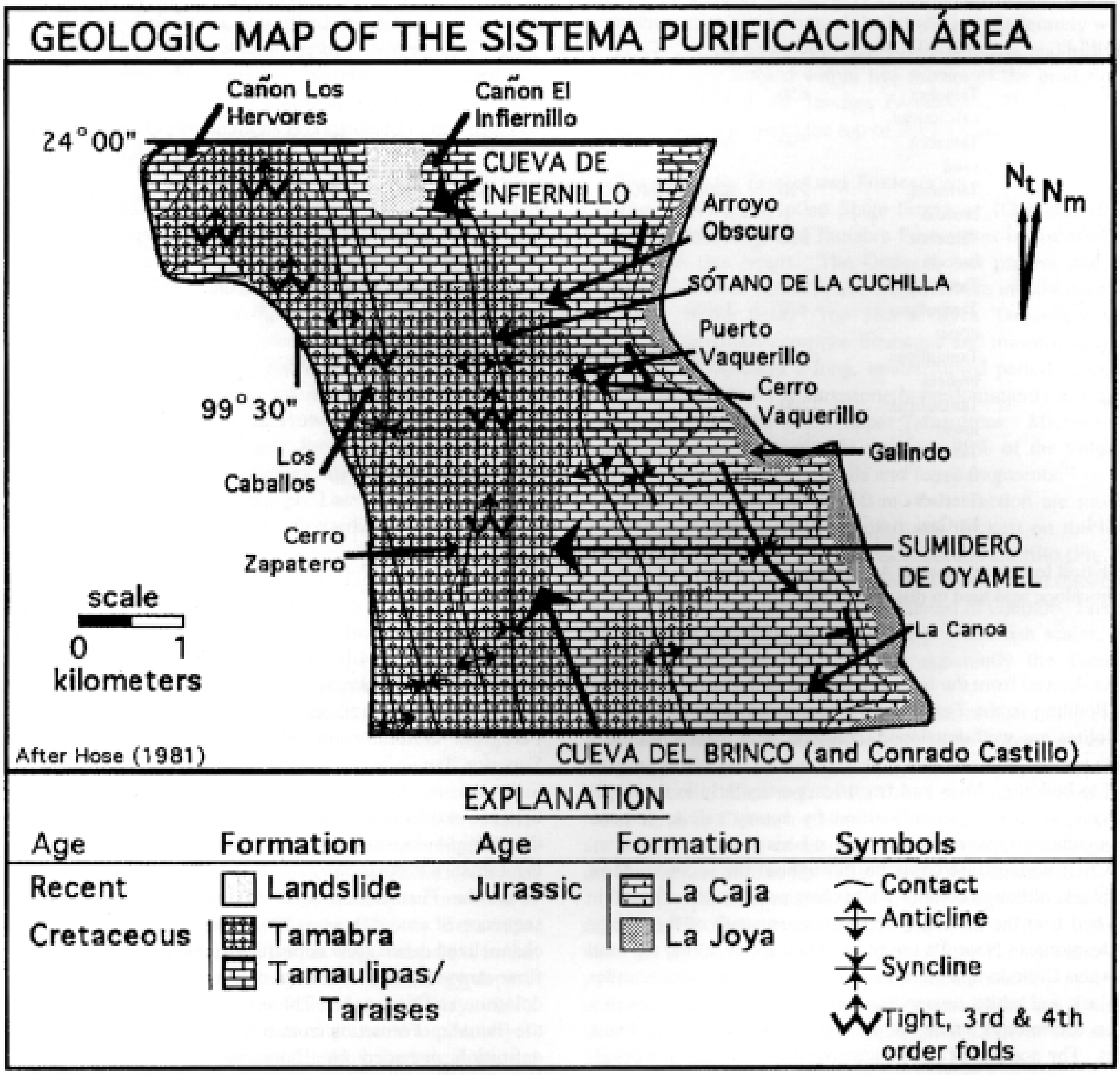

Figure 3. Geologic map of the Sistema Purificación area.

variation within the formation is dramatic. In Conrado Castillo, the lowest 100 m is a sequence of predominantly tabular and laterally discontinuous calcirudite beds. Channels, cut and fill structures, rip-up clasts, graded bedding, and sole-marked surfaces (Fig. 5) indicate that at least some of these beds are products of turbidity currents. Open framework, random orientation of clasts, and contorted bedding in some breccia layers indicate deposition as massive channelized debris flows.

The longest dimensions of the equant to tabular clasts range from one centimeter to one-and-a-half meters. They are predominantly sub-rounded but range from sub-angular to rounded (Fig. 6). Imbricated clasts, soft sediment deformation, and channel geometry of the calcirudite beds indicate a southern source.

Clasts were derived from two terrains. Many contain rudists and other bioherm material from the carbonate platform (Atkinson, 1982). Others are intraclasts of calcarenite and cal-

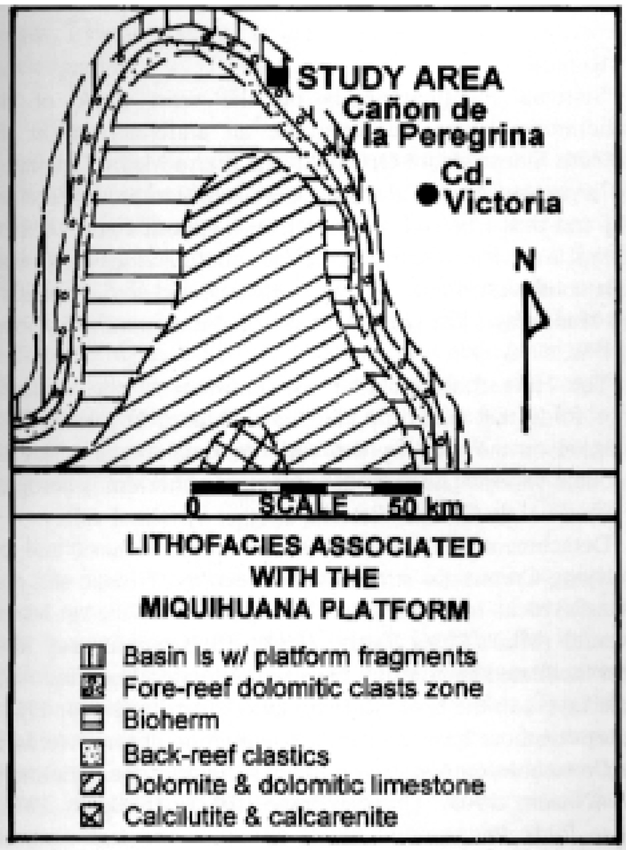

Figure 4. Lithofacies of middle Cretaceous units associated with the Miquihuana Platform. After Carrillo-Bravo (1971).

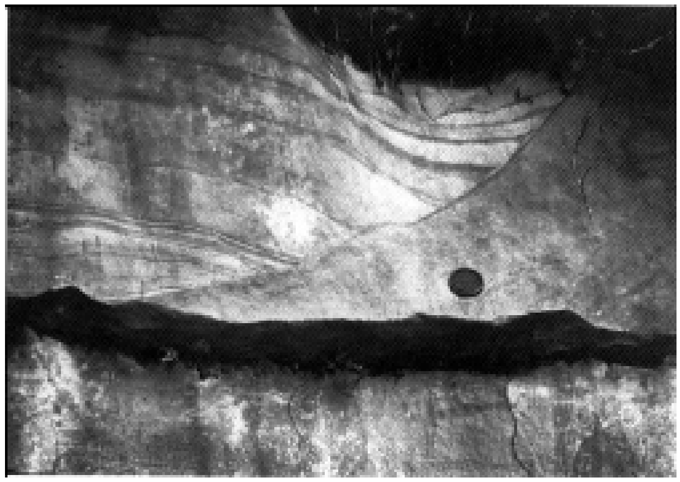

Figure 5. Channel structure in the Tamabra Formation.

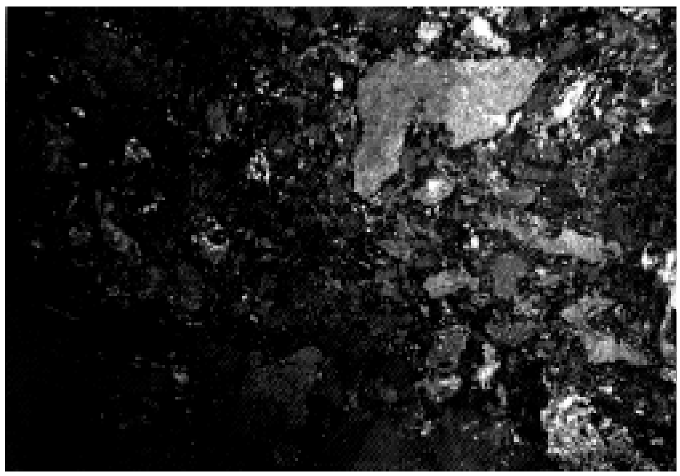

Figure 6. Breccia unit in the Tamabra Formation.

cilutite, similar to the surrounding matrix and the channel walls. Relative solubility of the clasts and matrix varies. On some weathered surfaces, clasts form positive features relative to the matrices but mostly the clasts are negative features or there is no change in relief at the clast-matrix contact.

Medium to massive calcarenite beds with thin laminations commonly form channel walls in the lower Tamabra. Calcirudite beds are missing in the northern parts of the area and only calcarenite beds overlie the Tamaulipas Formation. The upper Tamabra Formation is dominantly calcarenites. Channel structures, crossbedding, and graded bedding, locally topped by micrite and minor shale, are common. Contorted beds of calcarenite (soft sediment deformation) are associated with the channelized breccia.

The constituents of the calcarenite beds are sub-angular to rounded, but predominantly sub-rounded. Pressure solution along grain contacts in some samples has caused slight molding of the grains. Microfossils are prevalent in many samples, although fragments of megafossils compose more than 80% of some channel fillings. Rip-up clasts are also common in some channels.

The Tamabra Formation is mostly composed of dolomite and dolomitic limestone with mostly low calcium-magnesium ratios. Breccia beds in the lower part of the formation are strongly dolomitic with a calcium-magnesium ratio of 1.9:1. Insoluble residue ranges from 6.5% to 9.0% and is composed of clay, chert, and, in most samples, a large amount of petroliferous material with minor quartz and pyrite. Clay is prevalent at the top of graded beds, as fillings along fractures, and along stylolites which are often poorly developed in the calcirudite and calcarenite beds. Black chert, in beds up to 12 cm thick and in nodules from one millimeter to tens of centimeters in their longest dimension, is abundant in the calcarenite beds. The calcirudite beds contain minor amounts of black chert nodules. Silica within the chert is commonly mixed with abundant dolomite rhombs.

White rhombs of calcite are prevalent in the calcirudite as vug and fracture fillings, and clast replacements. Similar but less conspicuous recrystallization is also present in the Tamabra calcarenite and the highest beds of the Tamaulipas

Formation. Calcite rhombs are more resistant to dissolution than their surrounding material and, on the walls of the Historic Section of Cueva del Brinco, they form small positive features in the rooms formed by phreatic dissolution.

Contemporaneous chert and dolomite precipitation in an environment with organic decomposition products, followed by dedolomitization is congruent with the evidence from the Tamabra Formation. All analyzed samples that contained calcite rhombs were petroliferous and had abundant dolomite.

Pelagic caprinids in the Tamabra Formation confirm a basin or basin-margin depositional environment (Atkinson, 1982). The steep-sided Miquihuana Platform provided high relief a few kilometers to the south and west during the middle and Late Cretaceous. The bioherm probably accreted rapidly upward on a pre-existing topographic high, such as a horst proposed by Belcher (1979). Along the edge of much of the carbonate platform, the Tamabra Formation formed from debris flows and turbidity currents that carried material from the oversteep platform slopes into the surrounding basins (Carrillo-Bravo, 1961, 1971; Enos, 1974). The calcirudite is the product of both channelized turbidite flows and massive channelized debris flows derived from the shallow-water platform. The coherent clasts indicate that the source terrane had been at least partially cemented before the Tamabra Formation was formed. Submarine cementation of the rocks of the Miquihuana Platform has been documented by Enos (1974). However, differential cementation may have contributed to the building of a steep-sided, but unstable, platform.

While much of the material derived from the shallow-water platform was carried down submarine canyons and formed calcirudite, some fine-grained material was deposited on submarine overbanks and outwash plains, resulting in calcarenite beds. Channels filled with overbank deposits after the flow was pirated upstream. Stream flow sometimes returned to the original channel. This channel evolution is represented by dramatic changes in the section from calcirudite to calcarenite, and vice versa. Calcilutite deposits throughout the section are the result of quiet basinal deposition between turbidity and debris flows.

The Tamabra Formation tends to form slopes. Dolomitic breccia forms local karst grike and kegelkarst fields with little or no soil cover. Insoluble and impermeable bedded chert in the calcarenite often causes subterranenan water to flow to the surface. However, each stream returns underground within one hundred meters of flowing onto the Tamabra terrain.

Eleven of the 12 known entrances to the Sistema Purificación and nearly all of the known caves in the study area are in the Tamabra Formation. Most of the caves have developed along bedding planes, gradually gaining depth. However, Pozo Obscuro, a 120 m deep pit, and Sótano de la Cuchilla, which drops 164 m in a traversable distance in only 400 m from the entrance, are also developed in the Tamabra Formation.

STRUCTURE

REGIONAL

Sistema Purificación is on the west flank of the Anticlinorio Huizachal-Peregrina, an anticlinorium in the northern Sierra Madre Oriental. The Sierra Madre Oriental is the largest segment of the early Cenozoic (Laramide) foreland fold and thrust belt of southern North America and northern Central America. The range extends south and southeastward from southwest Texas, through Chiapas, and into Guatemala and Honduras. The general trend of the mountains is about N14°W.

The Huizachal-Peregrina anticlinorium is one of many large folds that make up the Sierra Madre Oriental. It is bounded on the west by the Valle de Jaumave, an elongate, synclinal valley. The east side of the anticlinorium is bordered by Sinclinal de Ciudad Victoria, another synclinal valley.

Detachment surfaces between the Upper Jurassic and the overlying Cretaceous strata and between the Triassic and pre-Triassic rocks are common throughout the Sierra Madre Oriental (Muir, 1936; Tardy, 1980). Separations may have been facilitated by gypsum beds in the Olvido Formation and shale layers in the La Joya Formation (Carrillo-Bravo, 1961). Various authors have recognized numerous chevron folds in the Cretaceous carbonates on the east flank of the anticlinorium (Nason, 1909; Carrillo-Bravo, 1971; Conklin, 1974). These folds are reported to be smoother and less common towards the synclinal axis. The frequency of folding also reduces with depth, indicating the importance of bedding detachment surfaces (Carrillo-Bravo, 1961). Folding on the gentler west flank had not been recognized prior to this study and the Cretaceous rocks had been assumed to dip uniformly to the west (Conklin, 1974).

Belcher (1979) documented a horst within the core of the anticlinorium. The western boundary of the horst is about one kilometer east of Conrado Castillo and Cueva de Infiernillo. He proposed that local horsts developed between the Late Permian and Middle Jurassic and acted as buttresses that interrupted tectonic transport of allochthonous strata during the Laramide Orogeny. Folds on top of positive elements are broad and low amplitude, reflecting the local absence of thick, incompetent sequences below the Aptian-Albian limestone. Although the Cretaceous rocks were folded and uplifted up to 3000 m, few faults are recorded in these younger rocks. Folding apparently accommodated most of the lateral shortening.

STUDY AREA

Located on the western flank of the Huizachal-Peregrina anticlinorium, the overall dip of the beds is to the west. Faults oblique to bedding are rare and typically have separations of less than three meters. Faults along bedding planes are common and the offsets are not known. Décollement surfaces in the carbonates formed during the Laramide Orogeny, accommodating lateral shortening by folds and bedding plane slippages. Folds and joints are important factors influencing speleogenesis.

FOLDS

Folds in the area are spectacular and abundant. Concentric folds with amplitudes of up to 250 m are accompanied by tight chevron, similar, and disharmonic folds. The average hinge line trend of most major folds, as well as most small folds, is N6°W ± 2°. Axial surfaces mostly verge towards the east.

A lineament from Los Caballos through Cañon El Infiernillo marks a dramatic change in the abundance and type of folds. To the east, folds are rare and, generally, concentric with shallow-dipping limbs. West of the lineament, folds with steeply dipping limbs are common and have variable styles, including concentric, similar, disharmonic, and chevron.

Second-order fold - Sinclinal de Infiernillo

The fold that most influences speleogenesis is a second-order syncline, Sinclinal de Infiernillo. Its axis trends about N8°W, one kilometer west of Conrado Castillo. The Infiernillo syncline is continuous along the entire north-south extent of the known cave system and through the Tamabra, Tamaulipas, and most, or all, of the Taraises Formations. It caused the sumps in Cueva de Infiernillo by perching water above underlying, impermeable beds, and probably has prevented further westward development of Sistema Purificación.

Third-order and fourth-order folds

Most of the other folds in the area are parasitic folds associated with the Infiernillo syncline. Third-order folds were caused by upwardly increased compressive stress along the limbs and near the axial surface of this major syncline. Most of the folds decrease in amplitude with depth, some terminating in the lower beds. A large, third-order fold to the east is an anticline that trends about N8°W and terminates at Cerro Vaquerillo to the north. The fold has acted as a drainage divide for subterranean flow to the upper parts of the Sistema Purificación. East of Conrado Castillo, the west limb of the fold has an amplitude of about 200 m.

The next major fold to the west is a syncline that trends about N4°W through Conrado Castillo and along Cuchilla El Angel, the ridge west of Arroyo Obscuro. The east limb has a moderate dip, averaging between 20° and 30° to the west. The axial surface dips steeply to the west. The west limb is steeply dipping to vertical, and is terminated by a similar trending anticline that passes through Cerro Zapatero. The west limb of the anticline is gentler than its east limb, with an average dip between 35° and 45°. The amplitude between these folds is about 250 m near Conrado Castillo and about 150 m below the La Curva-Los Caballos road, terminating at about 1200 m msl along a décollement surface (Fig. 7).

Small, fourth-order folds near synclinal axial surfaces of the higher order folds are common. They crop out at higher

Figure 7. Looking south at the head of Cañon El Infiernillo. The World Beyond and Dragon River have formed along the axial cleavage of the syncline in the major third-order synclinal-anticlinal fold pair shown in the upper central part of the photograph. The crest of the anticline is exposed in the Monkey Walk. The Cueva de Infiernillo entrance is prominent near the center of the photo.

elevations in the Tamabra Formation and die out with depth. Sótano de la Cuchilla has excellent exposures of these localized structures. Chevron folds formed in the alternating beds of chert and limestone. Joints are also well-developed near the axial surfaces. There are minor folds with little linear extent on the east limb of the syncline that terminate downward along décollement surfaces.

Ubiquitous third- and fourth-order folding along the west limb of the Sinclinal de Infiernillo is well-exposed in the west walls of the El Infiernillo and los Hervores canyons (Fig. 8). These east-verging folds have steeply dipping limbs and axial surfaces. Hinge lines trend parallel or sub-parallel to the major syncline. Some folds are concentric or chevron, but similar and disharmonic folds are more common in the nearly isotropic Tamaulipas Formation.

The amplitudes of the folds in the western part of the area range from less than one meter to about 100 m. Regional dip is to the east. Almost all axial surfaces strike between N15°W and N5°E and dip steeply to the west, although some dip to the east. Some of the folds can be traced down to décollement surfaces. Others terminate in manners that are most readily explained by slippage along bedding planes.

Geologic Factors Controlling Folding

The eastern edge of the Laramide Thrust Belt is approximately 20 km west of the cave (Tardy, 1980). A scarcity of faults in this intensely folded region and the presence of disharmonic, similar, and chevron folds are evidence that the rocks responded plastically during folding. Apparently, the stress that caused large thrust faults to the west was accommo-

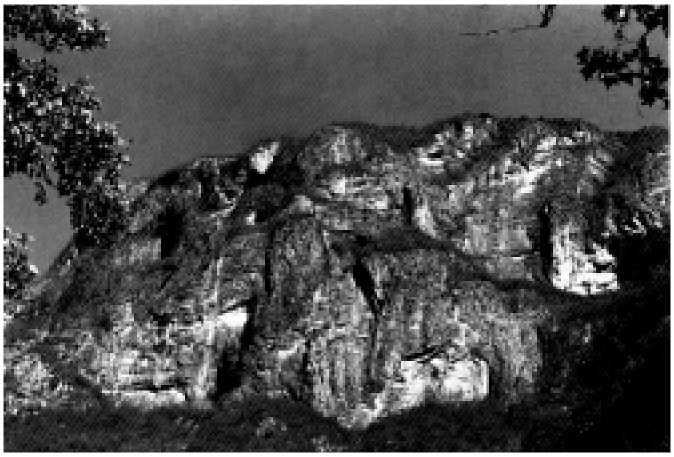

Figure 8. Disharmonic folds in the Tamaulipas Formation in Cañon los Hervores.

Figure 9. Looking northeast into Cañon Los Hervores showing the two structural regimes in the Sistema Purificación area. The cave system and all other large caves are in the nearly homogeneously west-dipping limestone beds on the right of the photo. No large (longer than 100 m) caves are known in the tightly folded limestone on the left of the photo.

dated by folding and bedding plane slippage in the Purificación area. Since the Laramide Orogeny in northern Mexico began towards the end of the Cretaceous, the rocks may not have been firmly cemented. Also, Carrillo-Bravo (1961) reported that up to 1200 m of sediments were deposited over the top of the Tamabra Formation. The overburden pressure on these youthful rocks caused them to behave plastically and probably was responsible for the lack of faults in the limestone. However, the abundant joints parallel to the fold axes indicate that the stress did cause incipient axial cleavage planes that enlarged as stress was released and the overburden eroded. A few, small-separation faults are sub-parallel to these trends.

Lithology determined the type of folding that occurred. The Tamabra Formation has primarily steep-angle chevron folds due to its mixture of bedded chert and limestone. The chert beds acted as the more competent layer, determining the form of the folds. Similarly, chevron folds in the Taraises and lower Tamaulipas Formations resulted from limestone beds acting more competently and determining the style of folding while the thin shale interbeds plastically deformed, particularly near the hinge line.

Similar and disharmonic folds are predominant in the massive bedded upper Tamaulipas Formation. Individual beds were passive and the type of folding was not controlled by changes in lithology in this nearly isotropic limestone. Low-amplitude concentric folds also formed in the Tamaulipas.

Anticlines flatten with decreasing elevations until the structures are non-existent. The necessary adjustments were made by bedding plane slippages and plastic flow within the beds. Bedding plane slippage often occurred within shale layers, but many slippage surfaces are marked by calcite gouge between limestone beds.

There is a dramatic change in style and intensity of folding between the west and east walls of Cañon El Infiernillo that must represent some change between the areas, since both sides experienced the Laramide stress (Fig. 9). As the Cretaceous sediments do not appear to change from east to west, the difference apparently is at depth. Belcher (1979) has proposed that the Purificación area lies near the western edge of a north- or northwest-trending, Jurassic age horst. He recognized changes in fold styles with broad, low-amplitude folds over the proposed horst and tightly folded strata to the west and attributed the difference to a change in the underlying stratigraphic sequence. Thick sequences of Upper Jurassic evaporites and shale were deposited within the graben to the west but are thin or absent on the horst. Tight, high-amplitude folds formed over the incompetent strata within the basins. Where the Lower Cretaceous carbonates are in contact with the basement, transport of allochthonous beds was inhibited.

The Jurassic Olvido and Zuloaga Formations are absent in Cañon El Infiernillo and to the east of the study area, suggesting that the area was elevated during the Late Jurassic. However, Carrillo-Bravo (1961) reported their presence on the east side of the anticlinorium, southeast of the study area. The Olvido Formation is 100 to 160 m thick in canyons seven to 12 km east of the cave. Thus, the Olvido may thicken dramatically away from the paleo-high. The conspicuous change in intensity and style of folding in the Cretaceous limestone west of the canyon may indicate such a change in lithology at depth (Fig. 10).

Alternatively, if there is a horst in the eastern part of the area, the Olvido Formation may be absent and the carbonates moved over the La Joya and La Caja Formations. The change in folding style may be caused by a facies change in the La Joya. Sediments to the west, deposited closer to the Jurassic basin, may be finer-grained than those near the paleo-high. Evidence for such a facies change is provided by conglomer-

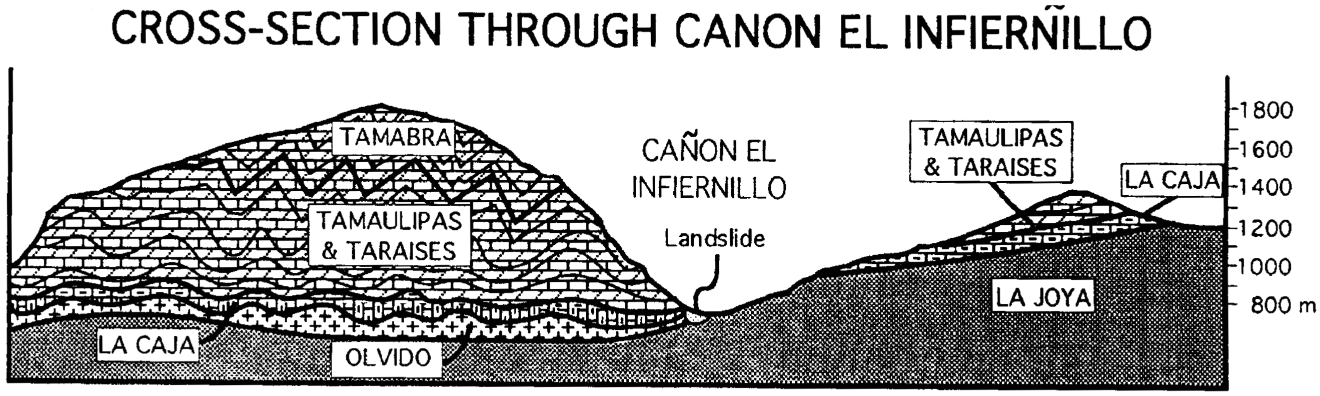

Figure 10. Cross-section through Cañon El Infiernillo.

ates with clasts up to 15 cm in diameter in the upper La Joya along the eastern boundary of the area but only shale, siltstone, and some sandstone are exposed in Cañon El Infiernillo. Finer-grained sediments to the west may have promoted transport of the overlying beds.

Either way, as described elsewhere in the Sierra Madre Oriental, the folds in the Cretaceous carbonates are probably formed above large décollement surfaces in the underlying Jurassic strata above thrust faults in the older rocks (Fig. 11).

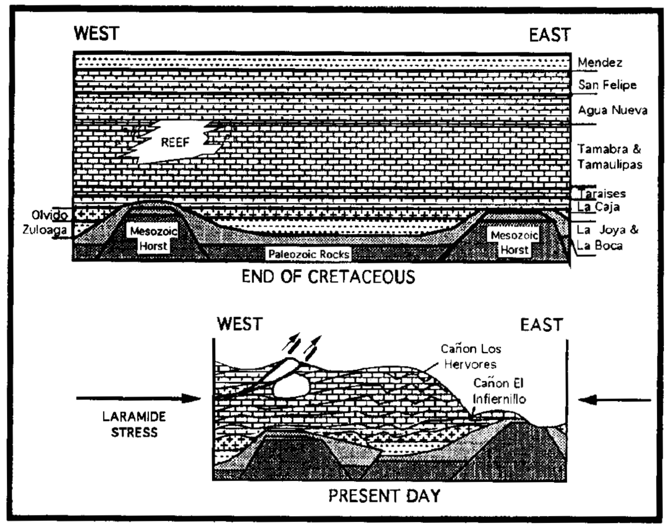

Figure 11. Schematic profile of Laramide folding.

Faults

During the extensive Laramide folding, much of the displacement of allochthonous units was along bedding planes. Slickensides between beds are common and are most frequently oriented about N78°E (Fig. 12). Faults, other than décollements, are rare. All observed faults that cut across beds have stratigraphic separations of less than three meters. In no case was the net displacement determinable. Most of the faults dip 70° to 85° and their strikes cluster around N9°W. The faults have both normal and reverse separations with some down on the east and others down on the west.

The largest fault has a gouge zone five to 50 cm wide and is within the Tamabra Formation. The trend of the fault is N86°W 84°S and the maximum stratigraphic separation is 2.95 m. Slickensides indicate that the most recent movement was strike-slip. If no vertical movement has occurred along this fault, the left-lateral displacement is 7.8 m. The fault is visible in the Historic Section from near the Brinco entrance into the Helictite Passage. The fault splits near the entrance of the Helictite Passage and one branch passes into the south wall of the Historic Section.

Several passages in the cave that are known to have developed along small displacement faults including the Carrot Tube and the 17 Hour Tube, two of the Confusion Tubes in Cueva de Infiernillo, and the Callisto Borehole. The fault in the 17 Hour Tube is a high-angle reverse separation fault with the south side up approximately 2.5 m. Most faults seem to have had no effects on either the surface or sub-surface morphology.

Joints

The thick and massive beds of the Tamabra and Tamaulipas Formations have been extensively fractured. Orientations of the two resulting joint sets cluster around N8°W and N85°E (Fig. 13), nearly parallel and perpendicular to the regional strike. The dips of most joints are perpendicular to the dip of the beds. Joints are abundant near the axial surfaces of the folds.

The joints developed along axial surfaces have influenced the speleogenesis. Most of the passages in the Sistema Purificación and Sótano de la Cuchilla are formed along joints. Many of the long, linear passages in the system, including the World Beyond, the Columbia, the Monkey Walk, and the Jersey Turnpike (Fig. 14), developed along joints that are near and parallel to axial surfaces. The highly fractured areas near the hinge lines are conducive to cave development.

The passage morphology within the system is also affected by the concentration and orientation of joints. Phreatic ceiling domes and wider passages have formed where two or more joints intersect. The largest room in the cave, the Netherhall,

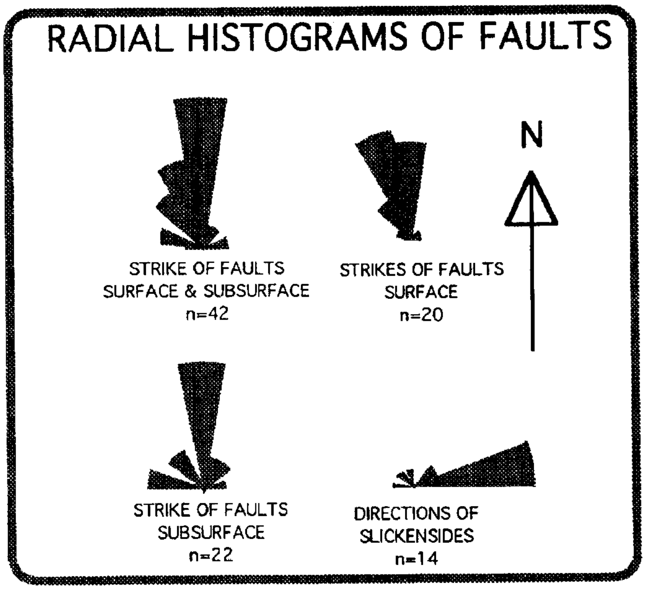

Figure 12. Radial histograms of faults in the Purificación area.

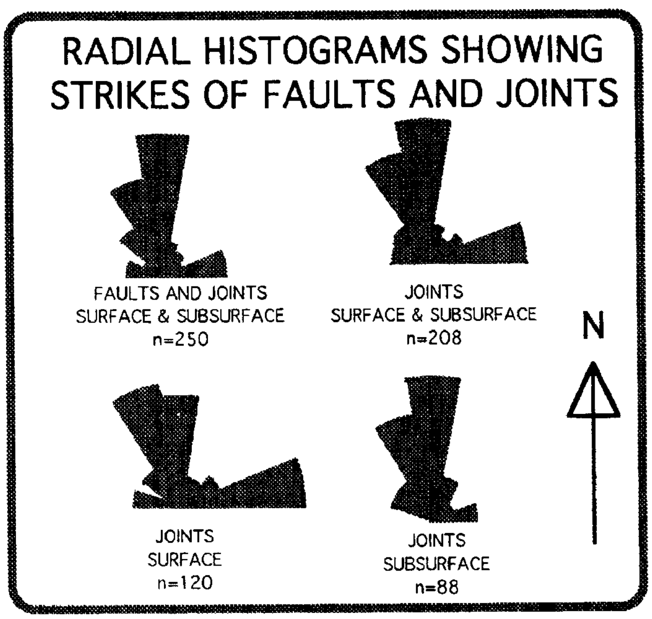

Figure 13. Radial histograms of tectonic features.

is forming by ceiling and wall collapse and solutional removal of the debris. The collapse process is aided by steep bedding and abundant joints. In addition to being weakened zones, joints and bedding planes provide voids in which gypsum develops and crystal-wedging is occurring (White & White, 1969).

Geomorphology

The local geomorphology resulted from combined actions of fluvial and karst erosional processes. Karst landforms that were produced dominantly by solutional processes mark portions of the Tamabra, lower Tamaulipas, and Taraises Formations, but fluviokarst, formed by both fluvial and solutional processes, is more abundant.

La Joya, La Caja, and Taraises Formations

The most striking feature of the terrain is the rugged topography. The La Joya Formation forms irregular contour patterns, often recognizable on aerial photos and topographic sheets. Because of the numerous springs near the top of the La Joya Formation, many small drainages have eroded deep into the hillsides below. The orientation of joints, a significant factor in the development of linear features in the overlying carbonate formations, gives less control of the erosion in the La Joya resulting in more rounded and irregular landforms.

In Cañon El Infiernillo, headward erosion has formed a waterfall, approximately 25 m high, at the La Caja-La Joya contact. A permanent stream, the resurgence from Sistema Purificación (Hose, 1996), emerges through the rubble at the base of the cliff. The waterfall is the result of water undermining the less resistant, underlying La Joya Formation by sapping at the spring and by the surface river waterfall during floods and the wet season. The more resistant La Caja limestone forms the cliff.

The calcareous shale and limestone sequence of the La Caja Formation forms steep, covered slopes broken by two to five meter high cliffs. Shallow dolines are the only karst features that have been noted in this unit. The overlying, shale-bearing Taraises has numerous springs and dendritic drainage patterns.

Tamaulipas and Tamabra Formations

Joints have greatly influenced the surface morphology, resulting in a rectilinear pattern of topography and drainage development within the cave-bearing Tamaulipas and Tamabra Formations. Cliffs in the Tamaulipas Formation have developed along joints and their development is associated with solutional activity within the joints. Surface drainages over these formations also follow the joint set trends, resulting in a rectilinear pattern of dry streamways. The canyon Arroyo Obscuro, the Puerto Vaquerillo saddle, and the cave entrances to Sumidero de Oyamel (Fig. 3) are formed along a prominent fracture. Although no offset is apparent, the lineament is conspicuous on aerial photographs and topographic maps and has dramatically affected the surface morphology.

The Tamaulipas Formation is a cliff-former. Canyons incised into the Tamaulipas Formation are steep-walled and broken by waterfalls. Cliffs are typically parallel to major joint trends. Shale in the lower part of the unit has contributed to slope failures. Groundwater moving through joints in the mas-

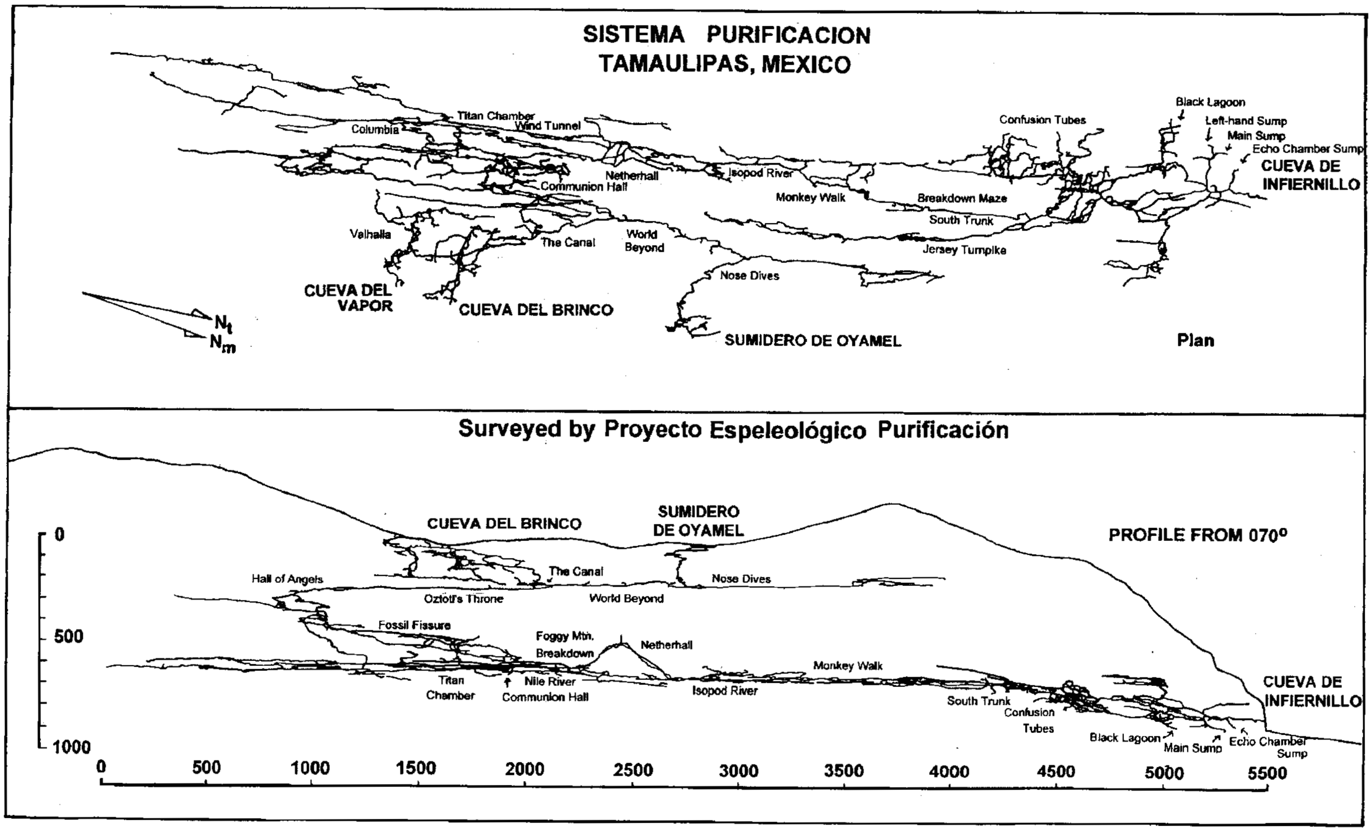

Figure 14. Plan view and profile view of Sistema Purificación.

sive limestone dissolves material along these fractures, enlarging them, until the water reaches the nearly impermeable shale layers. The limestone is undermined by the less competent shale beds and lacks lateral continuity because of the enlarged joints. This removal of support results in landslides occurring mostly in the lower half of the Tamaulipas.

The prominent cliff at the head of Cañon El Infiernillo resulted from similar processes (Fig. 7). Surface drainage south of the cliff enters the limestone through joints in the rock. These joints are enlarged by dissolution from the surface down. The shale beds and argillaceous limestone at the top of the Taraises Formation, which is immediately below the base of the cliff, weathers and weakens quicker than the Tamaulipas. This less competent rock below the massive limestone causes collapse of the upper strata along the solutionally enlarged and weakened joints.

Cañon El Infiernillo is notable because it lacks the usual permanent stream at the head of a blind valley (Jennings, 1971; Sweeting, 1973). Four springs flow from the Infiernillo cliff during flood conditions. Three of the springs, including the Cueva de Infiernillo entrance, issue from karst conduits partway up the cliff. The fourth spring, and the last to stop flowing after a flood, issues from rockfall debris at the head of the stream channel, below the Infiernillo entrance. This spring has probably assisted in the undermining of the cliff. The water from all of the springs has removed fallen debris as either chemical or clastic load. Since flood water quickly pulses through the underground system (Hose, 1996), water issuing from these springs may be undersaturated and capable of further dissolution of limestone.

During heavy rainfall, the local groundwater table fluctuates radically and rapidly . This change in the water level causes a rapid change in the hydrostatic pressure within the rocks, providing additional stress along fractures. An almost constant barrage of rocks, 70 cm in diameter and smaller, fell from the cliffs following a heavy rain in December 1979. The most active retreat of the cliff occurs during and immediately following voluminous rains. Recent large rock slide deposits in the canyon are further indications of the ongoing retreat of the surrounding cliffs (Hose, 1981).

Rockfalls of Tamaulipas limestone in the lower canyons are common even during the dry season. Four fresh, small rockfalls were seen in the normally dry segments of Cañones los Hervores and El Infiernillo in April 1980. Since large rivers flowed through these channels in December 1979, these four rockfalls must have occurred in the intervening four months. During a three-day visit to these canyons in April 1980, three separate rockfalls were heard. Since human visitation is rare and there are few grazing animals in the canyons, most of these rockfalls were probably unprovoked by people or domestic animals. Although these are technically "dry valleys" during most of the year (White, 1988), the lower canyons are actively enlarging and floodwater is carrying the fallen debris further downstream.

The upper one-third of the Tamaulipas Formation is dolomitic and less of a cliff-former. Karst features are more common than in lower beds. Enlargement of vertical joints in the massive carbonate rocks by dissolution from the surface downward formed bogaz or zanjones in the upper Tamaulipas Formation and Tamabra Formation (Cvijic, 1893; Monroe, 1964). The zanjones in the area are parallel trenches, about one to three-and-a-half meters wide, up to two meters deep and several tens of meters long with nearly vertical walls and a soil-covered floor. Some of the best developed zanjones cross the road between the villages of La Curva and Los Caballos. Rillenkarren and solution pockets are prevalent in the more dolomitic massive beds near the top of the Tamaulipas Formation.

The Tamabra Formation forms slopes with an abundance of karst features. Almost all of the known caves in the area and all but one of the known entrances to Sistema Purificación, are in this Formation. Dolines, both solutional and collapse, and pits up to 120 m deep are developed in the Tamabra. Grike fields and karst pinnacles are commonly developed in the dolomite units.

Present drainage is from the south and west. However, a small travertine deposit on the road one kilometer south of Puerto Vaquerillo contains well-rounded stream pebbles of reddish sandstone, apparently derived from the core of the anticlinorium to the east. After the thick carbonate section had been stripped along the axis, the Jurassic sediments were exposed above 2040 m, the elevation of the travertine deposit. Drainage, carrying clastic material from the east or northeast, passed through the Puerto Vaquerillo and flowed towards Conrado Castillo. Remnants of this ancestral drainage pattern are preserved in the travertine.

Geologic Factors Controlling the Speleogenesis

The principal geologic factors controlling the development of the Sistema Purificación are the stratigraphy and structure. Cave-forming affinities vary in the carbonate rocks. Portions of the heterogeneous Tamabra Formation are more susceptible to conduit development than others. The nearly homogeneous, thick-bedded Tamaulipas Formation resists passage development except along fractures. The poor conduit-developing characteristics of the underlying Taraises and La Caja Formations and the impermeable shale beds in the La Joya Formation change the manner of groundwater flow in the lower parts of the system.

Structure complements the effects of the stratigraphy. Most important are the folds and the associated fractures. One set of joints formed parallel to and near the axial hinge surfaces and the complementary set trends perpendicular to strike at approximately N85°E. The limestone above a décollement surface in the lower Tamaulipas is also fractured parallel to the trend of the folds and, thus, developed many conduits in the lower part of the middle cave. A few passages have formed along the trend of a fault. However, most faults exposed in the cave have caused only minor effects on passage development. No observed fault appears to have inhibited passage development.

The Upper Cave

The upper part of the known system is in the heterogeneous Tamabra Formation. Passage development was influenced by both lateral and stratigraphic changes, apparently facilitated in more soluble and/or permeable units, and tends to follow the intersections of preferred bedding planes and prominent joints. Although the passages are commonly developed along bedding planes, the cave drops to lower strata to the west until reaching the Tamabra-Tamaulipas contact (Fig. 15). The transition from the upper cave to the middle cave is along the contact at the Valkyrie River, The Canal, and the Nose Dives (Fig. 14).

The common joint sets in the cave are N5°W and N85°E, respectively parallel and perpendicular to the regional westward dip (Fig. 13). Many of the passages in the upper part of the cave follow joints along bedding planes and drop to lower beds along local fractures. As a result, the cave is generally deeper to the west. The main passage near the Brinco entrance is formed along a small fault that has a stratigraphic offset of approximately three meters. The fault zone apparently enhanced conduit development.

Permanent pools of water are formed in the trough of a third-order syncline including two near-sumps in the westernmost parts of the upper cave, The Canal and the Nose Dives. The water is perched on the less permeable Tamaulipas limestone. Fourth-order folds associated with this syncline have also influenced cave development in the Tamabra. Tin Can Alley is perched along the trough of a fourth-order fold. Chert beds up to 12 cm thick in the middle and upper beds of the formation act as hydrologic barriers. Chevron folds in Sótano de la Cuchilla, which is probably part of Purificación's hydrologic system, have fractured the chert, thus allowing water infiltration and cave development.

The Historic Section and Valhalla were formed when the phreatic base level was higher and the core of the anticlinorium was not exposed. As erosion continued and the water table dropped, streams flowed through the upper cave and deposited abundant flowstone. Small fragments of red siltstone cemented in travertine in Cueva del Brinco appear to be derived from the La Joya and, thus, represent drainage into the cave from the east when the La Joya was exposed at an elevation higher than 1900 m above present mean sea level.

The Middle Cave

Passages from the World Beyond and Dragon River to southeast of the Confusion Tubes are mostly long, nearly

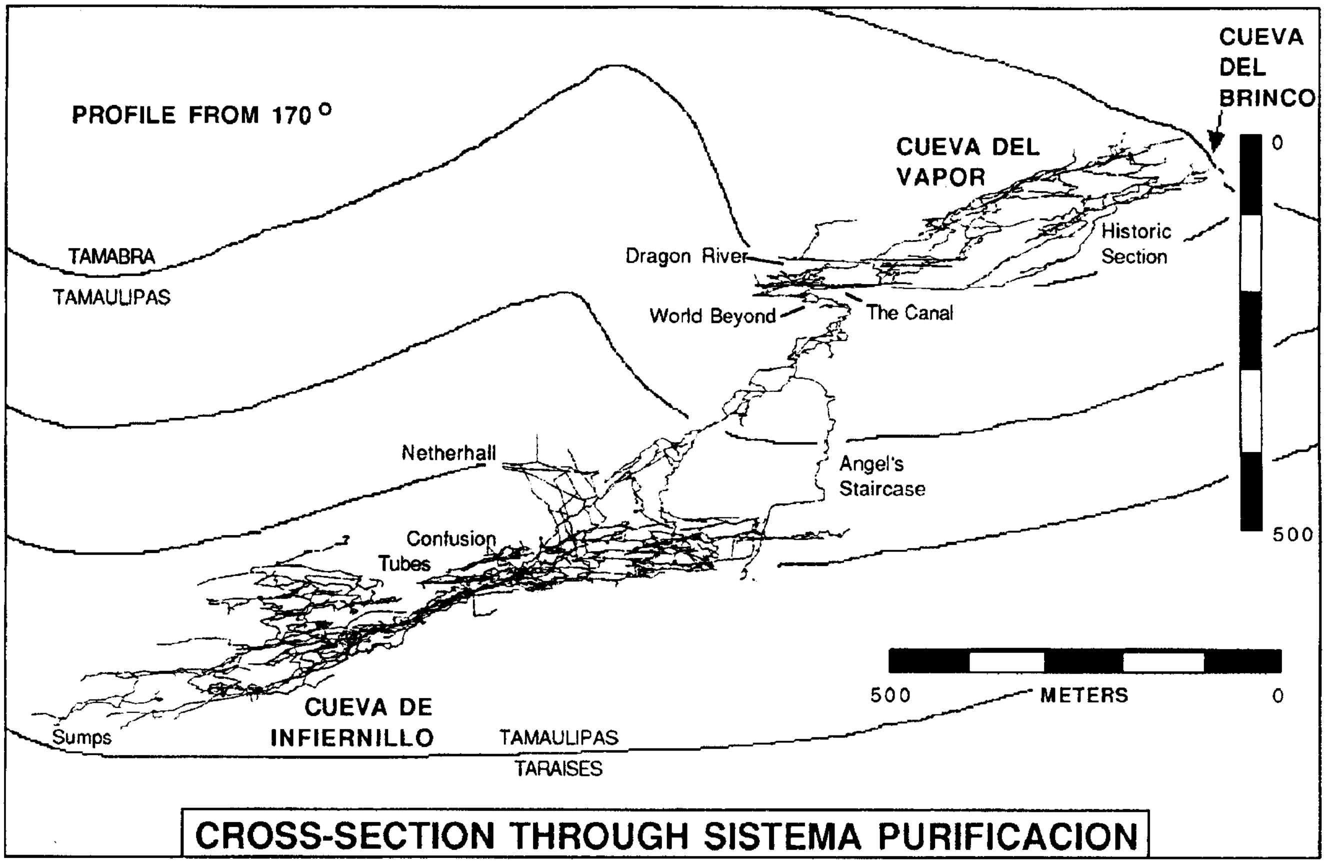

Figure 15. Cross-section through Sistema Purificación.

straight tunnels of varying diameter along joints that are physically and probably genetically related to the syncline and anticline exposed on the surface at Conrado Castillo (Fig. 3). These third-order folds, caused by compression in the upper beds on the east limb of the Infiernillo syncline, decrease in amplitude and disappear at depth. Due to the asymmetry of the fold, the synclinal axis is about 100 m west of the trough. The anticlinal axis is about the same distance east of the crest. Fractures near the synclinal hinge line, possibly enlarged since the Laramide Orogeny by the reduction in lithostatic stress, provided greater initial permeability and enhanced the conduit-forming potential of the rock. Dragon River and the World Beyond are formed along the axis of the syncline near the Tamabra-Tamaulipas contact (Fig. 15).

At the southern end of the World Beyond, the cave abandons its low-gradient, north-south trend near the top of the Tamaulipas limestone and rapidly drops in elevation and stratigraphic level along fractures in the west limb of the syncline. Water is locally perched on less permeable beds and flows along strike until reaching fractures that provide paths downward.

Much of the lower part of the middle section, including the Titan Chamber, Communion Hall, Nile River, Wind Tunnels, and Isopod River, formed near or along the décollement surface below the two folds. The crest of the anticline passes through Foggy Mountain Breakdown, south of the Netherhall. It is also exposed in the South Trunk, a passage formed along a joint near the décollement surface. Slickensides and calcite gouge between beds, evidence of bedding plane slippage, is abundant in this passage, as well as the Monkey Walk, the Wind Tunnels, Foggy Mountain Breakdown, and the Netherhall. The crest of anticline is exposed at two places in the Monkey Walk, which also formed near the décollement.

The entrance to the Jersey Turnpike crosses from the west-dipping to the east-dipping limb of the anticline in the South Trunk. Like the Fossil Fissure, the Jersey Turnpike is probably developed along an enlarged fracture near the hinge line surface of the anticline. The passage, higher than the Breakdown Maze, is above the décollement surface and within the east-dipping Tamaulipas limestone.

The Netherhall

México is well-known for some of the largest and deepest open-air natural pits in the world (Courbon, Chabert, Bosted, & Lindsley, 1989). Several pits in the country are more than 300 m deep, including the enormous 455 m deep El Sótano del Rancho del Barro in the state of Querétaro. The Netherhall, a unique feature in Sistema Purificación, is an interesting example of a grand, open-air pit in its incipient stage (Hose, 1988).

The Netherhall, about 330 m long and up to 130 m across, is the largest known room in the system. Its floor consists entirely of breakdown. The top of the breakdown pile is at 1500 m msl. The floor descends to 1345 m to the south and 1300 m to the north before a bedrock floor appears. Most of the system formed by phreatic and epiphreatic dissolution but the walls and ceiling of the Netherhall have been formed by collapse into an underlying void (Fig. 16). The room is in the west-dipping limb of the third-order anticline, immediately adjacent to the axial plane.

A stream apparently flows through the breakdown under the Netherhall and emerges from breakdown as the Isopod River at the north end of the giant room. It has been an important contributor to the speleogenesis of the Netherhall. Although there is no direct evidence in the Netherhall of a permanent underlying stream, waterlines on the walls of the southern part of the room indicate that water is occasionally dammed by the breakdown and rises into the lower parts of the room. The room is forming by upward stoping from an underlying void. The initial chamber below the present Netherhall might not have been large, but its ceiling was sufficiently weak to facilitate collapse. Since the Isopod River flows along the d collement surface, the ceiling failures exposed the folded, more fractured rocks of the overlying anticline and stoping continued into these rocks. If an active stream had not been present, the collapsed rocks would have filled the void and stoping would have stopped. Thus, a stream must pass through the breakdown and remove material by dissolution and, possibly, as clastic load. Thus, dissolution and stoping continue.

Evidence of gypsum crystal-wedging causing wall and roof collapse in the Netherhall has been documented (Hose, 1981). White and White (1969) state that this process is only active when the passage is high above the floodwater zone and well-protected by an overlying caprock. Most of the Netherhall is above any flood and the waterlines in the southern portion of the room are below the gypsum. Unlike other areas where mineral-activated breakdown in caves has been described, however, the Netherhall has no obvious caprock. The process seems to be the fortuitous result of thin beds of impervious chert in the Tamabra Formation, the overlying Tamaulipas Formation that resists conduit development, and the room's proximity to the hinge line surface of the anticline. The structure tends to divert groundwater along bedding planes and away from the hinge. A high evaporation-transpiration rate on the surface above the Netherhall may also contribute to this process.

The Netherhall ceiling is approximately 200 m above the Isopod River. If the process continues, the Netherhall could eventually reach the surface, creating an open-air pit. Once exposed to the surface, drainage into the hole would promote dissolution of the breakdown floor and deepen the pit. However, since the Netherhall is under Cerro Zapatero, nearly 700 m of stoping and surface erosion will be required to form such a pit.

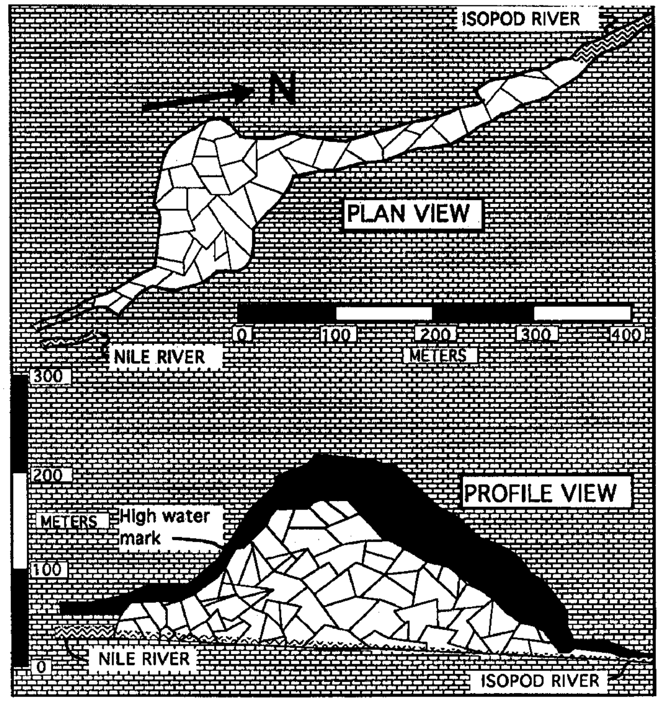

Figure 16. Plan view and profile view of the Netherhall in Sistema Purificación.

THE LOWER CAVE

The lower cave, including the Confusion Tubes and all passages north and west of them, are in the lower third of the Tamaulipas Formation. Beds dip 15° to 32° west. The Infiernillo syncline, which forms a trough in the less soluble, more impervious, underlying Taraises, La Caja, and La Joya Formations to the west, causes the sumps .

Most of the known passages in the lower part of the cave form an irregular network-type maze, appropriately named the Confusion Tubes. Like most of the system, the passages are formed along the intersections of joints or small faults and bedding planes. These phreatic tubes have solution domes and scallops in their ceilings. Flowstone deposits, which have been partially dissolved, record episodes of later vadose flow. These passages were probably formed by floodwater recharge as described by Palmer (1975) and some probably still carry water during floods, although they did not receive water during a 1979 flood or a 1988 hurricane (Hose, 1981; T.W. Raines, 1988, personal communication).

The entrance passage of Cueva de Infiernillo is unique in the system as it is not closely associated with any folds. It is a linear, north-south trending conduit with numerous feeders. The ephemeral river passage presently serves as an overflow route when the phreatic reservoir cannot pass water through the underlying Taraises and La Caja Formations to the permanent discharge point as fast as floodwaters enter the system.

Before adequate paths formed through the underlying units and when Cañon El Infiernillo was not as deep as present, the local water table was probably drained by a spring at the present cave entrance. The entrance passage may represent an old local water table level. The passages west of the Main Passage are younger features presently being enlarged by aggressive floodwaters rising from the sumps.

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REFERENCES

Atkinson, G. (1982). *Paleogeography of Mexico during the Upper Jurassic-Portlandian Stage and Lower Cretaceous-Neocomian Stage* [Senior thesis]: 22 p. University of Texas, Austin, TX.

Barnetche, A. & Illing, L. V. (1956). The Tamabra Limestone of the Poza Rica oilfield, Veracruz, Mexico. *20th International Geological Congress*: 38. Mexico, D.F.

Belcher, R. C. (1979). *Depositional environments, paleomagnetism, and tectonic significance of Huizachal Red Beds (Lower Mesozoic, northeastern Mexico)* [Ph.D. dissertation]: 276 p. University of Texas at Austin.

Carrillo-Bravo, J. (1971). La Miquihuana Platforma: *Boletín de la Asociación Mexicana de Geólogos Petroleros, 23*(1-6): 113 p.

Carrillo-Bravo, J. (1961). Geología del Huizachal-Peregrina anticlinorio al Noroeste de Cd. Victoria, Tamaulipas. *Boletín de la Asociación Mexicana de Geólogos Petroleros, XIII*(1-2): 98 p.

Conklin, J. (1974). Structural geology of the Huizachal-Peregrina Anticlinorium, in *Pan American Geological Society, Geology of Huizachal-Peregrina Anticlinorium*: 21-31.

Courbon, P., Chabert, C., Bosted, P., & Lindsley, K. (1989). *Atlas of the great caves of the world*. Cave Books, St. Louis: 369 p.

Cvijic, J. (1893). *Das Korstphanomen: Geographic Abhand.vonA.Penck 5*(3): 215-319.

Enos, P. (1974). Reefs, platforms, and basins of middle Cretaceous in northeast Mexico. *American Assocation of Petroleum Geologists Bulletin 58*(5): 800-809.

Gamper, M. A. (1977). Estratigrafía y microfacies Cretacicas del Huizachal-Peregrina anticlinorium (Sierra Madre Oriental). *Boletín de la Sociedad Geologica Mexicana Tomo XXXVIII*(2): 1-17.

Gulden, B. (1992). World deep cave list: *Geo^2, 19*: 67.

Hose, L. D. (1996). Hydrology of a large, high-relief, sub-tropical cave system: Sistema Purificación. *Journal of Caves and Karst Studies, 58*(1): 22-29.

Hose, L. D. (1988). The gestation, life, death, and rebirth of solution-collapse features in Mexico and Arizona (abst.). *GSA Abstracts with Programs, 20* (3): 170.

Hose, L. D. (1981). *The geology and hydrogeology of the Sistema Purificaí'on Area, Villa Hidalgo, Tamaulipas, México* [M.Sc. thesis]: 148 p. California State University, Los Angeles.

Imlay, R. W. (1943). Jurassic formations of the Gulf Region*: American Association of Petroleum Geologists Bulletin, 27* (11): 1407-1533.

Jennings, J. N. (1971). *Karst*. The M.I.T. Press, Cambridge, Massachusetts, 252 p.

Lancelot, Y. (1973). Chert and silica diagenesis in sediments from the central Pacific, in Winterer, E. L. and others, *Initial reports of the Deep Sea Drilling Project, 17*. (Washington, D. C.) United States Government Printing Office, 930 p.

Mixon, R. B., Murray, G. E., & Diaz, T. (1959). Age and correlation of Huizachal Group (Mesozoic), State of Tamaulipas, Mexico. *American Association of Petroleum Geologists Bulletin, 43:* 757-771.

Monroe, W. H. (1964). The zanjon, a solution feature of karst topography in Puerto Rico. *United States Geological Survey Professional Paper 501B*: 126-129.

Muir, J. M. (1936). *Geology of the Tampico region, Mexico*. Tulsa, American Association of Petroleum Geologists, 280 p.

Nason, F. L. (1909). Some phenomena of the folding of rock strata. *Economic Geology, IV*(5): 421-437.

Palmer, A. N. (1975). The origin of maze caves. *National Speleological Society Bulletin, 37*(3): 56-76.

Sprouse, P.S. (1992). Long caves of Mexico. *AMCS Activities Newsletter*, (19): 22. Austin, TX.

Sprouse, P.S. (1977a). Cueva del Brinco. *Association for Mexican Cave Studies Activities Newsletter*, (5): 19.

Sprouse, P.S. (1977b). Trip reports—Cueva del Brinco, Tamaulipas. *Association for Mexican Cave Studies Activities Newsletter*, (6): 4-5.

Sprouse, P.S., Ubico, J., and Cavanaugh, M. (1977). Purificación area. *Association for Mexican Cave Studies Activities Newsletter* (7): 18-27.

Sweeting, M.M. (1973). *Karst Landforms*. Columbia University Press, New York, 362 p.

Tardy, M. (1980). Trois lineaments transcontinentaux nord-americains: des anciens decrochements lies a l'ouverture du golfe du mexique. *Programme - 26e Congres Geologique International, Paris*, p. 103

Treacy, T. (1980). Purificación area—project report. *Association for Mexican Cave Studies Activities Newsletter*, (11): 24-28.

Treacy, T. (1979). Proyecto Espeleológico Purificación *Association for Mexican Cave Studies Activities Newsletter*, (9): 6-31.

Waisley, S. L. (1978). *Petrography and depositional environment of the Cuesta del Cura Formation, Upper Albian-Lower Cenomanian, northeastern Mexico* [MA thesis]: 135 p. University of Texas at Austin.

White, W. B. (1988). *Geomorphology and hydrology of karst terrains*. Oxford University Press, New York, 464 p.

White, E. L. & White, W. B. (1969). Processes of cavern breakdown. *National Speleological Society Bulletin 31*: 83-96.

Hose, Louise D.— Hydrology of a Large, High-Relief, Sub-Tropical Cave System: Sistema Purificación, Tamaulipas, Mexico. *Journal of Caves and Karst Studies 58*(1):22-29.

HYDROLOGY OF A LARGE, HIGH RELIEF, SUBTROPICAL CAVE SYSTEM: SISTEMA PURIFICACION, TAMAULIPAS, MEXICO

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Sistema Purificación, a 82 km long and 955 m deep cave system in the northern Sierra Madre Oriental of México, is developed on the western flank of the Huizachal-Peregrina anticlinorium in the middle Cretaceous Tamabra and underlying Tamaulipas Formations. Impervious beds above and below the cave cause groundwater to flow to the surface, resulting in many small springs. Larger springs emerge from karst conduits in the lower Tamaulipas Formation, particularly during and after intense rains.

Streams in the upper portion of the system mostly follow the dip of bedding near the Tamabra-Tamaulipas contact until trapped in the trough of a third-order syncline. Vadose flow in the middle part of the cave system follows axial plane fractures. The trough of the north-trending Infiernillo syncline, and the impervious underlying La Joya beds act as a local hydrologic barrier perching water in the lower carbonates and filling chambers in the lowest parts of Sistema Purificación.

The Sistema Purificación is the sixth longest (82 km of explored passage) and seventh most vertically extensive (955 m deep) cave system surveyed in the Western Hemisphere. Elevations within the area, which is 50 km northwest of Cuidad Victoria, Tamaulipas, México, range from 490 m msl in Cañon los Hervores to 2780 m msl on Mesas Juárez (Fig. 1).

Most of the area is a well-developed karst terrain with little surface drainage despite moderate rainfall. No permanent surface streams flow into the area although a river in the Arroyo Luna enters during heavy flooding. Rainwater mostly sinks underground before accumulating into streams. Even during heavy rains, water rapidly disappears into the ground at cave entrances, dolines, or along slightly enlarged joints in the limestone. Impermeable chert beds and shale layers force the water to the surface, generally as small (one to five liters per second) seeps.

Controlling factors for the development of the hydrologic system are the structure, stratigraphy, and lithology. Specifically, they are:

1. The folding and joints that have developed near the axial surface.
2. Bedding planes and their orientations.
3. The initial permeability of the limestone units.
4. The solubility of the limestone units.
5. The low permeability of chert beds in the Tamabra Formation and the shale layers in the Taraíses, La Caja, and La Joya Formations.

CLIMATE

The climate is temperate with moderate annual precipitation. The closest weather station, Estación El Barretal at an elevation of 196 m along the Río Purificación, has a mean annual rainfall of 780 mm. Rainfall is greatest in the summer

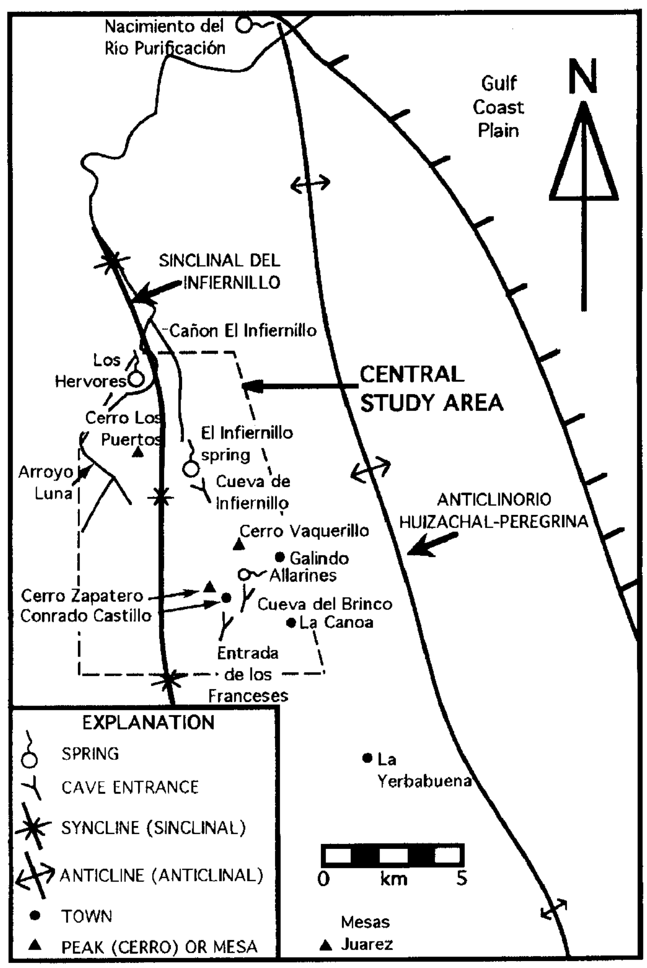

Figure 1. Map of geographic features in the Purificación area.

months and the dry season extends from approximately November through March (Fig. 2). The surface is rugged and mostly a pine-oak forest. Frost is common during winter nights but snow is rare. Moisture from the coastal plain to the east often causes clouds to engulf the mountains and humid, subtropical undergrowth covers shaded areas.

Geologic Setting

The Purificación area is on the western flank of the approximately north-south-trending Huizachal-Peregrina anticlinorium (first-order fold). Differential compression caused by the broad folding of the range in front of the Laramide Thrust Belt resulted in a major, second-order syncline called Sinclinal de Infiernillo about one kilometer west of the cave. This fold caused abundant third-order folds that significantly influence the development of the cave system .

The cave is contained within an ~800 m thick sequence of Upper Jurassic to middle Cretaceous marine sedimentary rocks, mostly carbonates (Carrillo-Bravo, 1961). Detailed descriptions of the stratigraphy and structure of the area are provided (Hose, 1996).

Surface Drainage

There is no surface water flowing into the area and all springs, with the exception of Los Hervores, return underground within the central study area. During and after heavy rains, surface water flows down Arroyo Luna. Runoff also floods the subterranean conduit system and the excess water flows through the lower surface canyon, el Infiernillo. All water ultimately joins the Río Purificación to the north (Fig. 1) and flows eastward to the Gulf of Mexico.

Sinks (Input Areas)

Water flows underground at sinks that are common in the carbonate terrains. Most sinks are fractures in the rocks. Some are only a few centimeters across while others are dolines tens of meters in diameter and greater than 100 meters deep. A few sinks are also the entrances to large caves (Sumidero de Oyamel) or deep pits (Pozo Obscuro). Many of the larger dolines have vegetated floors.

Sinks in the highest unit in the area, the Tamabra Formation, captures surface water before any large streams form, even during heavy rains. The water enters fissures and caves and in many places joins the streams in Sistema Purificación. The karst in the region is sufficiently developed to pirate rainfall quickly underground as nearly diffuse input and accounts for the lack of surface streams.

The underlying Tamaulipas Formation does not have any cave entrances that take water and surface water generally enters the subterranean system as diffuse flow through small fissures. However, at several places in the Cañones el Infiernillo and los Hervores, large streams sink in the gravel streambed within the Tamaulipas. Surface streams flow beyond these points after heavy rains either because the conduit system is not sufficiently developed to handle the flow or input zones are partially blocked.

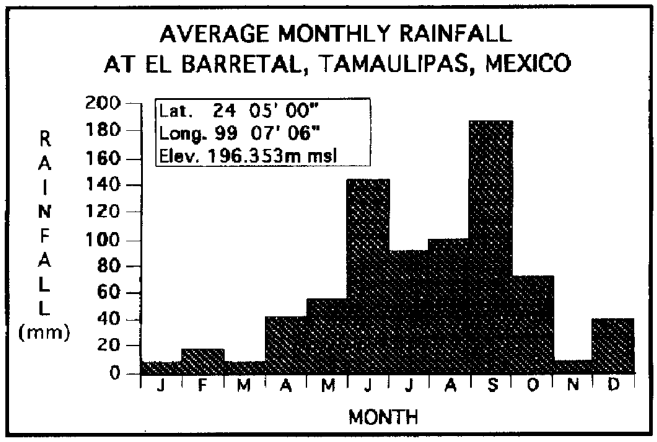

Figure 2. Average monthly rainfall at El Barretal, Tamaulipas, México over a sixteen year period (1960 to 1975).

The shale beds in the Taraíses and La Caja Formations below the Tamaulipas inhibit the development of karst conduits. Surface water goes underground in a diffuse manner, often reappearing on the surface above shale beds. Dolines with vegetation and soil on the bottoms are common in the La Caja near Galindo. Water flows quickly into the subsurface and does not pool at the bottom of these depressions.

Surface streams on the Cretaceous carbonate terrains are rare throughout the surrounding mountains. While this study includes the surface overlying all of the known passage of Sistema Purificación, the total system probably extends beyond these boundaries to the south. The plateaus of Mesas Juárez have well-developed karst surfaces that pirate rainfall underground (Fig. 3). The probable destination of that water is Sistema Purificación.

Springs (Discharge Areas)

Two factors force the subterranean water to the surface. The more common reason is that water, following a path along fractures and bedding planes enlarged by dissolution, encounters a chert or shale bed with low permeability and is forced to the surface. The second, and larger, type of spring only flows after heavy rains overload the lower, phreatic portion of Sistema Purificación.

Springs within the Tamabra Formation are small and result from groundwater moving through solutionally enlarged fractures until reaching an insoluble and impermeable chert bed where the water is perched and sometimes overflows to the surface. These springs are important water supplies to the

Figure 3. Karst field on Mesas Juárez.

people living nearby but they occasionally cease flowing in the spring months after the relatively dry winter.

Karst floodwater springs are restricted to the lower part of the Tamaulipas Formation. Four springs are known to flow after heavy rains. They are within 400 m of each other, near the head of Cañon el Infiernillo. Water issues from the entrance to Cueva el Infiernillo as a result of a rise in the water table during and after heavy rain. The cave entrance has the highest elevation of the four springs and is the first to quit flowing as the local water table level recedes. The other three flow for periods of up to several months, the lowest in elevation flowing for the longest period. Their geographic locations and behavior indicate a connection with the phreatic system in the cave.

A permanent spring of about 30 liters per second base flow rises in Cañon los Hervores but sinks into the gravel of the streambed before the canyon joins the Río Purificación. Los Hervores is a vauclusian, or boiling, spring. Water wells up through a tube in either the lowest Tamaulipas or highest Taraíses limestones under hydrostatic pressure. The forced flow causes a “boiling” effect, for which the spring is named. Such springs have been interpreted as rising from large underground reservoirs (Sweeting, 1973). This spring, the largest permanent water source in the central study area, is along the hinge line of one of the many tight, third-order anticlines west of Cañon el Infiernillo (Hose, 1996). The source of the flow is probably a streambed gravel and sand sink about 1500 m upstream and other sinks further south in Arroyo Luna. As the spring is located west of the second-order Infiernillo syncline trough, it is doubtful that the water in Sistema Purificación finds its way to this spring. Arroyo Luna drains 228 km^2 of surface area upstream from Los Hervores. While permanent streams do not flow through most of the channel, there are several permanent stream segments that rise and sink upstream from Los Hervores. This water and phreatic flow through the limestone near the stream channel are probably the sources of Los Hervores.

All of the known springs in Arroyo Luna and Cañon los Hervores are near the Tamaulipas-Taraíses contact. The water is apparently forced to the surface by the shale beds in the Taraíses Formation. The spring water flows along the surface channel to the point where the shale beds in the Taraíses Formation dip underground. Where the water again flows over the nearly homogeneous Tamaulipas Formation, the stream sinks in the stream alluvium and small fractures in the limestone.

The only other springs near the Tamaulipas-Taraíses contact are near La Canoa. There are several small seeps formed by groundwater flowing down dip above shale partings within the limestone until the water intersects the cliff. Unlike other springs in the area, these springs are supersaturated with respect to calcite when they reach the surface and large travertine deposits have formed below them.

There are many small springs and seeps in the limestone and interbedded shale of the Taraíses and La Caja Formations. They are the result of flow along bedding planes and fractures where groundwater is perched above shale layers. Many of these springs do not flow in the relatively dry spring months. Nearly permanent springs of this type are about 200 m west of La Curva, 300 m southwest of Puerto Purificación, 300 m west of Galindo, and in Cañon los Hervores.

The shale beds within the La Joya Formation cause small springs throughout its exposures. Groundwater passes through the sandstone and conglomerate beds as diffuse flow but is perched above the shale layers. Flow continues downdip until it reaches the surface. The largest spring in the La Joya Formation within the central study area is about ten meters below the contact of the La Caja and the La Joya Formations (1000 m msl) in the upper Cañon el Infiernillo. This is the probable resurgence of the Sistema Purificación. The rising water continues to flow northward along the surface channel as it crosses the outcrops of the La Joya and La Caja Formations downstream. The stream sinks downstream in alluvium above bedrock of either the Taraíses or Tamaulipas Formations.

During and after heavy rains, the flow from springs in Cañones los Hervores and el Infiernillo is too large to be handled by the sinks. At these times, some of the water sinks and the remainder continues to flow across the limestone in the surface channels. However, even at these times the streams sink again, to the north of the central study area. Whether surface flow is ever continuous to the Nacimiento del Río Purificación during intense rainfall, such as hurricanes, is not known.

The waters from Sistema Purificación, Cañon el Infiernillo, and Cañon los Hervores probably surface as part of the Nacimiento del Río Purificación, about 12 km north of the central study area. This large spring is the source of the large, southernmost tributary that makes up the Río Purificación (Fig. 4). The quantity of water and the different chemical components indicate that the Nacimiento receives water, at least in part, from different terrains than the Purificación area (Table 1).

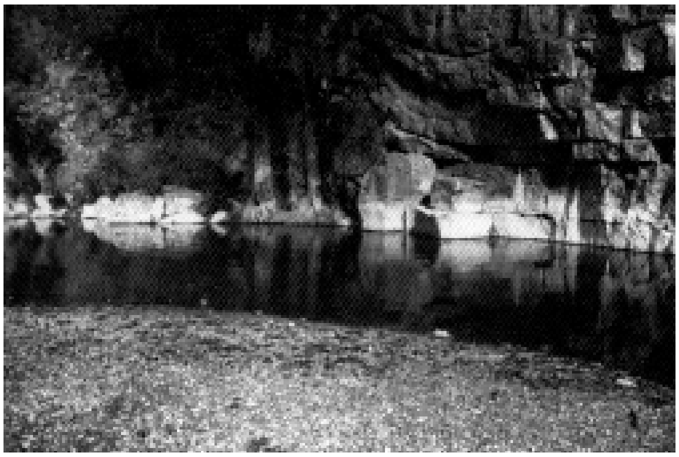

Figure 4. Nacimiento del Río Purificación. Water rises from fissures at the base of the cliff.

Hydrology of Sistema Purificacion

The hydrologic system of Sistema Purificación can be divided into three components: 1. input streams in the upper cave; 2. middle cave streams; and 3. phreatic system and lower cave.

Upper Cave

Input streams, commonly within the Tamabra Formation, generally flow from east to west down the dip of bedding planes along intersecting fractures in the limestone. These streams are small and have base level flows of only a few liters per second or less. The Valkyrie River, First Stream, and Río Verde are permanent input streams which have unknown sources and destinations (Fig. 5). They probably result from collections of diffuse flow, but the water has not been traced. Many other smaller streams flow during, and for a few days after, heavy rains. The input streams flow westward to the trough in bedding caused by the third-order syncline at the Canal and the Nose Dives. Water that has penetrated to the Tamabra-Tamaulipas contact is pooled in this trough, forming two near-sumps.

Middle Cave

Several stream segments make up the middle cave streams. These streams flow along a trend between N5°W and N10°W, following fractures near the axial surfaces of the anticline and syncline that crop out at the surface near Conrado Castillo (Hose, 1996). This axial plane cleavage has provided zones in the limestone of high permeability, enhancing water flow, dissolution, and the development of conduits along these joints. The streams mostly flow parallel to the folds, along the strike of beds and lose elevation along joints.

Table 1. Hydrochemistry of the Sistema Purificación area. Samples PW9 and PW10 are interpreted by this study to not be associated with the Purificación system. Sample 7 is a major resurgence that drains a large portion of the mountain range, probably including waters from the Purificación system.

SAMPLE	LOCATION	ELEVATION	pH	Conductivity	°C	Fe	Mg	Ca	Na	K	HCO_3	SO_4	Cl	log PCO_2
	Upper Springs													
PW2	Allarines	1980 m	7.4	210	16	0	5	105	4	<0.5	85	4	<50	-2.5
PW5	Conrado Castillo Well	1945 m	7.1	220	13	0	7	104	1	1.9	85	<1	<50	-2.2
	Cave													
PW3	Laguna Verde	1806 m	8.1	135	16	0	11	95	2	1.0	82	4	—	-3.2
PW8	World Beyond	1715 m	8.0	170	16	0	20	83	1	<0.5	73	2	<50	-3.1
PW4	Turkey Lake	1296 m	—	—	17	0	18	53	1	<0.5	—	<1	<50	-3.3
PW6	Isopod River	1290 m	8.3	210	17	0	27	77	1	<0.5	92	3	<50	-3.3
PW12	Main Sump	1070 m	8.3	190	17.25	0	27	85	1	<0.5	86	3	<50	-3.4
	Lower Springs													
PW11	Canon El Infiernillo	635 m	8.5	200	21.5	0	18	73	1	<0.5	73	2	<50	-3.6
PW9	Arroyo Luna	530 m	8.2	175	22	0	15	87	1	<0.5	79	0	<50	-3.3
PW10	Los Hervores (Fall 1979)	490 m	—	—	18	0	9	64	1	<0.5	—	<1	<50	—
PW1	Los Hervores	490 m	7.8	200	19.5	0	17	90	1	<0.5	85	<1	<50	-2.9

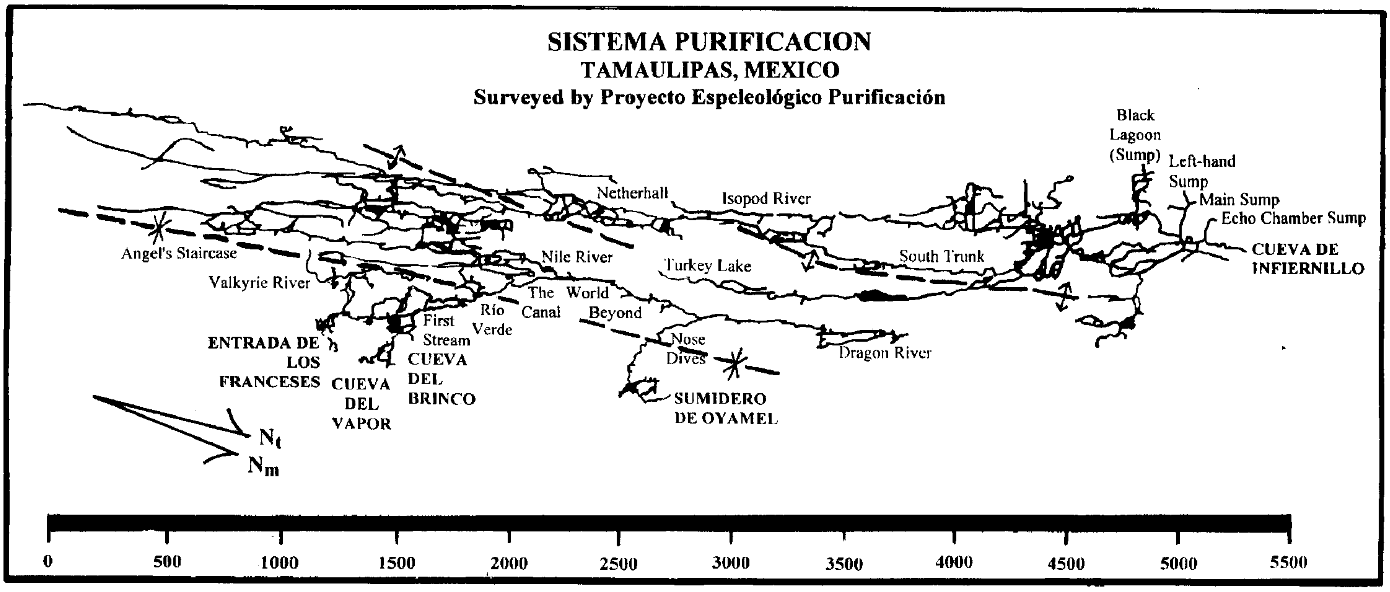

Figure 5. Plan view of Sistema Purificación showing crests and troughs of major folds.

Dragon River, The World Beyond, Nile River, and Isopod River are the major middle cave streams. Dragon River is formed in the lower part of the Tamabra Formation. Compression of the limestone near the synclinal axial plane resulted in numerous smaller, complementary folds, exposed in the walls and ceilings of the cave passage. Whether Dragon River water joins the World Beyond stream, or where the water may reappear within the system, is unknown.

The stream in the World Beyond flows along strike near the top of the Tamaulipas Formation. Water from the World Beyond passes into a pinch before reappearing slightly west and to the north where it flows down the Angel's Staircase, losing elevation through joints. The terminal sump of the Angel's Staircase is lower than Lake Victoria, the source of the Nile River. It is not known where, or if, the World Beyond water reappears in the known cave.

Tens of liters of water per second were added to the World Beyond at about six sites during a heavy, 12-hour, summer rain (Hose, 1994). Most of the sites are marked by flowstone deposits (Oztotl's Throne and Hall of Angels) and/or minor dripping during the dry season. Sites of numerous smaller waterfalls during the flood have no flow during the dry season. Densely fractured rock along the synclinal axial plane above the World Beyond provides convenient, dispersed paths for rapid input into the system during heavy rains.

The Nile River flows through nearly flat-bedded Tamaulipas limestone near a décollement under the third-order folds. The beds are only gently folded, but the stream flows parallel to the axial surface along complementary fractures. Flow in the Nile River in the dry season (early spring) has been estimated to be between eight and 30 liters per second. The Nile River is last seen in a pinch and its destination is uncertain.

Isopod River is approximately the same size as the Nile to its south and flows through the Tamaulipas Formation in a structurally similar position. Although a hydrologic connection has not been proven, it is likely that the two streams are the same water and much of the missing stream segment flows through the breakdown on the floor of the Netherhall. The Isopod River passes through a sump and re-emerges as the Babylon River (Sprouse, 1994, written communication).

Four new streams have been discovered and explored in the middle portion of the cave during the last decade. The relationships between Midnight, Flaming Nose, Tokamak/Texas, and Enigma streams have not yet been determined.

Lower Cave

The lowest part of the exposed hydrologic system is a group of sumps in Cueva el Infiernillo. Four sumps are known and have water at or near the same elevation at any given time, although the water levels appear to constantly fluctuate. The sumps are the manifestation of a perched water table that results from the underlying impermeable shales in the Taraíses, La Caja, and La Joya Formations, and the trough formed by the Infiernillo syncline, about 200 m west of the sumps. Recent underwater exploration of two of the sumps reached ~1005 m msl, only about five meters above the probable resurgence for the system in Cañon el Infiernillo. Exploration ended at a large, upward sloping breakdown pile (Sloan, 1993). About 40 m above this depth, the diver noted that "the wall no longer appeared as solid rock" and instead appeared to be calcite encrusted mud, possibly marking the transition from the Tara'ses limestone to the underlying, argillaceous La Caja Formation.

FLOODING EVENTS

During and after hurricanes and other heavy rains, many of the explored passages are flooded. One flood that resulted from a storm of 19 cm of rain in a 50 hour period in Conrado Castillo was observed by the author in December 1979 (Hose, 1994). Input and middle cave streams increased in volume and new streams flowed. The Canal and the Nose Dives filled to the ceiling and closed access to the middle cave. The middle streams were not observed, but water-filled depressions in the cave indicated that the streams rose tens of meters into what must have been raging rivers. (Waterlines in the normally dry Netherhall record floods in the past where water, probably from the Nile/Isopod River, has risen more than 60 m as it flowed through the breakdown-filled floor.) Most of the input and middle streams subsided to near-normal flow levels within three days after the rain stopped.

The sumps in the Cueva el Infiernillo rise tens of meters during heavy rains. Such a rise of the sumps during the December 1979 storm caused the system to back-up and flow out the entrance of Cueva el Infiernillo. Following a relatively dry summer and fall, the Main and Left-hand Sumps are believed to have been at approximately 1058 m msl and rose ~64 m to an elevation of 1122 m msl within three-and-a-half days after the rain started (Fig. 6). The rise stopped at this level as the system found a balance between the water entering the sumps from the higher streams and the water leaving the system through the springs in Cañon el Infiernillo, including the large cave entrance at 1102 m msl (Fig. 7). The flood rose to ~1268 m msl in the South Trunk.

The first spring to ceased flowing after the rain stopped was the highest, the Cueva el Infiernillo entrance. The sump level in the cave rapidly retreated, dropping as fast as one centimeter per minute in a passage 12 m wide and 10 m high. The consequent opening of previously flooded rooms to the cave's barometric system caused great movement of air and resulted in an occasional roaring wind that created waves up to five millimeters in amplitude on the surface of the water.

By the time the water level dropped to Camp I, ~1086 m above msl, the easternmost spring quit flowing. The middle spring was the next to dry up. The spring below the cave entrance has been observed to flow for more than two months after a flood (Treacy, 1979).

The decline curve in Figure 6 is based on only five measured levels of the Main and Left-hand Sumps and on high-water marks. Water in the Echo Chamber Sump was approximately the same elevation as the others at all times. The disruption in the curve at 170 hours may have been due to a delayed pulse of water being added from the upper system or by a change in the total area of the passages being drained. If a fixed amount of water is draining from the system, at levels of small tubes with steep slopes the water will drop in elevation quicker than when draining large rooms. It is possible that large rooms or passages were being drained at about 170 hours and temporarily slowed the rate of decline without a change in the input/output ratio for the system.

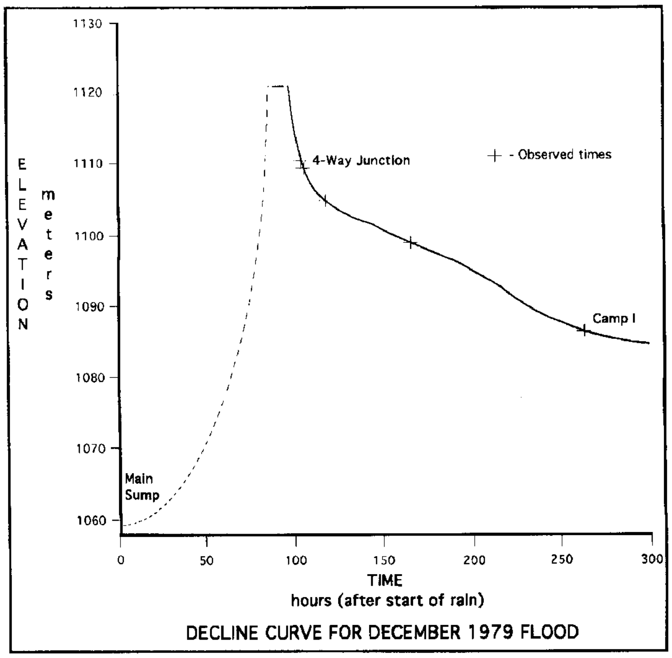

Figure 6. Decline curve for the December 1979 flood. Data used in the graph were measurements made on the Main Sump/Left-hand Sump as the combined sumps receded from the Four-Way Junction area in Cueva el Infiernillo.

HYDROCHEMISTRY

The chemical analyses presented in Table 1 are the results from a single sampling from each site during March and April 1980, except Los Hervores which was sampled on two occasions. The waters were collected in new, clean plastic bottles that were rinsed with the sample waters and drained three times before collecting. The bottles were filled and capped while held at least 15 cm below the water surface. A second sample bottle was filled and nitric acid added later to lower the pH and prevent precipitation of calcite. The samples were not filtered, thus the reported values of Ca^{+2} represent total calcium, includiing particulates. The temperatures of the waters were measured by a field thermometer graduated in 1° C intervals. Values of pH were determined by using a digital read-out pH meter using double buffer calibration which is accurate to within ±0.05 units. The meter was calibrated for each reading, and buffers were at the same temperature as the samples. Conductivities, indicating the total dissolved solids contents, were measured by a small field conductivity meter. All these measurements, except pH for the Laguna Verde, World Beyond, and Isopod River waters, were done at the sites. Bicarbonate measurements, either at the sites or within a half-hour after sampling, were made by potentiometric titration with an estimated error of ±10% (Hess, 1994, written commu-

Figure 7. Entrance to Cueva de Infiernillo. An ephemeral pool of water rises from behind boulders to the immediate right of the photograph.

nication). Cations were determined later by an atomic absorption spectrophotometer, and sulfate and chloride concentrations were measured using a Hach water quality kit in the lab. Several samples contained less sulfate and chloride than the minimum detection limits of one milligram per liter and 50 milligrams per liter, respectively.

All of the water collected in the central study area had a low total dissolved solids content and was slightly alkaline (Table 1). All but sample PW1 were collected in the spring of 1980 during low water flow and while the levels in the sumps were dropping. Iron, sodium, potassium, and chloride concentrations were generally too low to be accurately measured by the methods used. Sulfate concentrations were also low, even in the sump and lower springs, and indicate that the waters do not reach the level of the evaporites of the Olvido Formation, if they exist under Arroyo Luna and the Cerro Los Puertos ridge.

Samples PW2 and PW5 had relatively high calcium values and were collected at the two highest elevations. Both sources are water forced to the surface, or near it, by beds of chert in the Tamabra Formation. Agua los Allarines is a flowing spring and the Conrado Castillo well, where water pools in a small solution pocket, is only about three meters deep. The lower pH of these two samples probably indicates relatively short passage in the underground and close proximity to the source areas.

The partial pressure of carbon dioxide progressively decreases with decreasing elevation. It is important to note, however, that these samples represent low, dry season flow, which is probably not directly relevant to speleogenesis. Dry season samples probably accentuate the contributions of diffuse groundwater flow and minimize the characteristics of conduit waters. The only site sampled in Fall 1979, at the end of the wet season, contained 41% lower concentration of Ca and was more than a degree Celsius lower temperature than the same site three months into the dry season (Table 1, PW1 and PW10). These data suggest that the average residence time for the groundwater feeding Los Hervores is much longer during the dry season than during the wet season. This is probably also true within Sistema Purificación.

One water sample (PW7) was collected and measured from north of the central study area at the river resurgence, Nacimiento del Río Purificación (Fig. 1). The water showed substantially different chemical concentrations than the others in this study. Although the waters from Infiernillo canyon and from Los Hervores probably re-emerge at the Nacimiento, the chemical signatures indicate other sources as well. A sulfate concentration of 100 milligrams per liter may result from dissolution of evaporite beds in the Olvido Formation.

Discussion

The central study area is divided into several hydrologic systems, all of which ultimately drain into the Río Purificación to the northeast (Fig. 1). Rain falling near the eastern boundary flows along the surface to the east, over the La Joya Formation. The shale beds in this unit are nearly impermeable and forcing the rising of many springs. Similarly, the shale beds in the La Caja and Taraíses Formations commonly force groundwater to the surface. The La Caja and Taraíses are poor cave formers and probably cause the restrictions in the phreatic passages of Sistema Purificación that force the water to rise and overflow out Cueva el Infiernillo during heavy rains. However, the system's water at base flow apparently is not forced to the surface until it reaches the La Joya Formation and emerges at the bottom of the La Caja at ~1000 m msl in Cañon el Infiernillo.

Bedding planes and joints in the thick-bedded Tamaulipas Formation provide good conduits. Water flows down the dip, along the intersection of joints and bedding planes, on the flanks of folds. Near the axial surfaces of the anticlines and synclines, the passage development is nearly along strike, typically along the intersection of a bedding plane and a joint parallel to the folding, or dropping along fractures.

Groundwater flow in the Tamabra is enhanced by its susceptibility to karst development but inhibited by beds of chert. Water entering the ground above the chert beds either continues flowing downward through fractures in the chert near axial surfaces, as in the physically unconnected cave Sótano de la Cuchilla, or is forced to the surface after perching on the chert. Surface flow returns to the subterranean system after passing the chert bed. Water entering the Tamabra Formation below the bedded chert gathers in karst conduits and joins the karst hydrologic systems in the underlying Tamaulipas Formation.

The water flowing out of the central study area travels in two directions. Along the eastern boundary, the water leaving the area mostly travels on the surface to the east into Cañones El Rosario and El Olmo, and Cañada Guayabas. All these streams continue eastward to join the Río Purificación. The water from Sistema Purificación and Cañon el Infiernillo travels a subterranean route after leaving the central study area, except during floods. The flow from Los Hervores leaves the area on the surface but also goes underground to the north during base flow conditions. Although not confirmed, this water probably re-emerges from the karst springs at the Nacimiento del Río Purificación, along with waters from other parts of the mountain range.

The sumps in the lowest portions of Sistema Purificación are exposures of a localized, perched water table resulting from underlying, impermeable shale beds and the Infiernillo syncline to the west. The structure prevents groundwater from migrating to the east or west. Groundwater flow is further slowed in its downward progress by the poor conduit-forming limestone and interbedded shale in the Taraíses and La Caja Formations. The water probably passes through constricted passages in these units and emerges in Cañon el Infiernillo, approximately 800 m north of the Echo Chamber Sump.

The spring in Cañon el Infiernillo is probably only a part of the flow leaving Sistema Purificación. Some phreatic water may pass through the Taraíses and La Caja Formations and partially enters the clastic sediments of the La Joya Formation. Perched by the shale beds in this unit, some of the water overflows at the spring in Cañon el Infiernillo. The rest of the water probably flows through the conglomerate and sandstone beds of the upper La Joya northward along the trough formed by the Infiernillo syncline. If the Olvido Formation is present west of Cañon el Infiernillo, the water may gain sulfate ions. Such water probably emerges at the Nacimiento del Río Purificación, since none of the springs in the central study area have measurable sulfate ion concentrations.

The Infiernillo syncline and accompanying folds west of Sistema Purificación prevent the water from joining the hydrologic system in Arroyo Luna. The water at Los Hervores is probably from sources west of the cave system. Intense folding along the west limb of the syncline prevents water from flowing eastward into the Purificación system.

The southern boundary of the source area for the water in Sistema Purificación is unrecognized and further study is needed to identify it. Most of the groundwater in the study area south of Cañon el Infiernillo and between the Infiernillo syncline and an anticline through Cerro Vaquerillo probably enters the cave system. The source area probably extends south along a structural corridor approximately two or three kilometers wide.

Acknowledgements

The members of the Proyecto Espeleológico Purificación and the residents of the ejidos of Conrado Castillo and Puerto Purificación made this study possible. Special thanks are due to project coordinator P.S. Sprouse. D. A. Córdoba and Z. de Cserna of the Instituto de Geología provided support that was greatly appreciated. A grant supporting the field work was made by the National Speleological Society Research Grant Committee. Dr. John W. Hess and Dr. Roger L. Jacobson assisted with the hydrochemistry study. G. L. Atkinson provided hours of interesting discussions on these topics.

References

Carrillo-Bravo, J. (1961). Geología del Huizachal-Peregrina anticlinorio al Noroeste de Cd. Victoria, Tamaulipas. *Boletín de la Asociación Mexicana de Geólogos Petroleros, XIII*(1-2): 98 p.

Hose, L. D. (1996): Geology of a large, high-relief, sub-tropical cave system: Sistema Purificación, Tamaulipas, México. *Journal of Caves and Karst Studies, 58*(1): 6-21.

Hose, L. D. (1994). Sistema Purificación in flood. *Geo^2, 21*(2): 18-20.

Sloan, N. E. (1993). Underwater exploration in Sistema Purificación *The Death Coral Caver*, (3): 22-25.

Sweeting, M.M. (1973). *Karst Landforms*. Columbia University Press, New York, 362 p.

Treacy, T. (1979). Proyecto Espeleológico Purificación. *Association for Mexican Cave Studies Activities Newsletter*, (9): 6-31.

PLEISTOCENE CAVE FAUNA FROM PENINSULAR INDIA

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More than one hundred caves are carved out in Precambrian limestones in various parts of Peninsular India. The Kurnool Caves, a grouping of caves near Betamcherla, Andhra Pradesh are significant because they contain teeth and artifacts of early man. Systematic excavations revealed a rich fossil assemblage that has a bearing on past climate, environment, ecology, and migratory patterns of some of the mammalian groups. The existence of thick caves sediments and ideally situated rock shelters, which are three to four meters above ground level, suggest that detailed excavation is likely to yield fossil remains of early man.

In recent years, fossil hominids associated with artifacts in Pleistocene caves led to a marked increase in our knowledge and understanding of the evolution of hominids. Quaternary cave deposits containing Paleolithic tools associated with bone implements are known from many Pleistocene caves in Peninsular India. There are more than one hundred caves in the Tungabhadra River Valley, south of Kurnool in Andhra Pradesh, Peninsular India (Fig. 1). The Kurnool Caves, including the Billasurgam Caves (Fig. 2), are 4.5 km southeast of Betamcherla, a small mining town near Kurnool. These caves have attracted the attention of karst geologists and archeologists since their discovery by Newbold (1844).

Access to the Kurnool Caves is difficult due to the dissected terrain, rubble, and vegetation overgrowth. Other caves, such as Yaganti, Yerrazari Gabbi (Fig. 3), and the most famous cave in this region, Sanyasuli Gavi (Fig. 4), lie close to Billasurgam (Gabbi and Gavi, in vernacular, both mean cave). These caves were explored by Bruce Foote, of the Geological Survey of India, and his son, Henry Foote, in 1884. They gave special names to these caves such as Charnel House Cave, Cathedral Cave, and Purgatory Cave.

One of the early attempts to explore the caves by Prasad and Verma (1969) resulted in the collection of a large number of fossil samples of mammalian, reptilian, and avian groups. Murthy (1974, 1975) explored some of the Kurnool Caves, including Muchchatla and Chintamani Gavi, and brought out significant material. The mammalian material collected by Murthy was examined by Prasad in 1974 and a checklist was prepared for evaluation of the different groups. Besides the fauna, cave sites yielded a number of artifacts of prehistoric man (Badam, 1979).

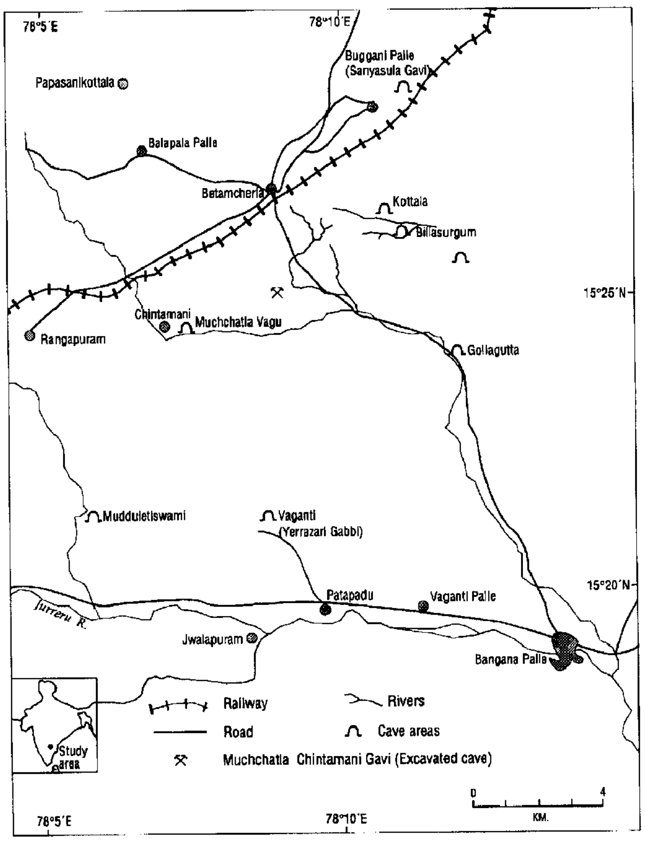

Figure 1. Map showing cave areas around Betamcherla, Kurnool District, Andhra Pradesh, S. India.

GEOLOGICAL SETTING

The caves are in the Precambrian Narji Limestones and belong to the Jammalamadugu Group of the Kurnool Supergroup. The limestones are bluish gray, fine-grained, and well-bedded. The underlying Cuddapah Supergroup also crops out near Betamcherla. It is overlain by sandstones, quartzite, and conglomerates of the Banganapalli Group, which is overlain by the Narji Limestone. The Auk Shale overlies the Narji Limestone (Table 1).

ORIGIN OF LIMESTONE CAVERNS

The caves formed by the dissolution and corrosion of subsurface and surface water above the water table. The galleries

Figure 2. A Billasurgam Cave.

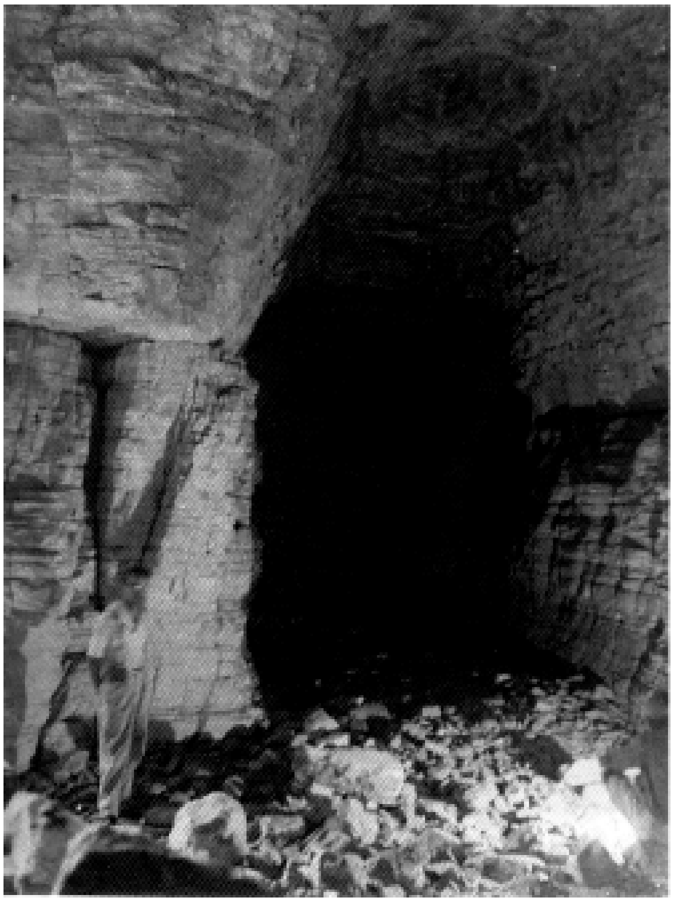

Figure 3. Yerrazari Gavi.

of the caverns developed successively at different levels. The highest passages formed by graded water table streams, which widened by lateral erosion. The several caves studied are located in steep hill slopes ~21 m above the valley floors. If the caves were coeval and dissolved by streams, it would be possible to estimate downcutting rates by streams in various caves.

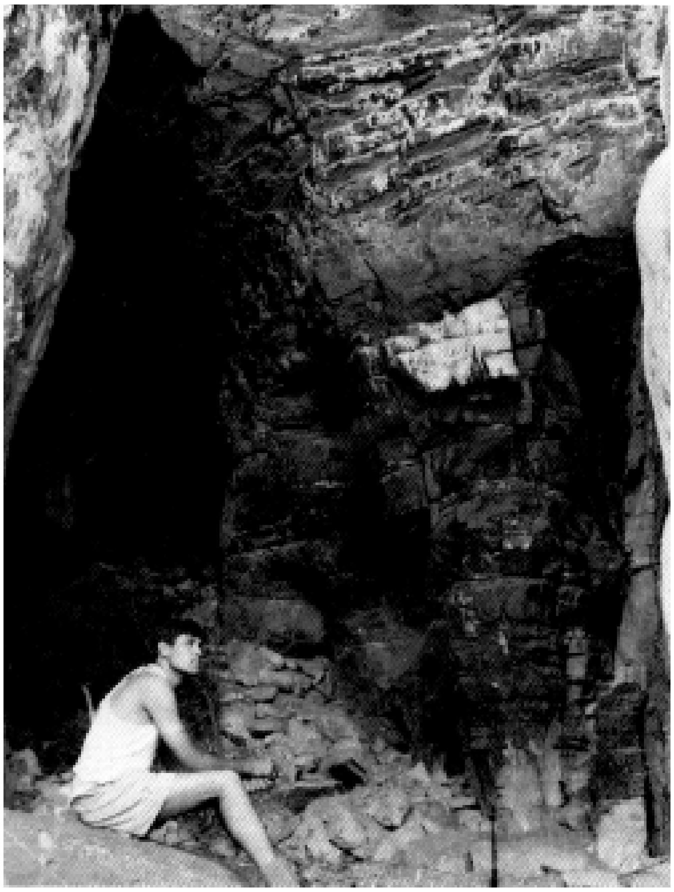

Figure 4. Sanyasula Gavi.

Table 1.

THE KURNOOL SYSTEM

Groups	**Formations**
Kundair	Nandyal Shales
	Koilkuntla Limestone
Paniam	Pinnacled Quartzite
Jammalamadugu	Auk Shale
	Narji Limestone
Banganapalli	Banganapalli Sandstone

Environment

The caves are located in limestone escarpments. Passages as low as a meter in height extend deep into the limestone. The floors are characterized by thick sediments of clays, stalagmites, stalactites, and cemented limestone blocks forming breccias. The plateau and hill slopes have a grass and xerophytic cover of deciduous type representing a semi-arid environment. Modern fauna are confined to animals such as *Hystrix*, *Vivvera*, *Lepus*, *Felis*, and *Manis*.

FOSSIL REMAINS OF THE KURNOOL CAVES

Foote's (1884) excavations in the Billasurgam Caves yielded 4000 dental and osteological remains of late Pleistocene age. These fossil elements were grouped under mammals, aves, amphibians, and reptiles. In addition, the cultural material recovered, including awls, barbed arrowheads, spears, and scrapers, were assigned by Foote to *Homo sapiens*. The artifacts confirmed the presence of man in these caves. The fossils also threw light on the former geographical distribution of some fauna presently in the Ethiopian region of Africa that no longer exist in this region. The caves lack ash, charcoal, and bone fragments (food refuse) and appear to have been temporary abodes. Deep trenches were required to recover samples, which were emplaced in the stalagmatic floors.

Table 2 provides the stratigraphic sections described from two of the Kurnool Caves, identified by Lydekker (1886) and Prasad and Yadagiri (1986).

Table 2.

Charnel House Cave		**Cathedral Cave**	
AI:	surface beds	C:	surface bed
A:	rubble (human dentition)	C:	gray sandy bed (stalagmite)
B&C:	red claly, sandy	Ca:	reddish cave sands
D,E,F&G:	rubble	Cb:	red clay
H:	reddish cave earth	Cc:	stiff red clay
I:	mottled cave earth	Cd:	reddish clay
J:	brown clay	Ce,Cf&Cg:	marl, dark
K&L	red sands, limestones (implements)	Ch:	loamy marl
M,N,O,P:	stiff marly clay	Ci&Cj:	gray marl

In addition to mammalian remains, the Kurnool Caves yielded late Pleistocene bone tools, flakes, and scrapers. Carbon-14 (C^{14}) dates have established an age of 50,000 years BP for the artifacts. Radiometric dating was carried out at the Physical Research Laboratory, Ahmedabad, in 1979 and subsequent years. Stone Age Man has left his relics in the form of lithic and bone tools. Mammals, such as *Equus*, *Rhinoceros*, *Sus*, and the Catarrhine monkeys *Presbyti*s, *Papio*, and *Procynocephalus*, had wide distribution in Siwaliks and Peninsular India. The *Rhinoceros* is now confined to Assam and Terrai Regions in the sub-Himalayas. The others are now confined to the Ethiopian and other regions of Africa and are absent in the Peninsula. Amongst the Catarrhines, only *Presbytis* has survived and is now widely distributed. The combined faunal assemblages from the Kurnool Caves are quite significant, as they provide notable information about the environment and ecology during the Pleistocene in Southern Peninsular India.

FAUNA OF THE KURNOOL CAVES

A rich assemblage of vertebrate fauna was recovered by Henry Foote from excavations in the Billasurgam caves. The collection was examined by Lydekker (1886). The revised names (Prasad & Yadagiri, 1986) are used in Table 3.

Table 3.

MAMMALIA	
FAMILY	***Genus species***
INSECTIVORA	*Sorex sp.*
CHIROPTERA	*Taphozous saccolaemus*
PHOLIDOTA	*Manis gigantea*
LAGOMORPHA	*Lepus* cf. *nigricollis*
RODENTIA	*Sciurus sp.*
	Bandicota indica
	Hystrix crassidens
PRIMATES	*Presbytis entellus*
	Papio sp.
CARNIVORA	*Panthera tigris*
	Felis rubiginosa
	Crocuta sp.
	Canis sp.
	Viverra karnuliensis
	Herpestes sp.
	Melursus sp.
ARTIODACTYLA	*Boselaphus tragocamelus*
	Gazella benneti
	Antelope cervicapra
	Sus cristatus
	Sus karnuliensis
PERISSODACTYLA	*Equus asinus*
	Rhinoceros karnuliensis
REPTILIA	*Crocodylus sp.*
	Varanus dracaena
AMPHIBIA	*Bufo melanosticus*

The other caves of importance are the Muchchatla and the Chintamani Gavi (Fig. 5). These were explored by Murthy (1974, 1975) and Prasad and Yadagiri (1986). The caves are 15 m up a 35 m escarpment. The stalagmitic floors have an assortment of limestone slabs and boulders as well as weathered shale. The caves are small and narrow, ranging from 0.5 m to 1.5 m wide. Narrow entrances restrict movement. However, average passage is 9 m high, on two sides, and has galleries 15 m long, which narrow down to corridors less than 1.5 m wide.

Surfaces of the Muchchatla and Chintamani Gavi floors are covered with excreta of bats. Sediments in these caves appear to be shallower than in the Billasurgam Caves. The section

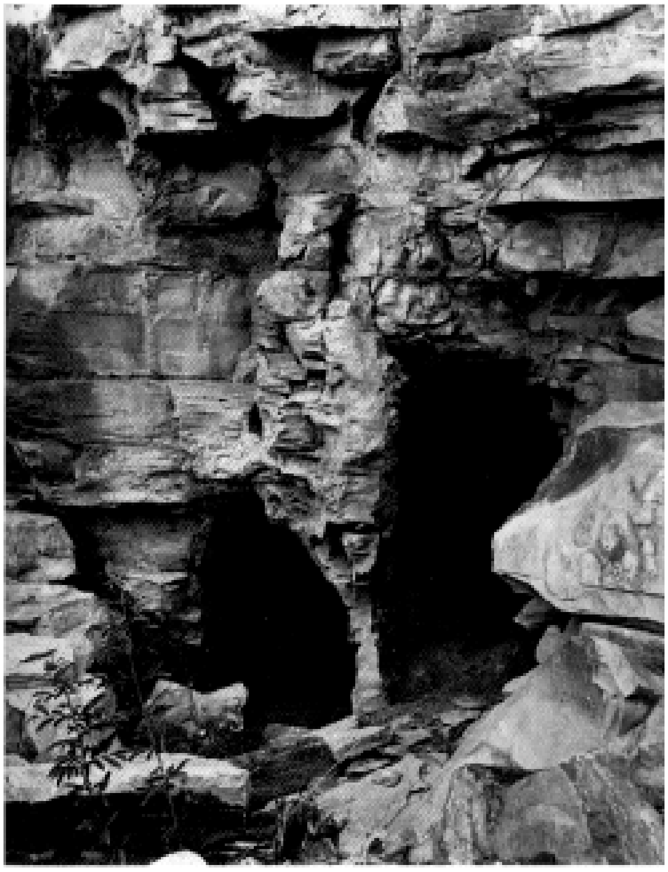

Figure 5. The entrance to Chintamani Gavi.

observed at Chintamani Gavi is as follows:

TOP	D. Clay: 25 cm
	C. Clay with limestone blocks: 35 cm
	B. Red marl: 50 cm
	A. Massive limestone

Table 4 illustrates the forms which have been identified in the collection from Chintamani Gavi, close to the Billasurgam Caves.

The cave floors were divided into three layers by Murthy (1974, 1975). These layers contain cultural elements (Table 5).

Based on the artifacts, the lithic industry from Chintamani Gavi indicates the utilization of flakes, blades, cores, and hammerstones. The bone tool assemblage is made up of chisels, scrapers, and barbs. They exhibit an Upper Paleolithic tradition and the layers do not show any typological or evolutionary variation.

Chandrapalle Cave

One of the largest caves in this region is the Chandrapalle Cave, ~12 km east of Peapally and ~50 km south-southeast of Bangana Palle. The cave is in Precambrian Cuddapah Limestones. The roughly 1 m wide cave entrance is ~24 m up a cliff face. The passage widens about 15 m into the cave and the roof is well over 18 m high. A stalagmitic floor with permanent water pools lies beyond. A well-preserved specimen of an *Ursus* bear skull (Fig. 6) was collected from this cave by the Archeological Department of Andhra Pradesh and was examined by the author. Two fossil species of Ursus are known from India: *Ursus theobaldi* from the Siwaliks of Kangra, Himachal Pradesh, and *Ursus namadicus* from Narmada Basin, Central India. The Chandrapalle Cave specimen has been described as a new species of *Ursus footei* (Prasad and Yadagiri, 1986).

Table 4.

MAMMALIA

FAMILY	***Genus species***
PRIMATES	*Presbytis entellus*
RODENTIA	*Nesokia bandicota*
	Hystrix crassidens
PERISSODACTYLA	*Equus sp.*
	Equus asinus
ARTIODACTYLA	*Boselaphus tragocamelus*
	Bos sp.
	Antelope cervicapra
	Sus cristatus
CARNIVORA	*Viverra karnuliensis*
	Felis sp.

Table 5.

FLOOR DATA	LAYER 1	LAYER 2	LAYER 3	TOTAL
Cultural Elements				
Lithic Industry	13	23	187	223
Bone Tool Industry	125	621	1257	2003
Fauna				
Dental	23	54	140	217
Osteological	7	15	51	73
Total	168 (6.7%)	713 (28.3%)	1635 (65.0%)	2516

Paleoecology

The area around Betamcherla presently is semi-arid with scanty vegetation and few rivers. However, the excavated fauna indicate that the moderately hilly terrain was covered with trees in the late Pleistocene. Rivers and streams in the basin support the forest. Tall grass prevailed in the plateau country.

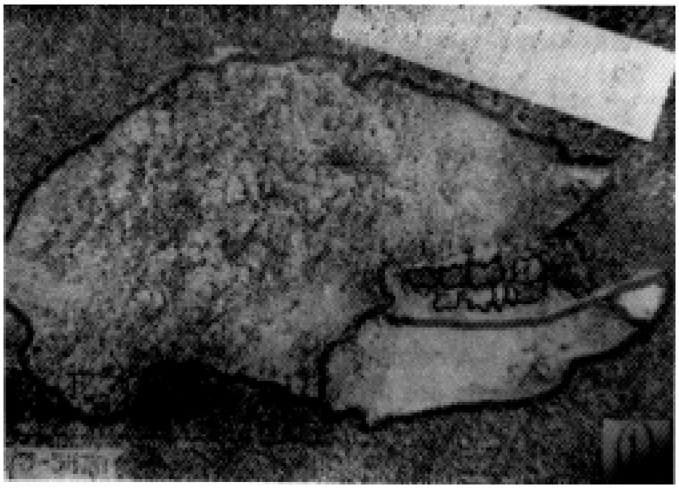

Figure 6. Ursus footei skull from Chandrapalle Cave.

The presence of *Antelope*, *Gazella*, *Cervus*, *Ursus*, and *Boselaphus* suggests that forest conditions existed on hill slopes. *Bubalus* and *Bos* thrived on forested regions, which was broken up by streams with open grasslands on the banks. The presence of *Presbytis entellus*, the arboreal Hanuman Langur, indicates a deciduous forest vegetation. They moved in groups and inhabited rocks and cliffs. The convincing proof of low forested hills and swamps having abundant vegetation is in the occurrence of *Rhinoceros karnuliensis*. *R. karnuliensis* is now absent in Peninsular India and is confined to the rain forests of Assam.

Conclusions

The study of the Kurnool Caves fauna is important. Sediments are as much as 25 m thick in some of the caves and their stratigraphy reveals considerable information on the Pleistocene history of the caves. The presence of rock shelters provides a basis for exploration of fossil remains of early man. So far, a portion of a jaw with dentition and an isolated tooth have been recovered from the cave floors. They may be assigned to *Homo sapiens*.

Acknowledgments

I would like to thank my former colleagues, Dr. C.V.N.K. Rao and Dr. P. Yadagiri, of the Geological Survey of India and Dr. G.L. Badam of Deccan College, Pune for helpful discussions. Thanks are due to the Geological Survey of India, Madras and Calcutta, for library facilities and examination of earlier collections. The research was supported by the Boise Fund, Oxford University. I thank Dr. George N. Huppert and Betty Wheeler, both of the Department of Geography and Earth Science, University of Wisconsin-La Crosse for kindly editing the paper and seeing it through the press. Appreciation is also expressed to Dr. Greg Chu, of the same department, for computer drafting the map.

References

Badam, G.L. (1979). Pleistocene Fauna of India. *Special Publication* (no number): 1-245. Deccan College, Post Graduate Research Institute, Pune.

Foote, R.B. (1884). Foote's work at the Billasurgam Caves. *Records, Geological Survey of India, 17*(4): 200-208.

Lydekker, R. (1886). The Fauna of Kurnool Caves. *Palaeontologia Indica Series C. 4*(2): 23-58.

Murthy, M.L.K. (1974). A Late Pleistocene Cave Site in Southern India. *Proceedings of the American Philosophical Society, 118*(2): 196-230.

Murthy, M.L.K. (1975). Late Pleistocene Fauna of Kurnool Caves, South India. In A.T. Clason (Ed.), *Archaezoological Studies*: 132-138. Special publication, North Holland Publishing Company, Amsterdam and New York.

Newbold, T.J. (1844). Notes on the Osseous Breccia and deposit in the caves of Billasurgam, Southern India. *Journal Asiatic Society of Bengal, 13*(2): 610-615.

Prasad, K.N. & Verma, K.K. (1969). *The Kurnool Cave Fauna*. Unpublished progress report.

Prasad, K.N. & Yadagiri, P. (1986). Pleistocene Cave Fauna, Kurnool District, Andhra Pradesh, *Records, Geological Survey of India, 115*(5): 71-77.

Koemel, Walton C.—Extremely Low Frequency Radio Emissions in Bat Caves. *Journal of Caves and Karst Studies 58*(1): 35-37.

EXTREMELY LOW FREQUENCY RADIO EMISSIONS IN BAT CAVES

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Bats produce very low frequency (VLF) radio pulses and display magnetic qualities. Extremely low frequency (ELF) radio emissions were observed inside bat caves. Ground return currents from 60 Hz AC power systems run through the ceiling of some bat caves.

MATERIALS AND METHODS

I developed a metal antenna tuned radio frequency (TRF) receiver that could be tuned to the radio electric wave to the exclusion of a microphone-detected audio wave (Koemel & Callahan, 1994). It is a wide band receiver, but only frequencies between 20 Hz and 18,000 Hz can be heard in the earphone. Atmospheric radio emission observations were made in an area not affected by 60 Hz AC power systems.

In July, 1993, I began observing extremely low frequency and very low frequency (ELF\VLF) radio emissions in caves and VLF radio pulses produced by flying bats. The pulses produced by bats were observed only during bat flight activity. This article contains preliminary data obtained with the TRF receiver.

METHOD OF RECORDING OBSERVATIONS

I recorded the observed ELF radio emissions by attaching an electric-shielded patch cable from the TRF receiver earphone jack to the microphone input jack of a computer-compatible cassette tape recorder set in the RECORD mode. This connection prevented the tape recorder from recording sound. I held the TRF receiver motionless while recording ELF radio emissions. I kept my body in contact with the TRF receiver chassis ground, while making observations, to prevent static discharges from "hand capacitance".

COMPUTER ANALYSIS OF EMISSIONS

I used a Heath-Zenith digital computer oscilloscope (Model No. IC-4802, Heath, Bent Harbor, MI) driven by a Tandy 1000-HX computer and Tandy JP 250 printer (Tandy, Fort Worth, TX 76102) to analyze the radio emissions. I played the tape recordings into the shielded oscilloscope probe by adapting the probe to the earphone jack of the cassette tape recorder. This connection prevented sound and static from entering the oscilloscope. The oscilloscope used the computer monitor as a display screen and it can freeze the waveform on the screen for analysis. Two movable cursors on the screen enable the operator to read the waveform frequency in hertz. I obtained a print (17.5 by 13.5 cm) of the waveform on the screen by entering the print code into the computer. The oscilloscope prints used in the following figures are from this oscilloscope. I also used an Audio Spectrum Analyzer to identify the frequencies in the observations.

RESULTS

I made observations at Mason Bat Cave on 17 October 1994, in the afternoon, during which time the weather conditions included a partly cloudy sky with rain showers. Figure 1 shows some of the observed ELF/VLF radio emissions in the atmosphere, including a static discharge from a rain cloud in the area near Mason Bat Cave. The waveforms produced by bats (Figs. 8-9) were not found in the analysis of these observations. ELF/VLF radio emissions of different weather conditions produce distinctive frequency spectra. Figure 2 shows radio emissions produced by a sand storm, Figure 3 demonstrates radio emissions produced by a blizzard, and Figure 4 shows radio emissions produced by a clear moonlit night sky. I do not know if the 2,000 Hz pulse in Figure 4 is from a bat. A clear daytime sky is similar to Figure 4.

Atmospheric ELF/VLF radio emissions can be observed inside Mason Bat Cave near the ceiling. Figure 5 indicates observed ELF/VLF radio emissions near the cave ceiling, and Figure 6 shows ELF/VLF radio emissions near the floor of Mason Bat Cave. The radio emissions produced by the bats were not found in the analysis of these observations. Figures 5 and 6 demonstrate no ground return current from 60 Hz AC power systems running through Mason Bat Cave. Figure 7 shows a strong 120 HZ radio emission near the ceiling of Lair Cave near Carlsbad, New Mexico. Ground return currents from 60 Hz AC power systems cause this frequency. The radio emissions observed near the floor of Lair Cave were similar to Figure 6. Mason Bat Cave has a prolific bat population while Lair Cave is sparsely populated.

I observed VLF radio pulses produced by flying bats inside these caves. They produce a "pop" sound in the TRF receiver earphone, and computer oscilloscope analysis shows their waveforms are different from atmospheric static discharges (Fig. 1). These pulses are multi-peaked with frequencies that range from 2,000 to 3,500 Hz. They last from one to three milliseconds (ms). Figure 8 shows a 2,500 Hz radio pulse produced by a flying bat (see cursors) and Figure 9 represents a 2,000 Hz radio pulse produced by a flying bat (see cursors).

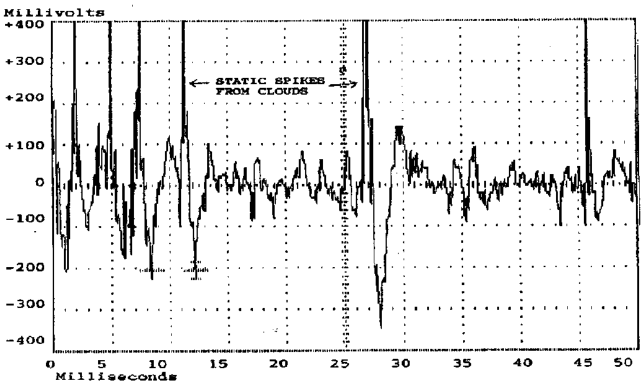

Figure 1. Oscilloscope recording of radio emissions in the atmosphere near Mason Bat Cave.

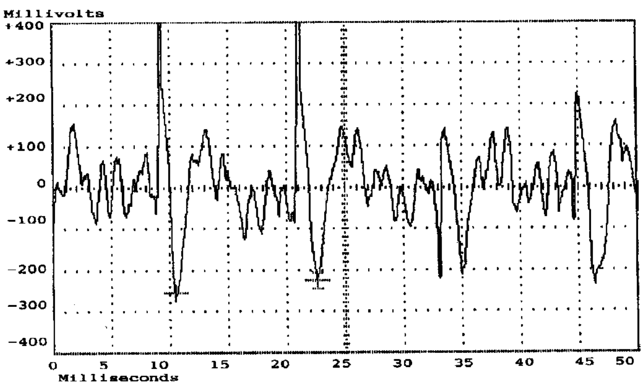

Figure 2. Oscilloscope recording of radio emissions produced by a sand storm.

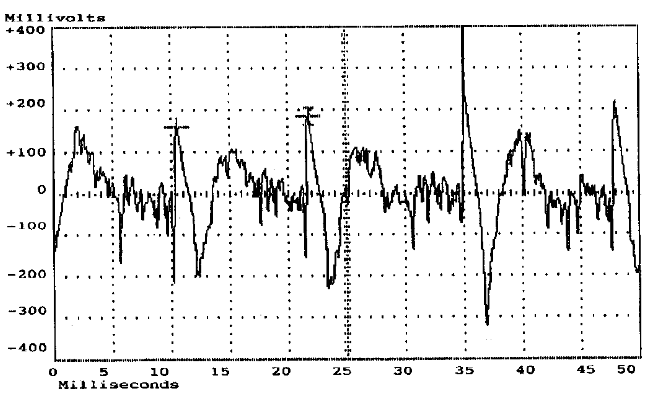

Figure 3. Oscilloscope recording of radio emissions produced by a blizzard.

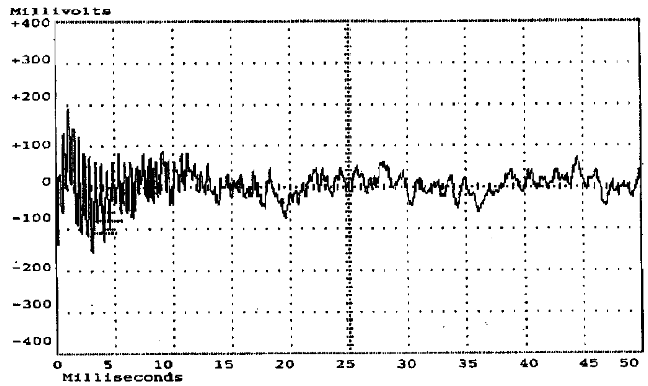

Figure 4. Oscilloscope recording of radio emissions produced by a clear moonlit sky.

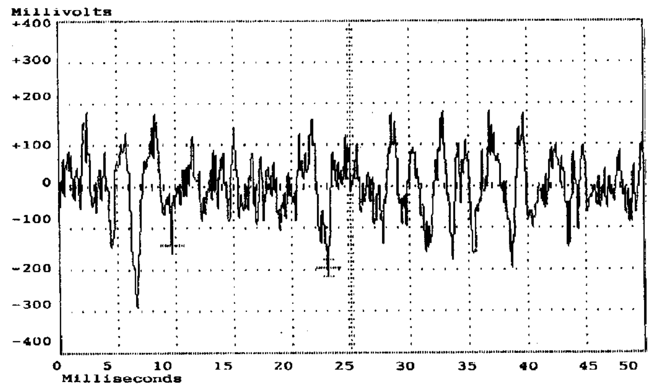

Figure 5. Oscilloscope recording of radio emission near the ceiling of Mason Bat Cave.

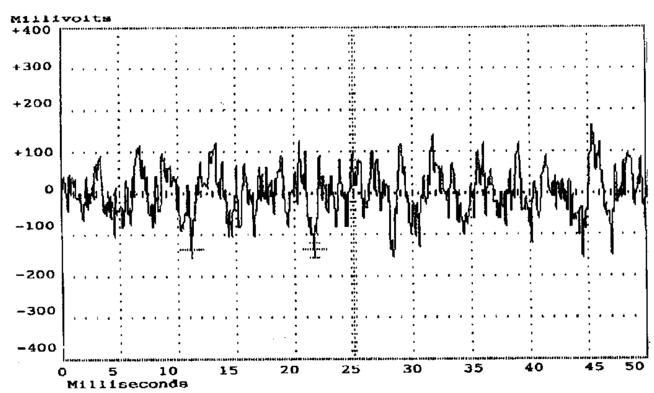

Figure 6. Oscilloscope recording of radio emission near the floor of Mason Bat Cave.

Bats have magnetic remanence (Buchler & Wasilewski, 1985). The magnetic rotation in the northern hemisphere is counter-clockwise, and clockwise in the southern hemisphere. Bats display magnetic qualities by flying in a counter-clockwise rotation as they exit caves in the northern hemisphere, and by flying in a clockwise rotation as they exit caves in the southern hemisphere.

Conclusion

Bats can use atmospheric radio emissions to detect weather conditions from inside a cave. Bats may be affected by 60

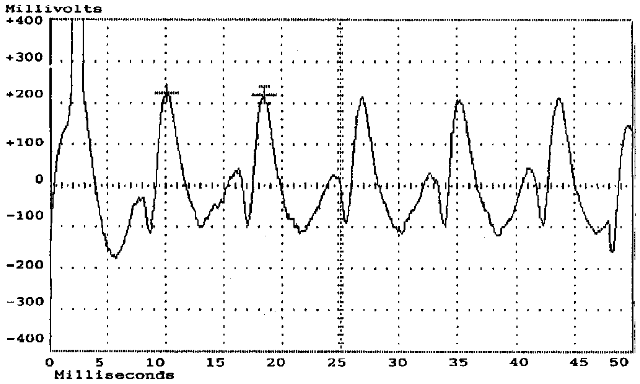

Figure 7. Oscilloscope recording of radio emission near the ceiling of Lair Cave.

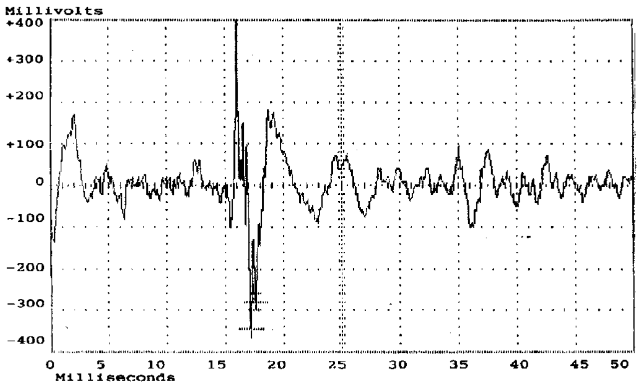

Figure 8. Oscilloscope recording of 2,500 Hz radio emission produced by a flying bat (species unknown) (see cursors).

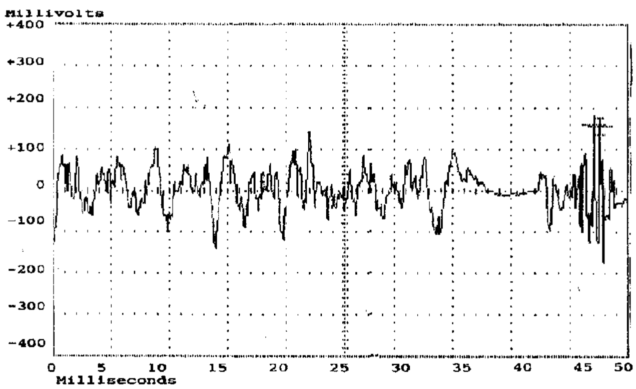

Figure 9. Oscilloscope recording of 2,000 Hz radio emission produced by a flying bat (species unknown) (see cursors).

Hz ground return currents in caves.

The VLF radio pulses produced by flying bats might be used to paralyze insects electronically immediately before catching them during predation. Another possible use for these VLF radio pulses is in a far-infrared imaging system. ELF radio and audio frequencies cause molecules to emit their far-infrared molecular spectrum (Callahan, 1989). This would enable a bat to locate its young inside a cave. The bat's whiskers and configurations on the bat's nostrils make perfect waveguides for microwave and far-infrared receptors (Callahan, 1975). Bats orient themselves to the earth's magnetic field at the cave entrance, enabling them to locate the cave entrance in total darkness.

References

Buchler, E.R. & Wasilewski, P.J. (1985). Magnetic remanence in bats. In J.L Kirschvink, D.S. Jones, and B.J. MacFadden (eds.), *Magnetite Biomineralization and Magnetoreception in Organisms: A New Biomagnetism*: 483-488. New York: Plenum Press.

Callahan, P.S. (1975). Insect antennae with a special reference to the mechanism of scent detection and the evolution of the sensilla. *International Journal of Insect Morphology and Embryology, 4*: 381-430.

Callahan, P.S. (1989). Fourier transform studies of audio stimulated surface enhanced scatter in biological systems. *High Resolution Fourier Transform Spectroscopy 1989 Tech. Digest Series, 6*: 105-108.

Koemel, W.C. & Callahan, P.S. (1994). Relationship of Extremely Low Frequency Radio Emission from Flying Insects to Semiochemical Communications. *Annals of the Entomological Society of America, 87*: 491-497.

Christiansen, Kenneth & Bellinger, Peter—Cave *Pseudosinella* and *Oncopodura*, New to Science. *Journal of Caves and Karst Studies 58*(1): 38-53.

CAVE *PSEUDOSINELLA* AND *ONCOPODURA* NEW TO SCIENCE

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Nine new species and two new subspecies of the genus Pseudosinella are described from caves in Indiana, Kentucky, North Carolina and Virginia. Three new species of the genus Oncopodura are described from caves in Oregon, Texas and Virginia. The Virginia species is the first cave species of the latter genus to be found east of western Illinois.

In connection with our updating of *The Collembola of North America* we have uncovered a considerable number of undescribed species of cave Collembola. Some of these, of the genera *Arrhopalites*, *Oncopodura*, and *Pseudosinella*, are so striking and clear cut that we feel it best to describe and name them before producing part II of the update. In this paper we describe nine new species of the genera *Pseudosinella* and *Oncopodura*. In a subsequent paper we shall describe the members of the genus *Arrhopalites*. The species described herein and the regions they are found in are given to the right.

First we describe several species of the genus *Pseudosinella*, which has been the subject of many studies in this country and elsewhere and whose phylogeny and classification are reasonably well understood (Christiansen, da Gama & Bellinger, 1983; da Gama, 1984). We take this opportunity to describe those for which satisfactory material is available, and to give tabular summary of these as well as other species that cannot be described at present because adequate material is not available (see Table 1). Data on these species will be entered into the BUGS DELTA program available through Grinnell College, which may be used to identify species of the genus (Christiansen, Bellinger & da Gama, 1990). Table 2 gives the character states of the new species fitting the different features discussed in the above paper.

Genus	***species***	**Region**
Pseudosinella	*bona*	Virginia
Pseudosinella	*erehwon*	Virginia
Pseudosinella	*extra*	Virginia
Pseudosinella	*espanita*	Kentucky [Tennessee?]
Pseudosinella	*flatua*	North Carolina
Pseudosinella	*fonsa*	Indiana, Ohio
Pseudosinella	*granda*	Virginia
Pseudosinella	*vespera*	North Carolina
Oncopodura	*fenestra*	Texas
Oncopodura	*hubbardi*	Virginia
Oncopodura	*mala*	Oregon [California?]

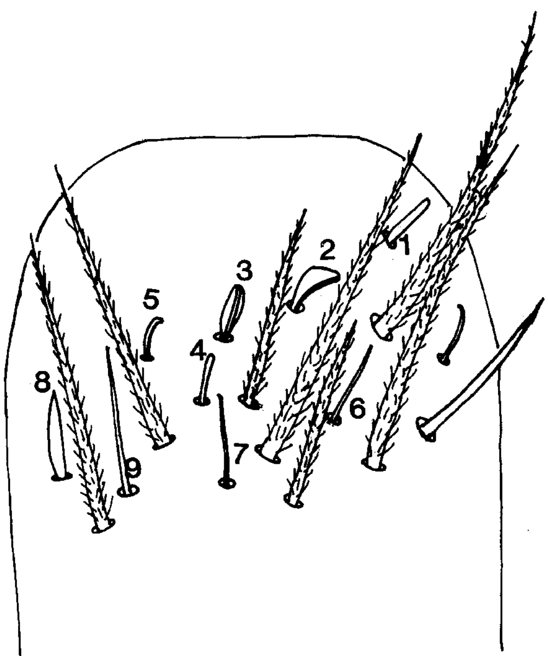
In addition to characters previously used to distinguish members of this genus, we call attention to the sense organ of the apex of the third antenna segment, whose structure is essentially similar to that described by Chen and Christiansen,

Table 1. New and Undescribed Species of Cave Pseudosinella.

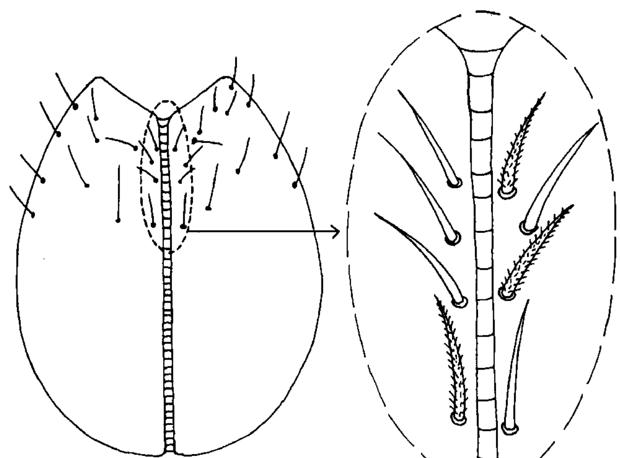
species	Eyes per side	Cephalic macrochaetae R0	R1	R2	R3	S	T	Labial triangle setae	Thoracic macrochaetae II	III	Abd.II chaetotaxy					Abdomen IV macrochaetae P1	M	Tenent hair	Unguis teeth	Macrichaetae along each side of labial groove s=smooth c=ciliate	Localities
bona	1-2vg	2	+	+	-	-	-	M_1 ($\underline{M}_1$) M_2 $\underline{r}$ E L_1 L_2	0	0	p	$\underline{a}$	$\underline{B}$	q_1	q_2	0	2	ac	3	0s 4c	Washington & Roanoke Co. Virginia
erehwon	0	+	+	+	-	-	-	$\underline{M}_1$ M_2 $\underline{r}$ E L_1 L_2	2	1	p	$\underline{a}$	$\underline{B}$	q_1	q_2	0	2	cl-ac	3	0s 4c	Scott Co. Virginia
espanita	0	+	+	+	-	+	+	$\underline{M}_1$ M_2 vg E L_1 L_2	3	2	$\underline{p}$(-)	$\underline{a}$	$\underline{B}$	q_1	$\underline{q}_2$	1	2	ac	3	0s 6-8c	Edmonson Co. Kentucky
extra	0	+	+	+	+	-	-	$\underline{M}_1$ M_2 $\underline{r}$ E L_1 L_2	2	1	p	$\underline{a}$	$\underline{B}$	q_1	q_2	0	2	ac	3	0s 4c	Scott Co. Virginia
flatua	0	+	+	+	-	-	-	m_1 ($\underline{m}_1$) M_2 r E L_1 L_2	0	0	$\underline{p}$	$\underline{a}$	$\underline{B}$	q_1	q_2	0	2	ac	3	3s 1c	Swain Co. North Carolina
fonsa	3-4 (2?)	+	+	+	-	-	-	($\underline{M}_{1s}$) $\underline{M}_1$ $\underline{M}_2$ $\underline{r}$ E $\underline{L}_1$ $\underline{L}_2$	0	0	p	a	$\underline{B}$	q_1	q_2	0	2	cl	3	0s 3-4c	Clark, Jennings & Harrison Co. Indiana, Adams Co. Ohio
granda	0	2	+	+	-	-	-	$\underline{M}_1$ $\underline{M}_2$ 0 $\underline{E}$ $\underline{L}_1$ $\underline{L}_2$	0	0	p	$\underline{a}$	$\underline{B}$	q_1	q_2	0	2	ac	3	0s 4c	Augusta Co. Virginia
vespera	0	+	+	+	+	-	-	M_1 M_2 0 E L_1 L_2	3	2	-	a	$\underline{B}$	q_1	q_2	0	2	ac	3	0s 4c	Swain & Rutherford Co. North Carolima
AB	0	?	?	?	?	-	-	M_1 M_2 $\underline{r}$ E L_1 L_2	0	0	p	$\underline{a}$	$\underline{B}$?	q_1	q_2	0	3	ac	3	0s 3c	Adair Co. Oklahoma
AC	3	+	+	+	-	-	-	M_{1s} M_1 M_2 r E L_1 L_2	0	0	?	?	?	?	?	0	2	ac	3	1s 3c	Hamilton Co. Tennessee
AD	0	+	+	+	-	+	+	M_1 M_2 0 E L_1 L_2	1	0	-?	a	B	q_1	?	1	2	cl	3	0s 3c	Medina Co. Texas
AE	3	+	+	+	-	-	-	$\underline{M}_1$ M_2 $\underline{r}$ E L_1 L_2	0	0	p	$\underline{a}$	$\underline{B}$	q_1	q_2	0	2	cl	3	0s 4c	Scott Co. Virginia
AF	0	+	+	+	+	+	-	$\underline{M}_1$ M_2 $\underline{r}$ E L_1 L_2	3	2	?	?	$\underline{B}$	?	?	0	2	ac	2	0s 4c	Lee Co. Virginia
AG	0	+	+	+	-	-	-	$\underline{M}_1$ $\underline{M}_2$ vg $\underline{E}$ L_1 $\underline{L}_2$	0	0	p	$\underline{a}$	$\underline{B}$	q_1	q_2	0	2	acv	3	0s 4c	Highland Co. Virginia

Table 2. Character States for BUGS DELTA Program for New Species of Cave Pseudosinella.

character state	bona	vespera	flatua	espanita	extra	fonsa	erehwon	granda	character state	bona	vespera	flatua	espanita	extra	fonsa	erehwon	granda
1	1	1	1	2	1	1	1	1	21	1	1	1	1	1	1/2	1/2/3	1
2	1	1	1	2	1	1	1	1	22	2	2	2	2	2	2	2	2
3	3/4	3	1/2	4	3	4	4	4	23	1	2	2	2	2	1-2	2	2
4	3	3	3	3	3	5	3	4	24	1	1	1	4	1	1	1	1
5	2	5	1	2	2	4	2	5	25	1	1	1	1	1	1	1	1
6	3	3	3	3	3	4	3	4	26	1-2	0	0	0	0	2-4	0	0
7	3	3	3	3	3	4	3	4	27	2	2	2	2/3	2	2	2	2
8	3	3	3	3	3	4	3	4	28	4-7	2	5-9	2	2	8/9	2	3-5
9	1	1	2	2	2	2	2	2	29	1	1	1	1	1	1	1	1
10	4	4	4	4	2	4	4	4	30	2	2	2	2	2	2	2	2
11	2	1	2	2	2	2	2	2	31	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	32	2	2	2-3	2-3	1	3	1/2	2
13	1	1	1	2	1	1	1	1	33	2.7	2.4	3.0	1.8	1.5	2.8	1.2	1.6
14	4	2	4	2	-	4	-	4	34	52-58	32-43	56-60	20-26	40-47	60-68	65-72	67-74
15	0	3	0	2/3	2	0	2	0	35	1.5-1.8	1.5-1.9	1.7-2.4	1.3-1.7	1.4-1.5	1.9-2.2	1.5	1.5-1.8
16	3	2	3	2	-	3	-	3	36	2	2	2	3	3	2	3	2
17	0	2	0	2/3	1	0	1	0	37	2	2	2	2	2	2	2	2
18	1	1	1	2	1	1	1	1	38	2	2	2	2	2	2	2	2
19	2	2	2	2	2	2	2	2	39	2	2	2	2	2	2	2	2
20	2	1	2	1	2	2	2	2	40	1	2	1	1	2	1	1	1



1A



1B

Figure 1B. Semidiagrammatic illustration of macrochaetae along ventral groove of head. Right side formula 3s1c, left side formula 2s2c.

Figure 1A. Semidiagrammatic illustration of typical 3rd antennal segment apical setae.

1993, in *Sinella*. Figure 1A shows the characteristic setae of this organ and the numbering used in the species descriptions. We also have applied to this genus a characteristic used by Mari-Mutt (1986) in the genus *Lepidocyrtus*. This is the macrochaetae directly along the sides of the ventral groove of the labium from the base of the ventral triangle to the posterior margin of the head. These setae are normally limited to the anterior 2/3 of the groove and are either smooth (i.e., probably with very closely appressed ciliations) or clearly ciliate (see Fig. 1B). The numbers of setae demonstrating the two different conditions is shown in the formulae (i.e. 3s 1c means three smooth and one cilaite per side).

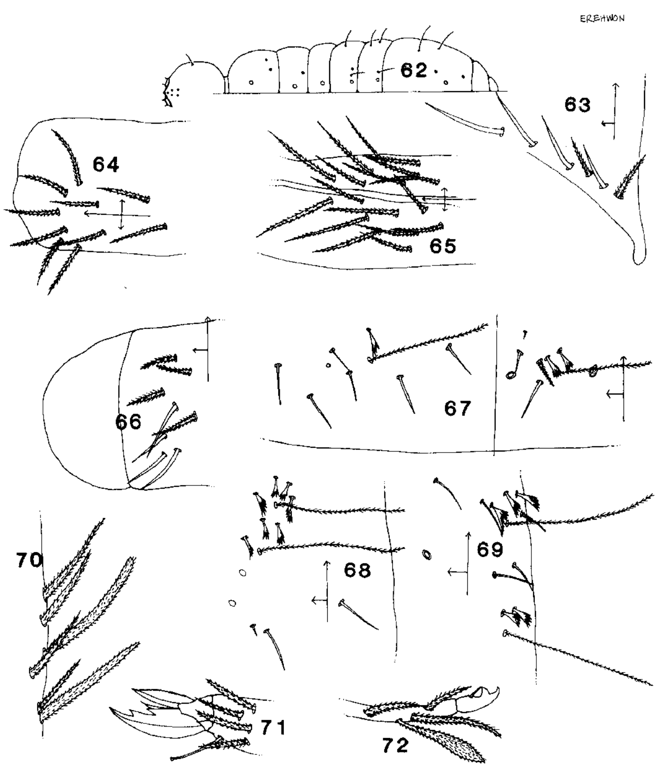
Pseudosinella erehwon sp. nov. (Figs. 62-72)
Description: White without eyes or trace of pigment. Maximum length, omitting appendages, 1.2 mm.

Antennae 1.48-1.5 times as long as cephalic diagonal and lacking apical bulb. Antennal segment ratios 1/1.8/1.2-1.6/2.1-2.3. Subapical organ rod-like or with a small apical swelling. Lenticular organs absent or weakly developed between the third and fourth and second and third segments. Third antennal apical setae not seen clearly but setae 8 and 9 as well as a series of additional not numbered setae appear to be blunt or acuminate, curved and slightly basally enlarged. Prelabral setae 4-5-5-4; all smooth. Labial palp with three sublobal hairs. Labial triangle with seta M1 and r ciliate; remainder smooth; seta M1 distinctly shorter than M2 and seta r about half as long as M2. With 4+4 ciliate, marginal macrochaetae along anterior end of labial ventral groove. Second abdominal segment with P seta relatively long but not clearly ciliate. Fourth abdominal segment with anterior bothriotrichal complex having a supplementary seta. Trochanteral organ with 4-5 setae in arms and one external seta. Ventral tube with 9+9 to 10+10 large ciliate setae on anterior face and 10-12 on the posterior face; distolateral patches with 8-9 setae, anterior 4 ciliate and remainder smooth. Hind tibiotarsus with clearly differentiated inner large seta, only slightly longer than other large setae but cylindrical and apically blunt or truncate, situated 0.32-0.42 distance from base to apex of tibiotarsus. Unguis with 3 clear teeth; basal pair moderately large with one only slightly larger than other; distal tooth prominent and 0.65-0.71 distance from base of apex of inner unguis. Unguiculus acuminate with outer margin very finely serrate. Tenent hairs generally weakly clavate and apically curved but sometimes truncate or even acuminate. Manubrial plaque with 2 inner and 2 outer setae. Uncrenulate dens 3-3.3 times as long as mucro. Mucronal teeth subequal with basal spine slightly exceeding apex of sub apical tooth.

Holotype female and 9 paratypes: Canyon to Nowhere Cave, Scott Co., Virginia, 18 April & 23 May 1995, D. Hubbard Coll. (locality nos. 7819 & 7838).

Derivatio nominis: named after type locality cave.

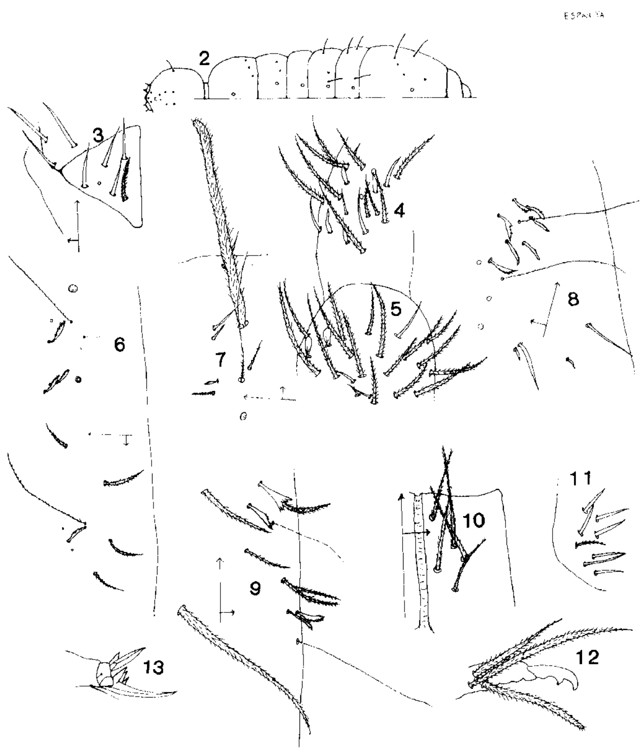
Remarks: This unusual species has no S or T setae on the cephalic dorsum but 2 & 1 macrochaetae on the second and third thoracic segments. It shares these unusual features with only one species: the North African and European *Pseudosinella helenae* (Arbea & Jordana, 1990). It differs strikingly from this species in ungual structure (3 versus 4 inner teeth) and labial chaetotaxy (most setae smooth as opposed to all save r being ciliate in *helenae*). There are other minor differences as well. It is probably part of the *orba-vita* group of species.



Figures 62-72 of Pseudosinella erehwon. All figures of type specimens. 62. Semidiagrammatic illustration of dorsal macrochaetae and pseudopores (hollow circles). 63. Setae of labial triangle, right side. 64. Posterior face of ventral tube. 65. Anterior face of ventral tube. 66. Right distolateral patch of ventral tube. 67. Second abdominal segment chaetotaxy, left side. 68. Outer bothriotrichal complex third abdominal segment, left side. 69. Bothriotrichal complex of fourth abdominal segment, left side. 70. Outstanding seta and neighboring setae of hind tibiotarsus. 71. Hind foot complex. 72. Mucro and distal end of dens.

Pseudosinella espanita sp. nov. (Figs. 2-13)
Description: Eyes and pigment absent. Maximum length, excluding appendages, 1.8 mm. Antennae 1.3-1.7 times as long as cephalic diagonal, without apical bulb; Antennal segment rations as: 1/1.3-2.0/1.1-1.3/2.3-3.0. Subapical sense organ a rod with a very small apical bulb. Lenticular organs weakly developed between third and fourth antennal segment, or absent. Third antennal segment apical sense organ with seta 1 unclear but apparently a minute rod; setae 2 & 3 large, flattened, and broadly oval; 4 short, swollen, and acuminate; 5 very small and acuminate; 8 slender and blunt. Second antennal segment with apical organ similar to that of third, lacking differentiated seta 1 but with 2 & 3 as in segment 3; ventral

surface with a number of differentiated setae, some medially thickened and acuminate, similar to seta 4 on the third segment. Prelabral setae 4-5-5-4; posterior row ciliate, remainder smooth. Dorsal lateral P setae absent. Labial palp with 3 sublobal hairs. Labial triangle with M^1 seta large and ciliate; R varying from minute and smooth to (rarely) absent. With 6+6 ciliate marginal macrochaetae along anterior end of labial ventral groove. The second abdominal segment P seta present and finely ciliate to smooth, and seta q2 finely ciliate. The fourth abdominal anterior bothriotricha complex lacking supplementary seta; median anterior P seta of this segment smaller and more posterior than normal. Trochanteral organ with 5-7 setae in dorsal arm and 4-5 in ventral one; no internal and 1



Figures 2-13 all of Pseudosinella espanita. All specimens from Mammoth Cave, Kentucky. 2. Semidiagrammatic illustration of dorsal macrochaetae and pseudopores (hollow circles). 3. Labial triangle setae. 4. Setae of venter of basal portion of third antennal segment. 5. Setae of dorsum of apical portion of second antennal segment, same specimen, but other antenna. 6. Second abdominal segment chaetotaxy of left side. 7. Detail of inner setae of second abdominal segment of different specimen. 8. Third abdominal segment, left side, outer bothriotrichal complex. 9. Lateral bothriotrichal complex, fourth abdominal segment, right side. 10. Left side of anterior face of ventral tube. 11. Distolateral setae of ventral tube. 12. Mucro and apex of dens. 13. Fore foot complex.

external seta. Ventral tube with 5+5 to 8+8 large ciliated setae on anterior face; distolateral patches with 7-10 setae, one or two finely ciliate, remainder smooth; posterior face with 4 large setae and 0-2 finely ciliate mesochaetae. Posterior leg with clear large clavate to truncate inner seta at 0.30-0.38 distance from base to apex of tibiotarsus. Unguis with 2 clear basal teeth and a third tooth so close to these as to be easily overlooked. Unguiculus acuminate with strong outer tooth. Manubrial plaque with 2-3 inner and 2 outer setae. Mucro with apical tooth twice as large as median, and without basal spine. Uncrenulate dens 2.5-3 times as long as mucro.

Holotype: female, Mammoth Cave National Park, Edmonson, Co., Kentucky, Styx River near Charon's Cascade, 4 August, 1979, E.A. Lisowski, Coll. (locality no. 4222). Paratypes: 4 females, all taken from Mammoth Cave on different dates (locality nos. 1112, 4223, 4225 & 5563).

Derivatio nominis: after the similarity between this species and *Pseudosinella espana*.

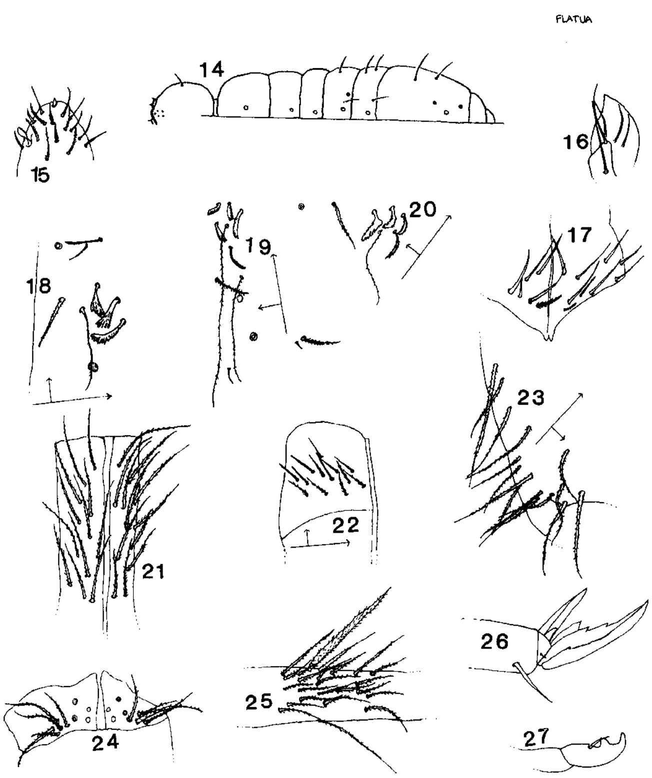
Remarks: This remarkable species is very similar to *P. espana*, found in caves in Arkansas and Missouri, but shows little relationship to any other species. The large wing tooth on the unguiculus and the absence of a basal spine on the mucro form a unique combination. In some respects these species are similar to the halophile European species *P. halophila* (Bagnal, 1939); however no specimens or recent redescriptions of this were available for comparison. *Pseudosinella anderseni* (Gisin, 1967), *petterseni* (Boerner, 1901), and the nearctic species *certa* (Christiansen & Bellinger, 1981), *rolfsi* (Mills, 1932), *sera* (Christiansen & Bellinger, 1981), and *violenta* (Folsom, 1924) all lack eyes and have ungual and unguicular wing teeth, but all have well developed basal spines on the mucro. Most differ from espanita in many other features as well.

There is some variation in the posterior thoracic macrochaetae. Most of the specimens have them as shown in Table 1; however, at least one specimen has 2 on segment 2 and another has 3 on segment 3. This species is the one we list under *P. espana* in *Collembola of North America* as Edmonson, Co.(?), but examination of additional Kentucky material shows clear differences, as shown in the table below:

Feature	***espanita***	***espana***
2nd abdominal segment seta Q1	microseta	macrochaeta
Expanded apical ant.2 setae	+	-
Cephalic macrochaeta S	+	-*
Lateral posterior macrochaetae on dorsum of head	-	+

* Erroneously indicated present in CONANRG. Two single specimens taken from caves in Montgomery, Co., Tennessee, are in such poor condition that they cannot be placed with certainty. They may be *espanita* or a closely related species.

Pseudosinella flatua sp. nov. (Figs. 14-27)
Description: Eyes and pigment absent. Maximum length,



Figures 14-27 all of Pseudosinella flatua. All figures of type specimens. 14. Semidiagrammatic illustration of dorsal macrochaetae and pseudopores (hollow circles). 15. Apex of fourth antennal segment. 16. Labial palp. 17. Labial triangle setae. 18. Inner bothriotrichal complex of second abdominal segment, left side. 19. Third abdominal segment, left side, outer bothriotrichal complex. 20. Fourth abdominal segment left side, anterior bothriotrichal complex. 21. Ventral tube, anterior face. 22. Ventral tube, right side, distolateral patch. 23. Posterior face of ventral tube. 24. Manubrial plaque. 25. Median portion of hind tibiotarsus showing differentiated seta. 26. Fore foot complex. 27. Mucro and end of dens.

excluding appendages, 3 mm. Antennae 1.9-2.5 times cephalic diagonal, without apical bulb, but several small pegs are present and one of these may be apical. Antennal segment ratios as: 1/2.3-2.7/2.2-3.1/3.9-4.0. Subapical sense organ a rod bearing oval apical swelling. Lenticular organs clear between both third and fourth and second and third antennal segments. Third antennal segment apical sense organ with seta 1 minute and blunt, 2 & 3 slightly swollen, 4 & 5 slender, short, and peglike; 7 filament-like and 8 more or less medially swollen and acuminate. Pre-labral setae 4-5-5-4, all smooth. Dorsal lateral P setae absent. Labial palp with 3 sublobal hairs. Labial triangle with M^1 seta 1/3-2/3 as long as M^2, usually ciliate but sometimes smooth. With anterior 3+3 smooth and posterior 1+1 usually ciliate, marginal macrochaetae along anterior end of labial ventral groove. The second abdominal segment has a P seta that is unusually large and ciliate; seta q2 cannot be seen clearly on any specimen and may be absent. The fourth abdominal segment with supplementary seta in anterior lateral bothriotricha complex. Trochanteral organ with 9-11 unusually large setae in each arm, 12-16 internal and 1-3 external setae. Ventral tube with 11+11 to 13+13 large ciliated setae on anterior face; distolateral patches with 11-13 setae, about half finely ciliate, remainder smooth; posterior face with about 14 large to medium finely ciliate setae. Posterior leg with clear acuminate large inner seta, at 0.32-0.35 distance from base to apex of tibiotarsus. Unguis with 3 clear teeth, distalmost 0.56-0.60 from base to apex. Unguiculus acuminate without trace of outer tooth. Manubrial plaque with 2 inner and 5-9 outer setae. Mucro with apical tooth only slightly larger than median and with clear basal spine whose apex excess tip of median tooth. Uncrenulate dens 2-2 1/2 times as long as mucro.

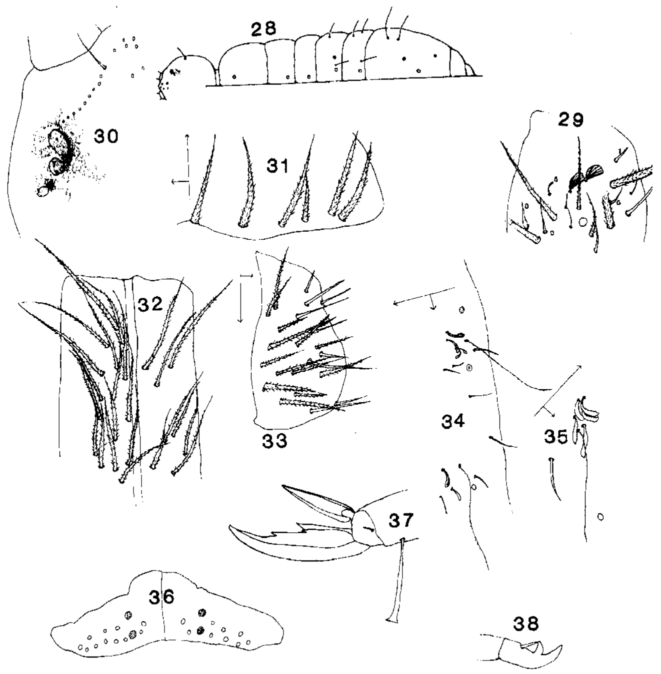
Holotype: female and 6 paratypes, Swain Co., North Carolina, Blowing Springs Cave, 18 & 22 March, 1979 (locality nos. 3985 & 3986), S. Platania & D. Ballard colls.

Derivatio nominis: from the Latin flatus, meaning blowing, after the type locality, Blowing Springs Cave.

Remarks: This species shows unusual variability in the M^1 seta of the labial triangle. The species is distinguished from the inadequately described species *maritima* (Bagnall, 1941), by the acuminate outstanding hind tibiotarsal seta. It differs from *styriaca* (Neuherz & Nosek, 1975), in lacking posterior thoracic macrochaetae. The entirely inadequately described *aggtelekiensis* (Stach, 1929) and *inaequalis* (Bagnall, 1941), cannot be distinguished from *flatua* by their original description; however, the conspecificity of troglobites on two different continents seems unlikely, and if the figure of the foot in Loksa (1961) really belongs to Stach's species, it is not at all similar. The remarkable large ciliate P seta on the second abdominal segment serves to separate this species form all Nearctic members of the genus. *Pseudosinella vespera* is also found in the type locality cave.

Pseudosinella fonsa sp. nov. (Figs. 28-38)

Description: Eyes 3-4 per side (possibly only 2 in one case), on loose eye patches. Pigment of blue granules scattered over head and body, with small darker clusters on head. Maximum length excluding appendages 2.8 mm. Antennae 1.2-1.9 times cephalic diagonal, without apical bulb; antennal segment ratios as: 2.1-2.6/2.3-2.9/3.2-4.0. Subapical sense organ peg-like with slight apical swelling. Lenticular organs weakly developed between third and fourth antennal segments, or absent. Third antennal segment apical sense organ with seta 1 small and peglike, setae 2 & 3 with slender central rod and thin oval expansion; 4 & 5 short rods; 6, 7 & 9 slender and 8 similar to these but slightly thicker. Pre-labral setae 4-5-5-4, with posterior row ciliate, others smooth. Lateral P setae absent. Labial palp with three sublobal hairs. Labial triangle with all setae ciliate, most specimens having supplementary



Figures 28-38 all of Pseudosinella fonsa. All figures of type specimens. 28. Semidiagrammatic illustration of dorsal macrochaetae and pseudopores (hollow circles). 29. Apical organ of right third antennal segment, seen from side. 30. Left eye patch. 31. Basal labial triangle setae of right side. 32. Anterior face of ventral tube. 33. Left distolateral patch of ventral tube. 34. Second abdominal segment chaetotaxy of left side. 35. Anterior bothriotrichal complex of fourth abdominal segment. 36. Manubrial plaque. 37. Hind foot complex. 38. Mucro and apex of dens.

M^1 seta about 2/3 as long as normal seta; R seta large, about half as long as M setae. With 3+3-4+4 ciliate, marginal macrochaetae along anterior end of labial ventral groove. Second abdominal segment P seta relatively large. Fourth abdominal segment anterior bothriotricha complex with supplementary seta. Trochanteral organ with 9-10 setae in each arm and numerous (>12) internal setae. Ventral tube with 11+11 to 15+15 large ciliate setae on anterior face; distolateral patches with 15-21 setae, 5-13 ciliate and remainder smooth. Posterior leg with one large inner acuminate ciliate seta, only slightly distinguished from other inner setae, at 0.31-0.39 distance from base to apex of tibiotarsus. Unguis with 3 clear inner teeth, distalmost one 0.60-0.68 from base of apex. Unguiculus without outer tooth. Manubrial plaque with 2 inner and 8-9 outer setae. Mucro with apical tooth about 2X median and with basal spine whose apex just reaches tip of median tooth. Uncrenulate dens 2 times as long as mucro.

Holotype: female and two paratype females, Peyton Spring Cave, Clark Co., Indiana, 19 August 1977, J. Lewis coll. (locality no. 3762).

Additional records: Indiana: Spring Cave, Clark Co., 11 June 1977, J. Lewis coll. (locality no. 3757); Rat Cave, Harrison Co., 20 July 1975, J. Lewis coll. (locality no. 3652); Dryden Sinks Cave, Jennings Co., 30 July 1994, J. Lewis coll. (locality no. 7747); and (?) Patton Cave, Monroe Co., 29 October 1992, H. Hobbs coll. (locality no. 7606). Ohio: Morrison's Cave, Adams Co., 2 July 1980, H. Hobbs coll. (locality no. 4618).

Derivatio nominis: from the Latin from, meaning fountain or spring, after the type locality, Peyton Spring Cave.

Remarks: The variable eye number in this cave species distinguishes it from all similar nearctic forms. The actual number of eyes is difficult to distinguish as the corneae appear to be much reduced. The single specimen from Spring Cave appears to have an asymmetrical single macrochaeta base in the center of the head. The third antennal segment sense organ is difficult to make out in Indiana specimens, but they appear to be rodlike and are definitely slightly swollen rods in the Ohio specimens. The species is very similar to *P. aera*, but the different labial and cephalic chaetotaxy as well as the difference in typical eye number serve to separate the two species. *P. fonsa* differs from *staryi* (Rusek, 1981) and *tridentifera* (Rusek, 1971) in the presence of setae M^2 and well developed R in the labial triangle. If differs from the former in several features of the second abdominal segment chaetotaxy, and from the latter in the eye distribution and ungual structure as well. It differs from *rapoporti* (de Izarra, 1965) in the absence of an apical antennal bulb, and from *stachi* (Christiansen et al., 1983) and *inaequalis* (Starch, 1960 nec Bagnall) in the eye distribution and much larger antenna/C.D. ratio (1.9-2.2 as opposed to about 1.5). The single specimen from Monroe Co. is immature; it appears to have 5+5 eyes and may represent a different species.

Pseudosinella granda sp. nov. (Figs. 39-50)

Description: Without eyes or trace of pigment. Maximum length, excluding appendages, 1.6 mm. Antennae 1.5-1.8 times cephalic diagonal, without apical end bulb. Antennal segment ratios as: 1/2.0-2.2/1.6-2.1/2.9-3.4. Subapical sense organ small and difficult to see, but apparently short, broad, and apically expanded. Lenticular organs weakly developed between second and third and third and fourth antennal segments. Apical organ of third antennal segment with seta 1 small and peglike; setae 2 & 3 with curved thickening along one margin and an ovoid, flattened blade; setae 4-8 cylindrical, slender, and blunt, with seta 8 distinctly thicker than others; seta 9 unclear but apparently short and thick and close to seta 7. Prelabral setae 4-5-5-4 with a basalmost row ciliate and others smooth. Labial palp with 3 (rarely 4) sublobal hairs. Labial triangle setae are ciliate macrochaetae with 4+4 ciliate marginal macrochaetae along labial ventral groove margin. Second abdominal segment sometimes with only two microsetae anterior to inner bothriothrix. Fourth abdominal segment anterior bothriotrichal complex with supplementary seta present. Throchanteral organ with 5-6 setae in each arm, 1-2 inner

Figures 39-50 all of Pseudosinella granda. All figures of type specimens. 39. Semidiagrammatic illustration of dorsal macrochaetae and pseudopores (hollow circles). 40. Macrochaetae at base of left antenna and R setae of cephalic dorsum. 41. Maxillary palp, left side. 42. Apical setae of third antennal segment, right side, seen from side. 43. Labial triangle setae, left side seen from below. 44. Second abdominal segment chaetotaxy, left side seta shown by dotted lines present in other specimens. 45. Manubrial plaque, right side. 46. Ventral tube setae, anterior face, seen from an angle. 47. Bothriotrichal complex of fourth abdominal segment, left side. 48. Hind foot complex. 49. Ventral tube, distolateral patch, left side. 50. Mucro and apex of dens.

setae, and 2-3 external setae. Ventral tube with 6+6 to 7+7 large ciliate setae on the anterior face, the 3+3 along the distal part of the ventral groove being distinctly heavier than the others; distolateral patches each with 8-9 large setae, 4 or 5 anterior ones ciliate and the others smooth, sometimes with one additional vestigial microseta; posterior face with 13 large ciliate setae of varying sizes, 7 along distal margin. Hind tibiotarsus with outstanding seta acuminate and weakly distinguished from other inner setae, 0.25-0.28 distance from base to apex of tibiotarsus. Unguis with 3 clear teeth, one basal clearly larger than the other; apical tooth 0.67-0.74 distance from base to apex of inner unguis. Unguiculus acuminate with smooth outer margin. Manubrial plaque with 2 inner and 3-5 outer setae. Uncrenulate part of dens 2.5-2.8 times as long as mucro. Basal mucronal spine slightly exceeding apex of anteapical tooth, which is 7/8 as long as apical tooth.

Holotype: female and four paratypes: Grand Caverns, Augusta Co., Virginia, 17 November 1994, D. Hubbard coll. (locality no. 7769).

Additional record: type locality, 6 December 1974, J. Holsinger coll. (Collection no. 3720).

Derivatio nominis: after the type locality, Grand Caverns.

Remarks: The cephalic macrochaetae are unusual: in the position where R^0 would normally be there is a pair of small macrochaetae, which we interpret as a doubled R^0 since the R^1 and R^2 setae are in their normal positions. This species is similar to *P. certa* from West Virginia, but the foot complex is strikingly different.

Pseudosinella vespera sp. nov. (Figs. 51-61)

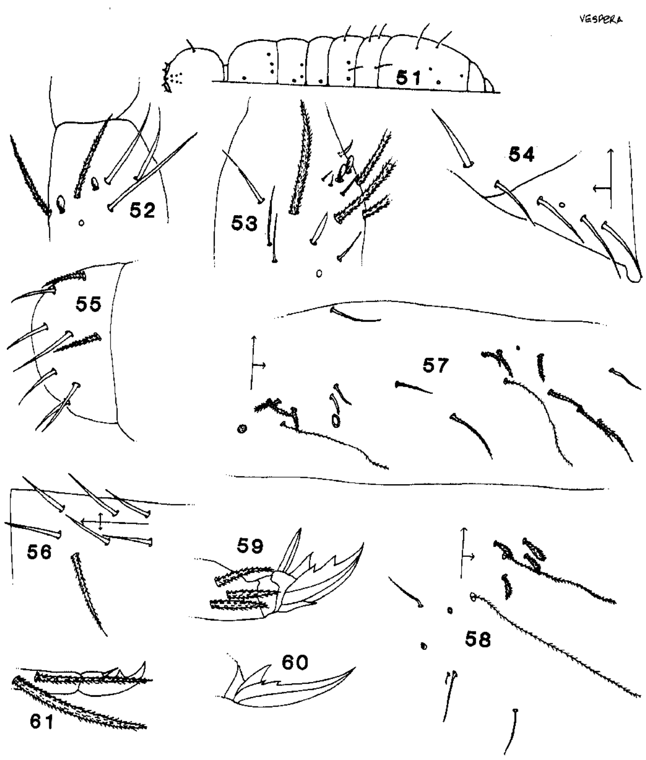
Description: Eyes and pigment absent. Maximum length, excluding appendages, 2.4 mm. Antennae 1.5-1.9 times as long as cephalic diagonal and without apical bulb. Antennal segment ratios as: 1/2.3-2.8/1.9-2.5/3.9-4.4. Subapical sense organ rod-like with a slight oval apical swelling. Lenticular organs unclear or absent. Third antennal apical sense organ (not observed clearly on type specimens) with seta 1 slender, short and blunt; setae 2 & 3 expanded, 4, 5 & 7 slender, filamentous and not acuminate; seta 8 slightly expanded medially and acuminate; seta 9 about as long but slender and blunt. Prelabral setae 4-5-5-4 all smooth. Lateral P setae absent. Labial palp not clearly seen but apparently with only 1 sublobal hair. All labial triangle setae are smooth macrochaetae except for R which is absent. Labial ventral groove with 4+4 ciliate machochatae along margin. The fourth abdominal segment anterior bothriotrichal complex lacking supplementary seta. Trochanteral organ with 5-7 setae in each arm, 3-4 internal and 2-4 external setae. Ventral tube with about 7+7 large ciliated setae on anterior face: disto-lateral patches with 8-9 setae, 1 or 2 ciliated, remainder smooth; posterior face with 2 large ciliated, and 6 medium smooth setae. Posterior leg with large inner seta acuminate and moderately distinguished from other setae, located 0.32-0.43 of the distance from base to apex of tibiotarsus. Unguis with 3 clear teeth, distalmost varying from 0.32-0.70 distance from base to apex. Unguiculus without outer tooth. Manubrial plaque with 2 inner and 2 outer setae. Mucro with apical tooth 2-2.25 larger than median and with basal spine whose apex reaches to tip of median tooth. Uncrenulate dens 2.8-4.0 times as long as mucro.

Holotype: female and one paratype female, Bat Cave, Rutherford Co., North Carolina, 6 July 1977, P. Hertl coll. (locality no. 3979).

Additional records: Blowing Springs Cave, Swain Co., North Carolina, 22 March and 18 May 1979, S.P. Platania coll. (locality nos. 3985 & 3986).

Derivatio nominis: from vespertilio, Latin for bat, after the type locality, Bat Cave.

Remarks: This species is distinguished from *P. granda* by



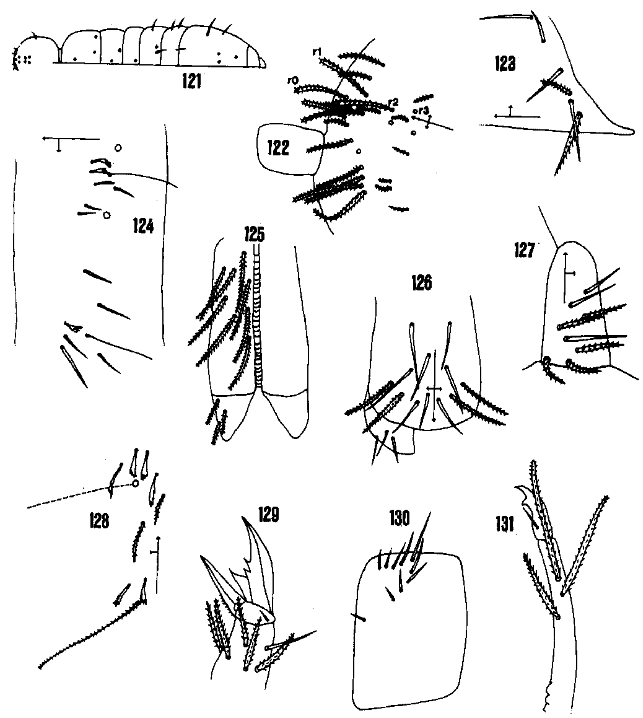
Figures 51-61 of Pseudosinella vespera. 51. Semidiagrammatic illustration of dorsal macrochaetae and pseudopores (hollow circles). 52. Apical region of second antennal segment, type specimen. 53. Apical setae of third antennal segment, right side seen from above, specimen from Swain Co. 54. Labial triangle setae, right side, type specimen. 55. Ventral tube setae, distolateral patch, right side, specimen from Swain Co. 56. Ventral tube, posterior face, seen from a posterior angle, type specimen. 57. Dorsal chaetotaxy, second abdominal segment, right side, type specimen. 58. Outer bothriotrichal complex, third abdominal segment, specimen from Swain Co. 59. Hind foot complex type specimen. 60. Hind unguis, specimen from Swain Co. 61. Apex of dens and mucro, specimen from Swain Co.

the smooth labial triangle setae. It is separated from *flatua* by the presence of posterior macrochaetae on thoracic segments 2 & 3. It is distinguished from *maritima* (Bagnall, 1941) by the acuminate tibiotarsal outstanding seta as well as habitat. It differs from the European *styriaca* (Neuherz & Nosek, 1975) in the absence of the P1 seta on the fourth abdominal segment, claw shape, and structure of setae 2 & 3 on the third antennal segment apex. It is difficult to analyze the insufficiently described New Zealand species *insoloculata* (Salmon, 1941); however *vespera* appears to differ in claw structure and a generally longer antenna. It appears to be most similar to the European cave species *virei* (Absolon, 1901) but differs in lacking the second abdominal segment p seta and the 4th abdominal segment P1 seta, as well as other minor features. Since both species are troglomorphic, conspecificity seems highly improbable.

The present collections are two populations differing strikingly in their level of troglomorphy. The Swain Co. specimens are much more troglomorphic than the Rutherford Co. ones. The fact that the cephalic chaetotaxy, thoracic macrochaetae, and other chaetotaxic features are the same in both populations indicates that they can be considered the same species. Further collections may well show intermediate conditions in caves found between these two areas.

Pseudosinella extra sp. nov. (Figs. 121-131)

Description: White without eyes or traces of pigment. Maximum length, omitting appendages, 1.5 mm. Antennae 1.38-1.5 times as long as cephalic diagonal and lacking apical bulb. Antennal segment ratios 1/2.0-2.4/1.30-1.65/3.0-3.4. Subapical organ small and rod-like. Lenticular organs weakly



Figures 121-131 all of Pseudosinella extra. All figures of type specimens. 121. Semidiagrammatic illustration of dorsal macrochaetae and pseudopores (hollow circles). 122. Detail of anterior dorsal cephalic chaetotaxy of left side. 123. Labial triangle setae. 124. Lateral chaetotaxy of second abdominal segment, left side. 125. Ventral tube, anterior face. 126. Posterior face of ventral tube. 127. Ventral tube, left side, distolateral patch. 128. Fourth abdominal segment bothriotrichal complex, left side. 129. Fore foot complex. 130. Trochanteral organ. 131. Mucro and ends of dens.

developed between third and fourth and second and third segments. Third antennal apical setae 2 & 3 small and peg-like; setae 1 & 4 curved, slender, and acuminate and about 3 times as long as setae 2 & 3. Seta 5 very small and peg-like; seta 8 curved, blunt and slightly basally enlarged; setae 6 & 7 slender curved and slightly truncate. Prelabral setae 4-5-5-4 all smooth. Labial palp with three sublobal hairs. Labial triangle with seta M1 and r ciliate; remainder smooth. Marginal macrochaetae along cephalic labial ventral groove 4+4, all ciliate. Second abdominal segment with P seta relatively long but not clearly ciliate. Fourth abdominal segment with anterior bothriotrichal complex having a supplementary seta. Trochanteral organ with five setae in arms and one external seta. Ventral tube with 7+7-8+8 large ciliate setae on anterior face and 10-12 on posterior face; distolateral patches with 8 setae, 3 smooth and remainder ciliate. Hind tibiotarsus with clearly differentiated inner large seta, only slightly longer other large setae but cylindrical and apically blunt or truncate, situated 0.32—0.37 distance from base to apex of tibiotarsus. Unguis with 3 clear teeth; basal pair large with one much larger than other; distal tooth prominent and 0.4-0.5 distance from base to apex of inner unguis. Unguiculus acuminate with outer margin serrate. Tenent hairs acuminate and apically curved. Manubrial plaque with 2 inner and 2 outer setae. Uncrenulate dens 2.1-2.8 times as long as mucro. Apical mucronal tooth about 1 1/2 times as long as basal with basal spine not quite reaching apex of subapical tooth.

Holotype: female and 1 paratype: Jack's Cave, Scott Co., Virginia, 14 June 1995, on debris, D. Hubbard coll. (locality no. 7854).

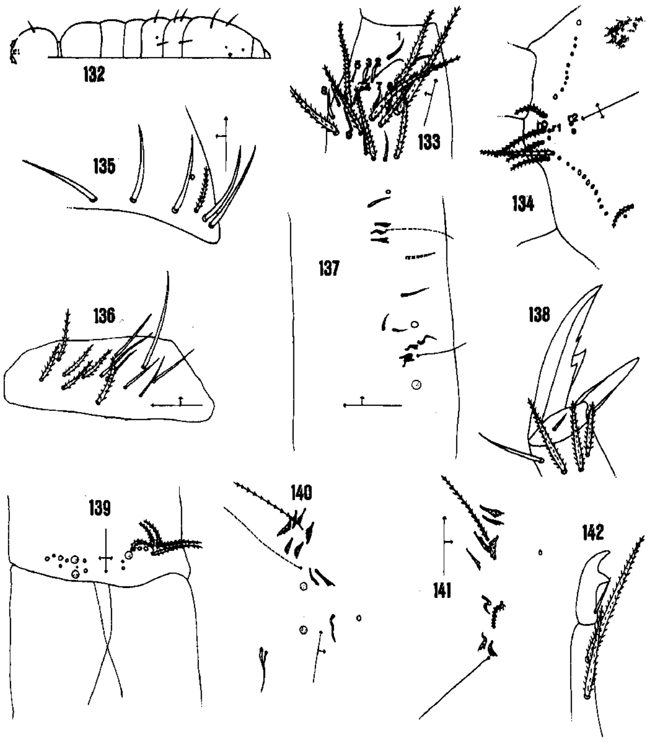
Other locality: Basil Duncan Cave, Scott Co., Virginia, 2 March 1995, D. Hubbard coll. (locality no. 7807).

Derivatio nominis: named because the first specimens were seen after the original manuscript had been completed.

Remarks: This species is quite close to *P. vespera* from North Carolina but the ciliate r seta on the labial triangle and the presence of a p seta on the second abdominal segment, as well as the different thoracic macrochaetae, readily serve to separate the two species.

Pseudosinella bona sp. nov. (Figs. 132-142)
Description: White except for eyepatches. Eyes 1+1 or 2+2 but generally without clear cornea visible. Maximum length, omitting appendages, 2.7 mm.

Antennae 1.5-1.8 times as long as cephalic diagonal and lacking apical bulb. Antennal segment ratios 1/2.2-2.7/1.85-2.25/3.1-3.35. Subapical organ rod-like, truncate, and with a slight taper. Lenticular organs well developed, one between second and third segments and 1 or 2 between third and fourth segments. Third antennal apical setae seen clearly on only one type specimen. Setae 1, 4, 6 & 9 are acuminate slender and longer than 2 & 3 which are swollen; setae 5 & 7 are short and peg-like; seta 8 is acuminate and slightly basally swollen supplementary seta between setae 5 & 8 seen in the type is absent



Figures 132-142 all of Pseudosinella bona. All figures of type specimens. 132. Semidiagrammatic illustration of dorsal macrochaetae and pseudopores (hollow circles). 133. Apex of third antennal segment, type specimen. 134. Detail of anterior, dorsal cephalic chaetotaxy. 135. Labial triangle setae. 136. Distolateral ventral tube setae, left side. 137. Chaetotaxy of second abdominal segment, right side. 138. Fore foot complex. 139. Manubrial plaque. 140. Third abdominal lateral bothriotrichal complex, right side. 141. Fourth abdominal segment bothriotrichal complex, right side. 142. Mucro and ends of dens.

in the Washington Co. specimens. Prelabral setae 4-5-5-4; posterior most row ciliate and remainder smooth. Labial palp with three sublobal hairs. Labial triangle with seta r and rarely seta M^1 ciliate; remainder smooth. With 4+4 ciliate, marginal macrochaetae along labial ventral groove. Second abdominal segment with P seta relatively long but not clearly ciliate. Fourth abdominal segment with anterior bothriotrichal complex having a supplementary seta. Trochanteral organ with 8-15 setae in arms, 9-20 internal and 1-3 external setae. Ventral tube with 10+10 to 14+14 large ciliate setae on anterior face and 2 ciliate macrochaetae and 14-20 mesochaetae on posterior face; distolateral patches with 9-14 setae, anterior 4-7 ciliate and remainder smooth. Hind tibiotarsus with clearly differentiated acuminate inner large seta, only slightly longer other large setae, situated 0.22-0.41 distance from base to apex of tibiotarsus. Unguis with 3 clear teeth; basal pair moderately large with one only slightly larger than other; distal tooth prominent and 0.52-0.58 distance from base to apex of inner unguis. Unguiculus acuminate with outer margin smooth. Tenent hairs acuminate. Manubrial plaque with 2 inner and 4-7 outer setae. Uncrenulate dens 2.3-2.5 times as long as mucro. Mucronal apical tooth slightly longer than subapical with basal spine slightly exceeding apex of subapical tooth.

Holotype: female and 10 paratypes: Goodwin's Cave, Roanoke Co., Virginia, 4 June 1995, on debris, D. Hubbard coll. (locality no. 7845), same cave Big Formation Room, 1 August 1973 (locality no. 4319).

Other locality: Lowe's Cave, Washington Co., Virginia, 7 September 1979, Holsinger et al. coll. (locality no. 4319).

Derivatio nominis: Latin bonum = good, named after type locality cave.

Remarks: This striking species was first sent to the senior author in 1974 by Ferguson; however the two specimens were not adequate for a description. An additional 2 poor specimens were sent by John Holsinger in 1979 from Washington Co. When David Hubbard started making extensive collections of Collembola in Virginia caves we suggested he return to Goodwin's Cave to see if the species could be rediscovered. He did so and sent a fine series of specimens.

The species is unusual in always having clear eye pigment but in only one specimen could we see an obvious indication of a cornea. It is close to the Virginia species *P. granda* but is clearly distinguishable on the basis of the eye pigment and the large ciliate r seta in the labial triangle. It also resembles *P. gisini* but can easily be separated on the claw shape. One specimen from Washington Co. has seta M^2 ciliate on one side but all populations show specimens with the typical labial chaetotaxy shown in Table 1.

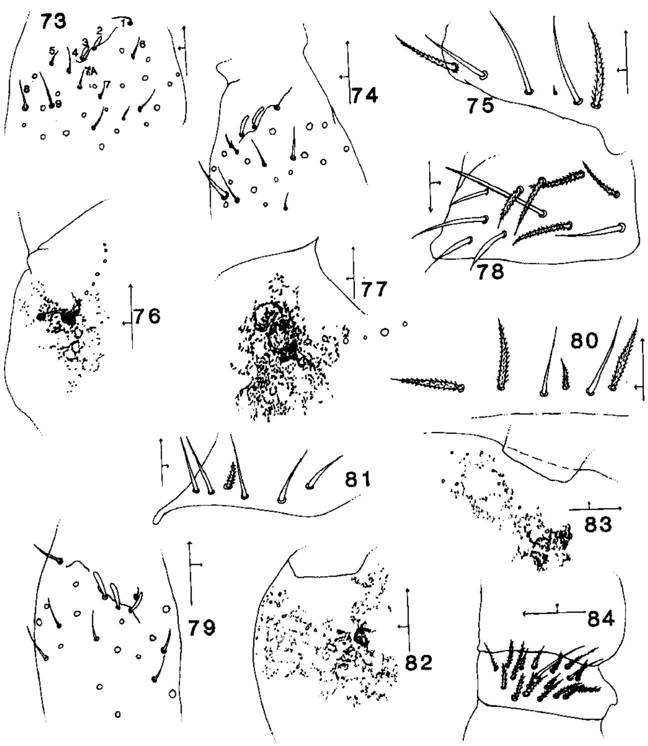
Pseudosinella gisini

This species is abundant in the caves of Pocahontas, Greenbrier, and Monroe counties, West Virginia. It also has one questionable record from Mercer county. More recently it has been collected from two caves in Rutherford Counties North Carolina and one cave in Lee County Virginia. The discovery of these two amazingly disjunct populations necessitated a thorough reexamination of the species. This led to the discovery that *Pseudosinella gisini gisini* has a very unusual structure of the third antennal segment apical setae. This is the existence of a supplementary seta which we call seta 7a (see Fig. 73). Both the disjunct populations lack this seta and have third antennal apical setae more typical of the genus (see Figs. 74 & 79). All subspecies of *P. gisini* share an unusually long seta 1. The *gisini* specimens vary in the labial ventral groove chaetotaxy from all smooth to one pair smooth and the others ciliate; however the majority have the 3 anterior setae smooth and the other pair ciliate. All specimens of the disjunct populations have all 4+4 setae ciliate. The two disjunct populations are sufficiently similar to the West Virginia ones that we feel specific separation is unwarranted; however, they are sufficiently distinct that we feel subspecific status should be given. The strong possibility that further intermediates may be uncovered with additional cave exploration reinforces the adoption of subspecific status. We name them and give their characteristics in Table 3.

Descriptions:

Pseudosinella gisini virginia subspecies nov. (Figs. 74-78)

Maximum length 2 mm. Body and appendages white. Blue pigment limited to region of eyes, and a scattering of granules over remainder of dorsum of head. Eyes generally 2+2 but a few specimens have these very obscure and may have only 1+1 eye. One specimen has distinctly darker pigmentation on anterior half of the dorsum of head. Tenent hair occasionally acuminate but generally weakly truncate. Unguiculus occasionally with very slight inner swelling on one pair of legs but generally without such. Ventral tube features as shown in Figure 78 and Table 3. Other features as in *P. gisini gisini*.



Figures 73-84 of Pseudosinella gisini. 73. Apical setae of apex of third segment of gisini gisini. Large setae with only bases shown. Figures 74-78 all of gisini virginia. 74. Apical third antennal setae as in Figure 73. 75. Labial triangle setae, right side. 76-77. Eyepatches, left side in two different specimens. 78. Setae of distolateral patch of ventral tube. Figures 79-84 of gisini carolina. 79. Apical setae of third antennal segment, as in Figure 73. 80-81. Labial triangle setae of two specimens from the same cave. 82-83. Eyepatch regions of same two specimens. 84. Setae of distolateral patch of ventral tube.

Holtype: female and 6 female paratypes, Spangler Cave, Lee Co., Virginia, 29 March 1995, D. Hubbard coll. (locality n. 7815).

Pseudosinella gisini carolina subspecies nov. (Figs. 79-84)

Maximum length 3 mm. Pigment varying from completely lacking or blue, limited to eye regions to dark around eyes and with a wash of granules over remainder of the dorsum of head and body. Eyes 1+1 to lacking. Tenent hairs generally acuminate but occasionally truncate or weakly clavate. Unguiculus with or without slight basal swelling. Ventral tube chaetotaxy as shown in Table 3 and Figures 84. Other features as in *P. gisini gisini*.

Holotype: female and 4 female paratypes, McGrath Fissure, Rutherford Co., North Carolina, 25 November 1994, Cato & Christ Holler colls. (locality no. 7774).

Other collection: Rumbling Bald Cave, Lake Lure, Rutherford Co., North Carolina, 2 July 1977, P. Hertl coll. (locality no. 3973).

The nature of this species and its distribution poses a presently unsolvable puzzle. The species is large (adult size mostly 3-5 mm) and readily recognizable. Extensive collections have been made in caves between the two disjunct populations and the West Virginia sites. It is very unlikely that it occurs in more than a few intermediate caves. Given the extensive surface collections done in this region it is highly unlikely that it occurs outside of caves. This would indicate a long occupation in caves and a troglobite nature. On the other hand, the fact that the species is weakly troglomorphic in a number of features (clavate or truncate tenent hairs often present, pigment and eyes present) plus the widely disjunct distribution would appear to point to a troglophile species with relatively recent invasion of caves.

Oncopodura

The other genus we shall deal with in this paper is *Oncopodura* (Carl & Lebedinsky, 1905).

This genus and the family Oncopoduridae have been reviewed by a number of authors, including Bonet (1943), and Szeptycki (1977a, b); most recently Deharveng (1988) has reviewed the literature, established species groups of *Oncopodura*, and proposed taxonomic use of new characters. Christiansen and Reddell (1986) described two new species from Mexican caves and discussed the Mexican fauna.

We have discovered a number of new cave and edaphic species in the course of our work updating the *Collembola of North America*. Most species of the genus appear to be troglobitic and this is true of the new species we have discovered from North America. Several of these species are too poorly represented by specimens to merit description. Table 4 indicates some of the diagnostic characteristics of these species, as well as all described cave species of the genus so far known from North America.

The genus is remarkably uncommon in collections, and most species we have seen are represented by very few specimens. Because of the extreme fragility of specimens and the deciduous nature of the diagnostic scales and spines, many are unsuitable for description. In the case of *O. fenestra*, in many hundreds of samples from the caves of Travis and Williamson counties in Texas only 5 specimens have been recovered, with no more than two from any one cave. Since the habitat in which they were found does not appear exceptional in any way,

Table 3. Distinguishing Characteristics of Subspecies of Pseudosinella gisini.

subspecies	Labial triangle setae	eyes per side	3rd antennal segment seta 7a	macrochaetae each side of labial ventral groove S = smooth C = ciliate	unguiculus basal swelling	ventral tube anterior face distal row setae	disto lateral ventral tube setae per side	disto lateral smooth setae per side
gisini	$\underline{M}_1 M_2 \underline{r} E \underline{L}_1 L_2$ $M_1 M_2 r E L_1 L_2$	2-3	+	4s + 0c - 1s + 3c	$(\underline{+})$+	2(3)	13-24	2-5
virginia	$\underline{M}_1 M_2$ vg $E L_1$ $\underline{L}_2$	(1?) 2	-	4c	$(\pm)$ -	1	10-11	4-5
carolina	$M_1 M_2 \underline{r} E L_1 L_2$ $\underline{M}_1 M_2 \underline{r} E \underline{L}_1 \underline{L}_2$	0-1	-	4c	+ , -	2,3	19-24	2-3

s = "smooth", c = clearly ciliate .

Table 4. Characteristics of US Cave Oncopodura.

species	Localities	no. inner serrate dental spines	P.A.O. lobes	lateral lamella unguis	no. setae types 7 & 8 on 2nd antennal seg.	No. setae types 7,8 & 13 on third antennal segment	No. setae types 7 & 8 on fourth antennal segment	scale on mucro	median long setae of abdominal segment 5 / length of segment	no. mucronal teeth
sp. CC	New Mexico	3?	0	+	12-14	8-10	7-8	+	?	4
cruciata	Montana	3	4	-	5	3	5	-	.3	4
sp. E	Wyoming Montana	1(0)	5-6	-	3	3	5	+	.35	4
fenestra	Texas	3	0	+	13-15	9-14	6	+	.4-.5	4
hoffi	Missouri	5	3(4)	-	5	5-6	5	-	.33-.38	4
iowae	Iowa, Illinois, Missouri	2	2	-	3	1	4	-	≈.3	4
mala	Oregon California?	2	1-4?	-	2	3	4	+	≈.3	4
tunica	California	2	5	-	2	0	10	+	≈.45	4
hubbardi	Virginia	1	5-6	+	3 (2?)	2	5	+	.37	4

this rarity is difficult to explain. The only two large series of *Oncopodura* we have seen were from rocks isolated in midstream, suggesting that individuals are extremely solitary and aggregate only when compelled to do so by rising water.

Both Szeptycki (1977a,b) and Deharveng (1988) have good general discussions of the taxonomic features of the group. In general we follow the model of Deharveng (1988) in the following descriptions. Among the characters he used are the types of antennal setae; we find some of these to be generally useful in descriptions, and illustrate a number of types (from his description of *O. pelissei*) which can be recognized in our species.

Oncopodura fenestra sp. nov. (Figs. 86-97)

Description: Habitus: typical of genus (see Fig. 86). Maximum length 2.0 mm. Color white without trace of pigment. Antennae 1.5-1.8 times cephalic diagonal, without apical bulb or scales. Fourth segment with subapical trio not clearly separated from other setae. Two apically sharply curved acuminate setae and one more basal short one, apically acuminate and basally expanded; a similar seta may be present near the second type 8 seta; six type 8 setae, one basal, a second and third close to each other, and three additional, widely spaced, all in a line; the basalmost of these usually has a well developed type 11 seta next to it; almost all other setae are of type 1A. Third segment with 9-14 apical and subapical type 8 setae; ventral surface with a number of very long slender setae; other setae are thick type 1A. Second segment with 12-15 type 8 setae; others are type 1A, of varying thickness and length. First antennal segment with one small type 8 seta, two ventral microsetae, and type 1A setae of varying sizes. PAO absent. Unguis moderately broad, untoothed, and with a prominent inner lamina, slightly shorter than the unguiculus; outer pretarsal seta about 1/10 length of inner unguis; inner seta minute and difficult to observe. Unguiculus acuminate, without clear basal swelling. Apically expanded seta of mesotibiotarsus clavate; most other tibiotarsal setae are large, acuminate, and extremely finely ciliate. Tenent hair slender and acuminate. Ventral tube without prominent papillae; with 4+4 type 1A setae on distolateral lobes. Tenaculum with 44 teeth and large stout acuminate ciliate seta on the corpus. Manubrial chaetotaxy not intact on any specimen seen but there are many (about 25+25) dorsal setae, at least 15 being of type 14 and at least 5 of type 4. Dens distoventrally with 4 large type 1 setae; external face basally with one extremely finely ciliate, acuminate mesochaeta, and distally with one very large curved spine having many minute scales on its median face; dorsally not intact on any specimen, but apparently with 5 large type 14 setae (2 basal, 1 medial, 2 distal) plus one medial and 2 basal small type 1A setae; internally with 3 curved, deeply serrate spines, increasing in size distally. Mucro with 4 teeth and a large scale. Fourth abdominal segment with median row of 4+4 and 1+1 posterolateral macrochaetae, and 10+10 microchaetae. Fifth abdominal segment with 4+4 posterolateral

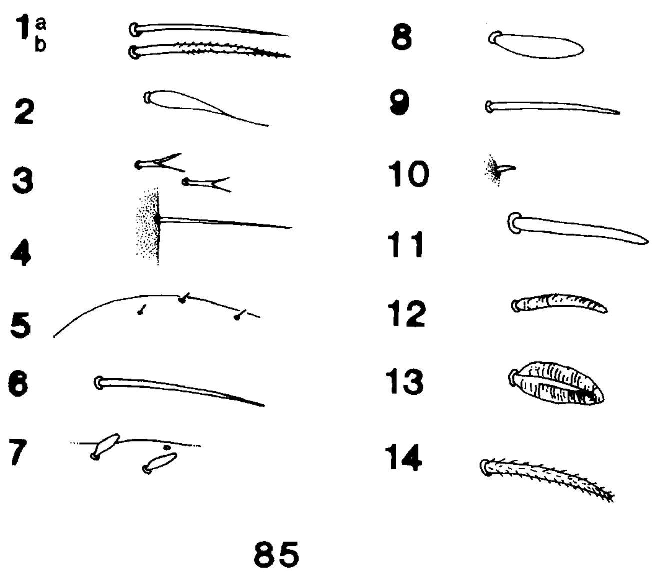
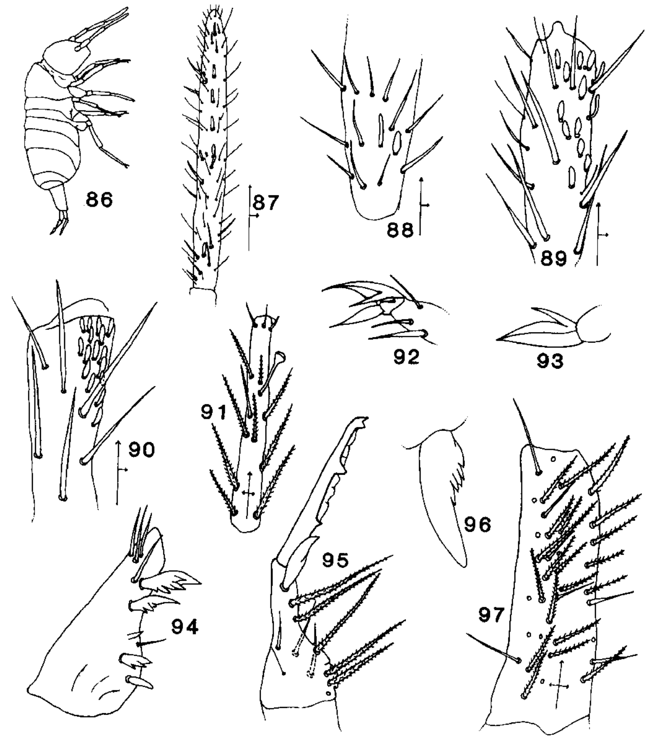


Figure 85 semidiagrammatic illustration of antennal seta types of Oncopodura modified from Deharveng (1988), see text.

Type	Description (see Fig. 85)
1A.	Normal medium to large smooth setae, gradually tapering to point.
1B.	Similar to 1A. but finely ciliate.
2.	Normal setae swollen at the base, with or without a slender apical extension.
4.	Setae similar to type 1A but prominently at right angles to body or antennal surface.
6.	Setae similar to type 1A but slightly truncate.
7.	Short blunt fusiform setae.
8.	Large blunt flattened fusiform setae.
9.	Long blunt subcylindrical setae, often thinwalled.
13.	Setae similar to type 8 but with clear striations at right angles to central axis.
14.	Marochaetae, multilaterally ciliate.



Figures 86-97 of Oncopodura fenestra. 86. Habitus, type specimen. 87. Right fourth antennal segment, type specimen. 88. Base of fourth antennal segment, specimen from Maple Run Cave, Travis Co. 89. Apex of third antennal segment, type specimen. 90. Apex of second antennal segment, type specimen. 91. Outer face of mid tibiotarsus, type specimen. 92. Hind foot complex from side, type specimen. 93. Mid unguis inner view, same specimen. 94. Inner face, right dens, type specimen. 95. Outer face, right dens and mucro, same specimen. 96. Enlarged view of distal outer spine, specimen from Sting Cave, Williamson Co. 97. Dorsum of manubrium, type specimen.

macrochaetae in rows, 3+3 small type 1A setae anteriorly, and 5+5 microchaetae in posterior half. Sixth segment with 2 rows of macrochaetae, 4 anterior and 5 in posterior row.

Holotype: Cueva de la Ventana, Travis Co., Texas, 10 February 1993, M. Wharton coll. (locality no. 7564).

Other records: Maple Rune Cave, Travis Co., Texas, 31 January 1991, J. Reddell coll. (locality no. 7332). Inner Space Caverns, Williamson Co., Texas, 6 May 1989, W. Elliott coll. (locality no. 7125). Sting Cave, Williamson Co., Texas, 7 November 1994, Reddell & Reyes colls. (locality no. 7824).

Derivatio nominis: Latin fenestra, window, after the type locality cave (ventana = window).

Remarks: This unusual species was originally identified as *O. prietoi* (Bonet, 1943), but on closer examination was seen to be very different in antennal chaetotaxy and different in other minor features. The presence of 6 type 8 setae on the fourth antennal segment distinguishes it from all other New World members of the genus; in this respect it resembles *O. lebretoni* (Deharveng, 1988), a French troglobite which is otherwise very different. The type 11 seta on the base of the fourth antennal segment is absent in the holotype but present in the specimens from Maple Run Cave and Sting Cave. The specimens from Inner Space Cave, Williamson Co. do not show the antennal structure clearly, but are otherwise similar to the type. *O. fenestra* would belong in Deharveng's group 2.2.

We have seen only 5 specimens form 4 localities among hundreds of samples from Texas caves, implying a remarkable rarity.

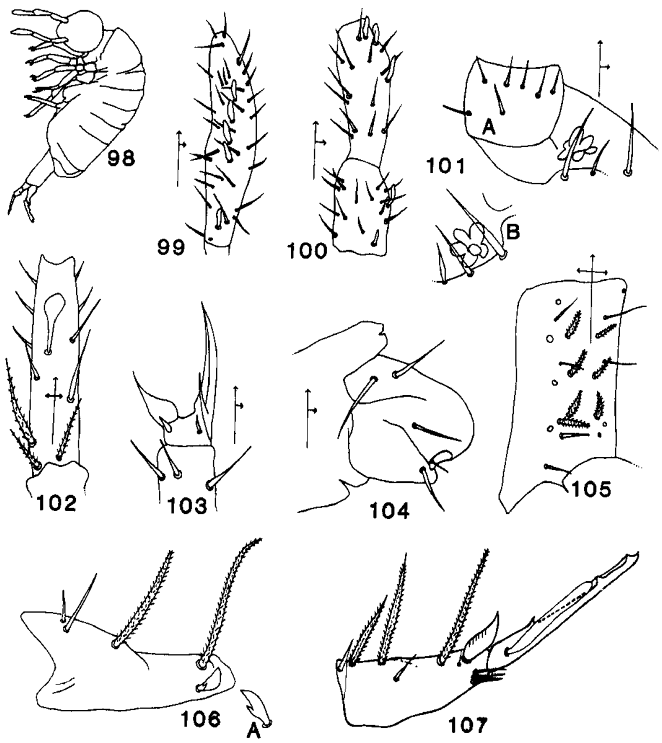
Oncopodura hubbardi sp. nov. (Figs. 98-107)
Description: Habitus: typical of genus (see Fig. 98), except that the suture between the third and fourth abdominal segment is often obsolete so that the two appear to be one segment. Maximum length 1.2 mm. Color white (yellowish in alcohol), without trace of pigment. Antennae 1.14-1.38 times as long as cephalic diagonal, without apical bulb. Fourth antennal segment with one type 6 and two type 9 setae in subapical trio: one basal and a row of 4 distal setae of type 8; other setae of type 1A or 4. Third antennal segment with 2 apical setae of type 8 and a medial one, (sometimes absent?); other setae of type 1A. Second antennal segment with 2 setae of type 8 in medial file; other setae of type 1A or intermediate between types 1A and 2. First antennal segment with distal ring of 9 setae and a few others, of type 2 or intermediate between types 2 and 1A. PAO distinct, in shallow groove, with 5-6 radiating lobes of unequal lengths. Unguis very slender, untoothed, and with pronounced slender lamina about 3/4 as long as unguiculus; pretarsal setae very small, the inner one often difficult to see and only 0.03 times length of inner unguis. Unguiculus basally strongly swollen, between 1/2 and 2/3 as long as inner unguis. Apically expanded mesotibiotarsal seta with flattened ovoid shape and pronounced ridge along one margin; 3 basal tibiotarsal setae finely ciliate, remainder smooth. Ventral tube with 4+4 large smooth setae on distolateral lobes, and 2 small curved blunt setae, often difficult to observe, in deep groove behind posterior lateral setae; pair of large apically indented papillae anteriorly at end of the ventral groove, and smaller pair, not indented, in equivalent position on posterior face. Tenaculum with 4+4 teeth and single small blunt seta on basal part of the corpus. Dorsal surface of manubrium not clearly seen, but apparently with 12+12 setae, 4+4 (5+5) of type 4 and remainder of type 14. Dens ventrodistally with 3 stout type 1A setae; external face with a small slender straight spine basally and a very large curved distal spine with a few very fine inner serrations; dorsally with 3 basal and 2 distal type 14 setae, and two basal and one medial smooth type 3 setae; inner face with one moderate distal curved spine having one (rarely two) large serrations. Mucro with 4 teeth and large basal scale. Fourth abdominal segment with medial row of 3+3 macrochaetae but otherwise not clearly seen. Fifth segment with 3+3 anterior type 1A setae and 4+4 lateral type 14 macrochaetae. Sixth segment not clearly seen, but apparently with 12 posterior macrochaetae in 3 rows of 4, 3, and 5 setae from front to back.

Holotype: and 14 paratypes: Reasor's Cave, Lee Co., Virginia on rock near stream, 13 July 1994, D. Hubbard coll. (locality no. 7739).

Other localities: Burton Cave, Lee Co., Virginia, 6 June 1994, D. Hubbard coll. (locality no. 7710); Spangler Cave, Lee Co., 29 March 1995, D. Hubbard coll. (locality no. 7815).

Derivatio nominis: after David Hubbard who collected this species and whose other incredible collections have been invaluable for this as well as other studies.

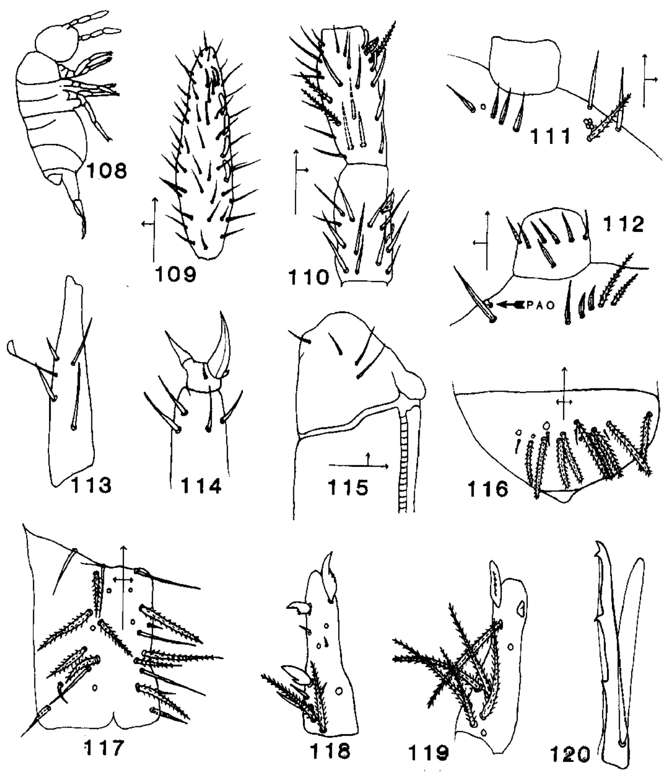
Remarks: This is the only Nearctic species combining the features of a dental scale, ungual lamella, and lobed PAO. It would fall in Deharveng's (1988) group 2.2.



Figures 98-107 of Oncopodura hubbardi. All figures of type specimens. 98. Habitus. 99. Dorsal surface of fourth antennal segment. 100. Dorsal surface of second and third antennal segments, same specimen. 101A-B. P.A.O. of two specimens. 102. Inner face of mid tibiotarsus. 103. Fore foot complex, seen from side. 104. Ventral tube. 105. Dorsal surface of manubrium. 106. Inner face of left dens, A. distal spine from different angle. 107. Outer face of left dens.

Oncopodura mala sp. nov. (Figs. 108-120)
Description: Habitus: typical of genus (see Fig. 108). Maximum length 1.3 mm. White without trace of pigment. Antennae 0.9-1.04 times as long as cephalic diagonal, without scales. Fourth segment without apical bulb, but with a conical projection; subapical trio with sharply curved type 6 setae and one straight thick stout acuminate seta; a distal file of 4 type 8 setae; other setae of type 1A. Third antennal segment with one type 13 seta, one distal and one smaller subapical seta of type 8, about 15 dorsal setae intermediate between types 2 and 1A; ventral surface with setae of types 1A and 3. Second antennal segment with one apical and one subapical seta of type 8 , one short, spine-like apical seta, and remaining dorsal setae intermediate between types 2 and 1A; ventral surface with setae of types 1A and 3. First antennal segment dorsally with type 2 setae in apical row plus one basal; ventral surface not seen

clearly. Single unlobed, small globular PAO in type specimens; California specimens have 4 weakly to well developed lobes in small PAO. Unguis short, stout and untoothed, without lateral lamina; inner pretarsal seta about 0.3 times as long as inner unguis. Unguiculus broad, acuminate, and not basally swollen. Differentiated outer seta of mesotibiotarsus shaped like a lacrosse stick. Tenent hair slender and acuminate. Other tibiotarsal setae acuminate and smooth or finely ciliate. Ventral tube with 4 distolateral type 1A setae, and small papillae at tip of ventral groove; small canals similar to those shown by Dehaveng (1988) in *O. lebretoni* are present. Tenaculum with 4+4 teeth and a short acuminate type 14 seta on the corpus. Manubrium dorsally with 5+5 type 3 and 8+8 type 14 setae, plus 1+1 microsetae. Dens ventrally with 5 acuminate, smooth setae distally; externally with a large curved spine having many small to minute scales; dorsal surface not intact on



Figures 108-120 of Oncopodura mala. 108. Habitus, type specimen. 109. Right fourth antennal segment, type specimen. 110. Third and second antennal segment, same antenna. 111. Right P.A.O. and antenna base, specimen from Eagle View Cave, Calveras Co. California. 112. Left P.A.O. and antenna base, type specimen. 113. Differentiated seta of mid tibiotarsus, type specimen. 114. Hind foot complex, type specimen. 115. Ventral tube seen from side, type specimen. 116. Chaetotaxy of 6th abdominal segment, type specimen. 117. Dorsal surface of manubrium, type specimen. 120. Mucro, type specimen.

any specimen, but with 4 long type 14 and 1-2 thick type 1A setae basally and 2 long type 14 setae and 2 microsetae medially; inner face with 2 spine-like type 1A setae basally, one large basal bidentate spine, and one smaller bi- or tridentate spine distally. Mucro with 4 teeth, crenulate lamella, and large basal scale. Fourth abdominal segment setae not clear on any specimen, but with 4+4 macrochaetae plus row of smaller type 14 setae along each posterolateral margin. Fifth abdominal segment with 4+4 stout, acuminate, ciliate setae anteriorly, medially with 2+2 slender type 1A setae, posteriorly with a row of 4+4 microchaetae, and 4 type 14 setae in an angled row on each side. Sixth segment with type 14 setae in anterior row of 6, a medial row of 3, posterior row of 5; and row of 4 microsetae between the first 2 rows.

Holotype: and 5 paratypes: Malheur Cave, elevation 1,300 m, Harney Co., Oregon, 10 November 1978, E.H. Gruber & L. Wright colls. (locality no. 3987)

Other records? (see remarks): Eagle View Cave #2, Calaveras Co., California, 29 March 1979, Rudolph coll. (locality no. 4405); Three Rivers, S. Fork Kaweah R., Tulare Co., California, 10 April 1974, P. Bellinger coll. (locality no. 3416); Tilden Park, Inspiration Point, Contra Costa Co., California, 29 July 1972, V. Landwehr coll. (locality no. 4685).

Derivatio nominis: Latin malus, -a, bad, after the type locality, Malheur ("bad fortune") Cave.

Remarks: This peculiar species is easily distinguished from all other nearctic forms by the unusual chaetotaxy of the fifth abdominal segment and the tiny PAO. The California specimens differ from the types in having lobes on the PAO, but appear otherwise identical and are best treated at resent as a geographic variety; they were erroneously identified in the Collembola of North America as *O. cruciata*, but differ from this species in antennal and dental structure and the presence of a mucronal scale.

Acknowledgments

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References

Absolon, Karl (1901). Über einige theils neue Collembolen aus den Höhlen Frankreichs und des südlichen Karstes. *Zool Anz, 24*: 82-90.

Arbea, Javier & Rafael Jordana (1990). New species of *Pseudosinella* and *Lepidocyrtus* from Navarra (northern Iberian

Peninsula) (Insecta: Collembola: Entomobridae). *Spixiana, 13*: 25-31.

Bagnall, Richard (1939). Notes on British Collembola. *[V]: Ent. monthly Mag*., 75: 188-200.

Bagnall, Richard (1941). Notes on British Collembola. *[VIII]: Ent. monthly Mag 77*: 217-226.

Bonet, Federico (1943). Sobre la clasificación de los Oncopoduridae (Collembola), con descripción de especies nuevas. *An. Esc. nac. Cienc. biol., 3*: 127-153.

Börner, Carl (1901). Neue Collembolenformen und zur Nomenclatur der Collembola Lubbock. *Zool. Anz., 24*: 696-712.

Carl, J. & Lebidinsky, J. (1905). Matrialen zur Höhlen Fauna der Krim. *Zool. Anz., 28*: 562-565.

Chen Jian-Xiu & Christiansen, Kenneth (1993). The genus *Sinella* with special reference to *Sinella s.s.* (Collembola: Entomobridae) of China. *Oriental Ins*., 27: 1-54.

Christiansen, Kenneth (1961). The genus *Pseudosinella* (Collembola, Entomobryidae) in caves of the United States. *Psyche 67*: 1-25.

Christiansen, Kenneth & Bellinger, Peter (1980-81). *The Collembola of North America north of the Rio Grande*. Grinnell, Iowa: Grinnell College.

Christiansen, Kenneth; da Gama, Manuela, & Bellinger, Peter (1983). A catalogue of the species of the genus Pseudosinella. *Ciênc. biol. Syst. Ecol., 5*: 13-31.

Christiansen, Kenneth & Reddell, James (1986). The cave Collembola of Mexico. *Speleol. Monogr. Texas mem. Mus. 1*: 126-164.

Christiansen, Kenneth; Bellinger, Peter, & da Gama, Manuela (1990). Computer assisted Identification of Specimens of *Pseudosinella* (Collembola Entomobryidae). *Rev. Ecol. Biol. Sol. 27*: 231-246.

Deharveng, Louis (1988). Collemboles cavernicoles VIII. Contribution à l'étude des Oncopoduridae. *Bull. Soc. ent. Fr., 92*: 133-147.

Folsom, Justus (1924). New species of Collembola from New York State. *Amer. Mus. Novit., 198*: 1-12.

da Gama, Manuela (1984). Phylogénie des espèces européennes de *Pseudosinella* (Collembola: Entomobryidae). *Annls. Soc. r. zool. Belg., 114*: 59-70.

Gisin, Hermann (1967). Espèces nouvelles et lignées évolutives de *Pseudosinella* endogés (Collembola). *Mems. Estud. Mus. Zool. Univ. Coimbra, 301*: 1-21.

de Izarra, Dora (1965). Fauna colembologica de Sierra de la Ventana (Provincia de Buenos Aires, Argentina). *Physis, B. Aires, 25*: 263-276.

Loksa, Imre (1961). Ökologisch-faunistische Untersuchungen in der Freiheitshöhle bei Égerszög. *Acta zool. hung., 7*: 219-230.

Mari-Mutt, Jose (1986). Puerto Rican soecies of *Lepidocyrtus* and *Pseudosinella*. *Caribi. Jour. Sci., 22*: 1-48.

Mills, Harlow (1932). New and rare North American Collembola. *Iowa St. Coll. J. Sci., 6*: 263-276.

Neuherz, Heinz & Nosek, Josef (1975). *Pseudosinella styriaca* sp. n. (Collembola: Entomobryidae), a new collembolan species from the Styrian cave "Raudner-Höhle" (Austria). *Int. J. Speleol., 7*: 399-402.

Rusek, Josef (1971). Zweiter Beitrag zur Kenntnis der Collembola (Apterygota) Chinas. *Acta ent. bohemoslovaca, 68*: 108-137.

Rusek, Josef (1981). Some Collembola from Iraq. *Vestn. cesk. Spol. zool., 45*: 63-80.

Salmon, John (1941). The collembolan fauna of New Zealand, including a discussion of its distribution and affinities. *Trans. R. Soc. New Zealand, 70*: 282-431.

Stach, Jan (1929). Verzeichnis der Apterygogenea Ungarns. *Annls hist.-nat. Mus. natn. hung., 26*: 269-312.

Stach, Jan (1960). Materialien zur Kenntnis der Collembolenfauna Afghanistans. *Acta zool. cracov., 5*: 507-581.

Szeptycki, Andrzej (1977a). Morpho-systematic studies on Collembola. V. The Body chaetotaxy of the genera *Oncopodura* Carl et Lebedinsky, 1905 and *Harlomillsia* Bonet, 1944 (Oncopoduridae). *Revue Ecol. Biol. Sol., 14*: 199-209.

Szeptycki, Andrzej (1977b). North Korean Collembola. II. The genus *Oncopodura* Carl et Lebedinsky, 1905 (Oncopoduridae). *Acta zool. cracav., 22*: 45-54.

WHAT ARE "ANTHODITES"?—CONTINUED

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Having considered William White's (1995) response to my taxonomic challenge to his usage of "anthodite", based on that of Hill & Forti (1986), I feel that further discussion is called for.

The central problem, which is not resolved by Dr. White's response, is that the name "anthodite" is being applied to two separate speleothem forms that are distinct in both morphology and growth mechanism. This, it seems to me, is not tolerable under any system of nomenclature. Nor is the question as trivially academic as might be supposed; such imprecision in definitions has ill effects on the ongoing practice of geologic inventory recording in caves (Bergthold, 1995).

Dr. White's point that most speleothem names were defined by laymen, and are often imprecise, is well taken. However, in the case of anthodites, we have a reasonably informative type description in Henderson's paper of 1949, whose text and illustrations show clearly that anthodites are quill-like growths having central canals. There is no indication that the name was intended to cover acicular aragonite without central canals, which had been called frostwork since the 1890s.

Dr. White disagrees with my suggestion that anthodites are a subclass, or "style," of helictite. Because of the confusion that has arisen from the arbitrary changes in the usage of "anthodite," I may need to clarify my suggestion: I suggest that anthodites as originally defined at Skyline Caverns may be a style of helictite. I do not suggest that "anthodites" in the sense of frostwork are helictites. (The need to make this clarification illustrates the problem!)

Dr. White rejects the original anthodites as falling under helictites. As part of his basis for this, he states that helictites "are composed of calcite." This surprised me, as speleothem types are not ordinarily defined as restricted to a single composition; flowstone, dripstone, moonmilk, etc., may be composed of any of a number of minerals. Regarding helictites in particular, the literature has references to non-calcite examples—e.g., helictites of marcasite, galena and sphalerite (Peck, 1979,). Hill and Forti also index helictites of a dozen other compositions—even lava—and refer explicitly to "aragonite helictites," under which they categorize the beaded growths of Cave of the Winds, Colorado (which resemble the Endless Caverns anthodites more than they resemble frostwork).

However, if calcite produces morphology that is most characteristic of the "helictite" concept, this suggests one possible resolution of our problem: retain the word "anthodite," but restrict its use to non-gravitogenic, helictite-like speleothems having central canals, and composed of—or originating as—aragonite; i.e., those which might otherwise be thought of as aragonite helictites. This would be consistent with the original anthodite definition, but would exclude frostwork and its variants from falling under anthodites. In this scheme, aragonite speleothems would fall into two general classes: anthodites, for those having internal canals; and frostwork and its elaborations such as "aragonite bushes," for the acicular forms.

The above solution, however, makes the terms "anthodite" and "aragonite helictite" synonymous and therefore redundant. Alternatively, we could conclude that "anthodite" has been hopelessly confused and corrupted by contradictory use over the years, that it was not necessary in the first place, and that future authors would be better advised to abandon it entirely, and instead to employ "aragonite helictite" for the quill-like type and "frostwork," "aragonite bush," etc., for the acicular kind. This would be my own preference.

To "regard frostwork as an anthodite style," as Dr. White suggests (which, in effect, is what Hill and Forti did), would go against his own definition of "style" as a variation on a basic depositional mechanism. Frostwork does not have the same fundamental origin as anthodites (as originally defined). Indeed, they may be even more radically distinct than formerly thought, if Klimchouk, Nasedkin and Cunningham (1995) are correct that acicular speleothems often crystallize from aerosols. Nor does it seem logical to classify frostwork as a subclass of an "anthodite" category that was not invented until decades after frostwork was described, and whose definition was inconsistent with the properties of frostwork.

In botany and zoology, there are controversies about the level of taxonomic entity that is valid for a population (leading to "lumping" or "splitting"), but there are nevertheless accepted rules in which priority of publication is primary in establishing validity of the names themselves. In the nature of cave mineralogy, such taxonomic rigor may not often be possible, but the more closely we can emulate it, the less confusing and ambiguous our literature will be.

REFERENCES

Bergthold, L. (1995). Geology/Mineralogy [Review]: What are "Anthodites"? *Guadalupe Hooter 10*(7):3. July.

Henderson, E.P. (1949). Some unusual formations in Skyline Caverns, Va. *National Speleological Society Bulletin 11*: 31-34.

Hill, C.A. & Forti, P. (1986). *Cave Minerals of the World*. National Speleological Society, Huntsville, Alabama. 238 p.

Klimchouk, A.B., Nasedkin, V.M., & Cunningham, K.I. (1995). Speleothems of Aerosol Origin. *National Speleological Society Bulletin 57*(1): 31-42.

Peck, S.B. (1979). Stalactites and helictites of marcasite, galena, and sphalerite in Illinois and Wisconsin. *National Speleological Society Bulletin 41*(1): 27-30.

White, W.B. (1995). What are "Anthodites"?: Reply. *National Speleological Society Bulletin 57*(1): 54-55.

WHAT ARE ANTHODITES?: REPLY

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Pennsylvania State University
University Park, PA 16802

There is at least one point on which Mr. Davis and I can agree. Henderson's (1949) published description of the anthodites from Skyline Caverns, Virginia was unfortunate. Henderson describes the speleothems as "tubular". Some of the speleothems are indeed tubular, at least to casual inspection. These appear to be very similar to the "quill anthodites" described by Hill and Forti (1986). Some are faceted and look more like acicular crystals than tubes. Henderson says he examined one broken fragment which was a tube with a central canal. Unfortunately, he gives no sketches, photographs, or further details so we do not know whether the fragment was of the radiating sprays of aragonite crystals or how representative it was of the speleothem population.

I had access to two substantial chunks of the Skyline Caverns anthodites as described in the original paper. The radiating crystals, quills, tubes, or whatever did not have central canals. It is hard to be sure because the speleothems had been extensively recrystallized, with the aragonite preserved in one of them and converted to calcite in the other. I didn't make any thin sections and so cannot be sure that there might not have been canals present originally which had been destroyed in the process of recrystallization. Mr. Davis insists that a speleothem with a central canal should be classified as a helictite. Quite so. We have no disagreement. It's just that most of the speleothems to which the term anthodite is applied do not appear to have central canals. This includes those from the type locality although the Skyline Caverns speleothems are mineralogically much more complicated than a cluster of branching aragonite crystals.

With regard to usage of the term "anthodite", it is instructive to consult the various textbooks on cave and karst phenomena. Sweeting (1972) has a section entitled "Helictite (or anthodite)" which describes only helictites. Moore and Sullivan (1978) describe "aragonite helictites" and show an illustration very similar to the "quill anthodite" illustrated in Hill and Forti. Jennings (1985) doesn't use the term. White (1988) defines anthodites as "...clusters of radiating crystals. The shapes are dictated by the growth habit of aragonite...". Ford and Williams (1989) say "Aragonite in caves displays a principal habit as radiating clusters of needles, termed 'anthodites'". There is not much consistency in the definitions except that what many eastern cavers would call "anthodites", Mr. Davis would likely call "frostwork". The small radiating clusters of aragonite growing on nodular speleothems in Butler Cave, Virginia (White, 1982, Fig. 4) are very similar to the prototypical frostwork from Wind Cave, South Dakota (Tullis and Gries, 1938, Fig. 1).

I return to a point made in the first reply. It is premature (and quite possibly pointless) to attempt to establish rigorous terms until more detailed mineralogical, textural, and crystallographic information is in hand. It is a sad comment on our pitiful state of knowledge that what remains one of the very best descriptions of the relation between crystal growth habit and speleothem morphology was written by W. Prinz in 1908! In the meantime, Hill and Forti's thoughtful description of anthodite/frostwork/ helictite speleothems provides a useful starting point for badly needed research.

REFERENCES

Ford, D. & Williams, P. (1989). *Karst Geomorphology and Hydrology*. Unwin Hyman, London, 601 pp.
Henderson, E.P. (1949). Some unusual formations in Skyline Caverns, Va. *National Speleological Society Bulletin 11*:31-34.
Hill, C.A. & Forti, P. (1986). *Cave Minerals of the World*. National Speleological Society, Huntsville, AL, 238 pp.
Jennings, J.N. (1985). *Karst Geomorphology*. Basil Blackwell, Oxford, 2nd edition, 293 pp.
Moore, G.W. & Sullivan, G.N. (1978). *Speleology: The Study of Caves*. Zephyrus Press, Teaneck, NJ, 150 pp.
Prinz, W. (1908). Les Cristallisations des Grottes de Belgique. Nouveaux Memoires de la Societe belge de geologie, de paleontologie et d'hydrologie. Ser. 4, pp 1-90. English translation in *Cave Geology 1*:191-258 (1980).
Sweeting, M.M. (1972). *Karst Landforms*. Macmillan, London, 362 pp.
Tullis, E.L. & Gries, J.P. (1938). Black Hills Caves. *The Black Hills Engineer 24*:233-271.
White, W.B. (1982). Mineralogy of the Butler Cave - Sinking Creek System. *National Speleological Society Bulletin 44*:90-97.
White, W.B. (1988). *Geomorphology and Hydrology of Karst Terrains*. Oxford University Press, New York, 464 pp.

BULGARIAN ARCHAEOASTRONOMY SITE OR BULGARIAN QUARRY SITE?

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Stoev and Stoytchev (1992) identify circular rock carvings near Bailovo, Bulgaria as lunar calendars or observatories. Based on their photographs, we observe that strikingly similar sites in California and elsewhere have been identified as known or probably soft-stone quarry sites (Schumacher, 1879; Heizer, 1954; Meighan and Johnson, 1957; Wlodarski, 1979; Mark, Newman & Rogers, 1990). The materials quarried include steatite (soapstone), chlorite-glaucophane blueschist, and greenstone, all relatively soft rock and capable of being worked with flint or other hard stone tools.

The best-known sites, in ethnographic Chumcash territory on Santa Catalina Island, California (Figures 1 and 2), were still being used to quarry bowls or jars, and other utilitarian and ritual objects when the Spanish arrived. CA-SBn-12, a petroglyph site in San Benito County, California, is also thought to have been used as a quarry site (Mark et al., 1990) (Figure 3). Meighan and Johnson (1957) report that "Stone bowls were quarried…cutting a circle of the proper size on the rock face. Then…cut downward and inward to isolate a block…[and] as soon as he could, he broke off the block." The cores were then hollowed out using other stone tools (Figure 4). Whole faces were reduced in this manner, leaving numerous circular scars in close proximity (Figure 1). Some separation scars were smooth and fat due to the planar cleavage of minerals in the rock (Figure 5). In others, due to the proximity of other scars or to jointing or other imperfections, the rock split in an uneven manner and the resulting scar appears to be a half-moon or crescent to full circles with raised interiors in shape (Figure 6).

The apparent random array of circular scars on the travertine faces at Bailovo and Lipnitza appears to be very similar to some of the sites in California, where it appears that the location of the bowl cores was selected to both utilize the best material available and maximize ease in quarrying. At both the quarry sites on Santa Catalina Island and a likely quarry site in San Benito County (Figures 3, 5, and 6), the quarry faces are covered with closely packed scars indicating maximum utilization of the soft schist. It appears that Stoev and Stoytchev's (1992) photographs may be of similar quarry sites. Have travertine artifacts been found in the region, and if so, could they have been produced from such quarry sites?

In view of the possibility of alternative interpretations, we suggest that the authors may want to review the literature on the quarry sites and then reexamine and reevaluate the Bulgarian sites.

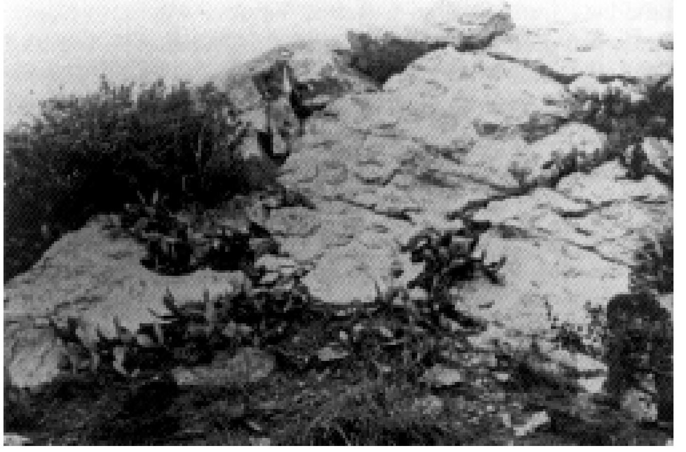

Figure 1. Site of Native American quarry in steatite outcrop on Santa Catalina Island, California (from Meighan & Johnson, 1957). Note closely packed scars especially under the figure at top center, where the large stone jars were quarried out with stone tools. Over 80 jars were removed from this outcrop alone.

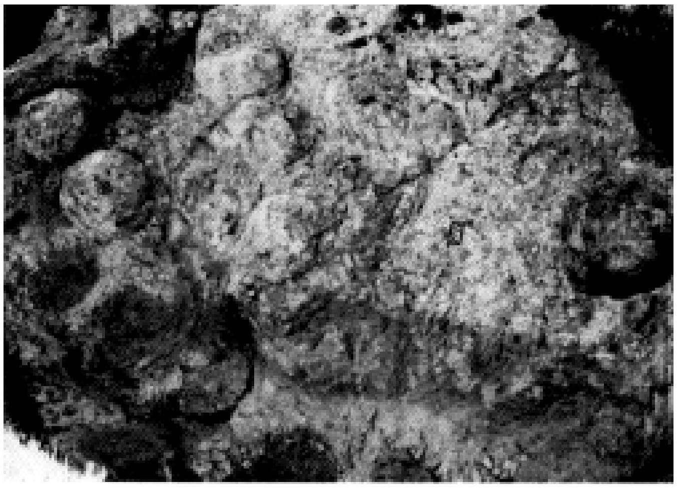

Figure 2. Another steatite quarry site on Santa Catalina Island, California. The quarry face here has apparently been worked to a considerable depth. The remaining cores are in bas-relief and appear very similar to those depicted in Stoev & Stoytchev's (1992) photographs of both the Bailovo and Lipnitza sites. Centimeter scale at right center of photograph.

Figure 3. Top of a 20 m long chlorite-glaucophane blueschist outcrop at CA-SBn-12 site, San Benito County, California. Note dense concentration of bowl core scars at this location. Field of view is approximately 2.5 m. Centimeter scale is at right edge of photograph.

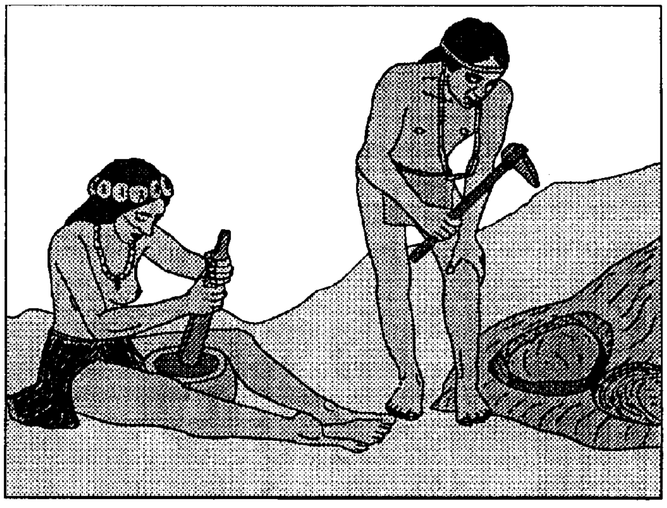

Figure 4. Reconstruction of Native Americans making bowls. After the bowl blank is quarried and broken out of steatite or soapstone outcrop, it is hollowed with stone chisels and smoothed with sandstone files. Some bowls are then decorated with incised markings. After contact with Europeans, metal tools were probably used. Illustration adapted from original by Stanley Cowards in Heizer (1954).

Figure 5. Detail of CA-SBn-12 site, San Benito County, California. Note flat-bottomed full circle quarrying scar on left and two crescent-shaped scars just to the right. Note jointing and structural grain in rock which, along with tool marks(?) has been accentuated by weathering. Scale is in centimeters.

Figure 6. Detail of CA-SBn-12 site, San Benito County California. Note large circular core base at left and small circular scar at center. Also note crescent raised core bases either side and below center where cores were quarried from outcrop. Most scars are in contact with each other. Largest scar at upper left of outcrop is approximately 20 cm in diameter.

References

Heizer, R.F. (1954). Indian Occupation in Southern California, in *Geology of Southern California* (pp. 45-53). California Division of Mines and Geology.

Mark, R.K., Newman, E.B., & Rogers, B.W. (1990). Site CA-SBn-12 Reexamined. In K. Hedges (Ed.), *Rock Art Papers*, San Diego Museum Papers, 7(26): 49-52.

Meighan, C.W. & Johnson, K.L. (1957). Isle of Mines. *Pacific Discovery 10*(2): 24-29.

Schumacher, P. (1879). The Method of Manufacture of Soapstone Pots. In 1st Lt. George M. Wheeler, *Report Upon United States Geographical Survey West of the One Hundred Meridian, Vol. VII-Archaeology* (117-121). US Army Corps of Engineers.

Stoev, A. & Stoytchev, T. (1992). Archaeoastronomical Identification of the Functional Elements in the Rocky-Cave Sanctuary

Connected with Ancient Cult Toward the Moon on Bulgarian Land. *National Speleological Society Bulletin, 54*(1): 1-6.
Wlodarski, R.J. (1979). Catalina Island Soapstone Manufacture. *Journal of California and Great Basin Anthropology, 1*(2): 331-355.

THE CALCITE/ARAGONITE PROBLEM

Those interested in the calcite/aragonite problem (what determines which is precipitated in cave formations) might be interested in an article in the 5 January 1996 issue of *Science*. A similar question exists concerning the form of $CaCO_3$ in the shells of organisms, and it appears that they use large organic molecules at templates to force the precipitation of whichever form they prefer. The authors have duplicated the effect in the lab. Full reference is "Control of Aragonite or Calcite Polymorphism by Mollusk Shell Macromolecules." Guiseppe Falini et al., v. 271, p. 67-69.

REVIEW OF CAVE LAWS IN ENVIRONMENTAL GEOLOGY

A paper reviewing significant state and federal laws that protect karst, caves, and associated unique minerals and biota appeared in the September 1995 issue of *Environmental Geology 25*(2). NSS member and *Journal* associate editor George Huppert of the University of Wisconsin Department of Geography and Earth Science wrote "Legal Protection For Caves in the United States," which gives an overview of the laws and acts that can be used to protect cave resources in the US.

NEANDERTHAL CAVE ARCHITECTS

The "research news" section of *Science*, 26 January 1996, page 449, has a brief article reporting that an evidently manmade low wall composed of broken speleothems in a cave at Bruniquel, southern France, has been tentatively dated to 47,000 years ago. This date places the construction in the days of the Neanderthals, quite a bit older than the oldest paleolithic cave paintings (Grotte Chauver, 31,000 years). That Neanderthals, previously thought to have little mastery of fire, could have been so far into the dark zone of the cave is remarkable—assuming, of course, that the dating (said to be only a lower limit to the age) holds up to further scrutiny.

RASS OFFERS RESEARCH GRANTS

The Howard T. Urbach Research Grant is awarded annually by the Richmond Area Speleological Society (RASS) to a graduate student in one of the affiliated disciplines of speleology. The maximum grant in 1996 is $1500. The deadline for submission is 10 February 1996 and the award will be made 1 May 1996. Although this notice is late for this year, students and professors may wish to note the availability of the grant in their files.

Information on the grant program can be obtained from Sandra Altorfer at:

RASS
5300 W. Marshall Street, Suite 10
Richmond, VA 23230
804-673-2283

GSA MEETING FEATURES PAPERS ON KARST

The annual, national convention of the Geological Society of America was held between 6-9 November 1995 in New Orleans, LA. At least 19 papers on karst topics were accepted and presented at the meeting. The abstracts are published in the publication, *1995 Geological Society of America Program with Abstracts, v. 7.* In addition, most of the abstracts have been reprinted in *Geo² 23*(1). Some of the titles and authors are shown below.

Spring monitoring to access impacts from land application of animal wastes to ground water quality in northwest Arkansas: Sinor, N.J., Davis, R.K., and Steele, D.F.

A 6000 year stalagmite growth banding record for Cold Water Cave, northeastern Iowa: annual and seasonal precipitation changes: Jones, M.C., and others.

A speleothem record of recurrent dry periods and catastrophic flooding in central Missouri: Recelli-Snyder, H.L. and others.

Littoral karren along the western shore of Newfoundland: Malis, C.P., and Ford, D.C.

Principles for delineating boundaries of wellhead and springhead protection areas in carbonate terrains: Quinlan, J.F., Schindel, G.M., and Davies, G.J.

Hydrogeologic, geochemical, and biological data integration for characterization and management of groundwater drainage basins in karst aquifers: Veni, G.

Penn State's waste water land application nutrient management program: Parizek, R.R. and others.

A karst inventory of the Oak Ridge Area, Tennessee: the first step towards characterizing hazardous waste sites in carbonate terranes: Lemiszki and others.

Geochemistry of Lechuguilla Cave pool water: Turin, H.J., and Plummer, M.A.

Tritium in Lechuguilla Cave pool water: implications for recharge processes: Turin, H.J. and Plummer, M.A.

Flooding patterns in karst wetlands in middle Tennessee: Wolfe, W.J.

Controls on regional flow velocities in unconfined carbonate aquifers: Worthington, S.R.H.

KARST SYMPOSIUM SCHEDULED AT 1996 AAAS CONVENTION

The Geology and Geography Section of the National Speleological Society plans a half-day symposium titled Interactions of Karst Geology and Ecology at this year's American Association for the Advancement of Science (AAAS) convention in February. The NSS is a member society of the AAAS and special program was originally proposed by our representative to the AAAS, Dr. Daniel L. Chess of Connecticut. Chess and Dr. George Veni, the Geology and Geography Section chair, are the co-chairs.

CLIMATIC CHANGE - THE KARST RECORD
CALL FOR PAPERS

A symposium will be held next summer at the University of Bergen, Department of Geology, Bergen, Norway on karst systems as a unique source of paleoclimatic information. The University of Bergen and The Karst Waters Institute of the United States will sponsor the event between 1-4 August 1996.

Contributions are invited to the following sessions:
1. Speleothems as high-resolution recorders of paleotemperature, erosion rates, ice cover, sea level, and mechanisms and processes of speleothem deposition.
2. Cave sediments and stratigraphy, including paleomagnetism.
3. Inference of climatic change from the morphology and function of karst landforms.
4. Climatic change as inferred from paleontological and archeological records in karst caves.
5. Present day speleofauna and environmental change.

In addition to abstracts that will be pre-printed in a conference volume, full manuscripts are required from all contributors for later submission to special issue(s) of international, refereed journals.

For additional information concerning costs and pre- and post-conference excursions, contact:

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LIFE SCIENCES EDITOR REPLACEMENT NEEDED

Dr. Horton H. Hobbs, III is retiring from his position of Life Sciences Associate Editor of the *Journal of Caves and Karst Studies*. Hobbs has served on the Editorial Board since 1987 and his many years of service to the publication (formerly called the *NSS Bulletin*) are greatly appreciated. We wish him success with his new endeavors. The new editor of the *Journa*l needs a replacement for Dr. Hobbs. The responsibilities of the Associate Editors are to solicit articles, arrange for appropriate reviews for papers within 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 sections of the *Journal*. Interested candidates are asked to send a letter of interest and a curriculum vitae by June 1, 1996 to:

Editor, *Journal of Caves and Karst Studies*
PO Box 3388
Littleton, CO 80161-3388

ABSTRACTS

We will occasionally publish abstract from scientific conferences that are directly related to cave and karst studies. The following abstract was submitted by the author.

REDWALL LIMESTONE KARST AND COLORADO RIVER EVOLUTION DURING LATE TERTIARY, GRAND CANYON NATIONAL PARK, ARIZONA

Noel Eberz, Grand Canyon River Guides, 4433 Kathy Rd., Flagstaff, AZ 86001

Presented at the Quaternary Geology/Geomorphology Session at the Geological Society of America's National Meeting, New Orleans, LA, November 1995.

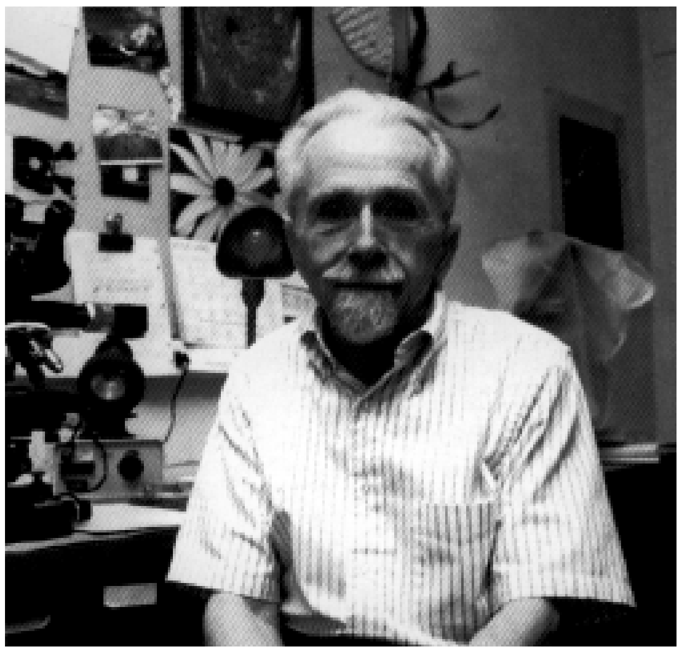
The extended Colorado River has a long, complex and segmented history of evolution. In Grand Canyon, several models of this history have centered on the classic problem of how the river incised the Colorado Plateau, and specifically the Kaibab upwarp of the Kaibab Limestone (Permian) peneplain. Was the upwarp the topologic obstacle it appears to be today?
New data on the age of the river bring into question stream superimposition through Mesozoic strata, now very remote, and favor a more recent history in a regional topography not significantly different from the present. As an alternative, there is evidence for stream capture through karst conduits abundant in the Redwall Limestone (Mississippian) near the Chuar Basin, a transitional area between upper Marble Canyon and lower Grand Canyon N.P.

Field mapping of horizontal lineaments of collapse breccias, dissolution topography, and cave conduits show a large subterranean drainage system that predates the present river course. The conduits terminate in the vicinity of the friable Butte Fault zone, consequently tunneling across a critical segment of the Kaibab upwarp. As such, an upper, mature river valley with a high water table was captured by a youthful, high-gradient stream aided by high-pressure karst conduits 2000 ft. below the Kaibab peneplain. Many artesian springs eroded the broad Chuar Basin during an early phase. A latter phase was subsequent collapse and surface capture of the river at the lowest and southernmost location near Cape Solitude. As the new river incised Marble Canyon, the other now-isolated and preserved karst routes reversed flow to form narrow, steep side-canyons creating high buttes of the original peneplain surface. Other evidence includes renewed cutting of side streams in the lower basin and exposure of major aquifer routes in the upper basin. Present erosion rates of the river support this area being a knickpoint with a capture time of 2-4 Ma ago.

Louise Hose has explored and studied the caves of Mexico for 25 years. Her work at Sistema Purificación spans more than a decade. She has a Ph.D. in geology and is currently working on a book on the geology of the Grand Canyon.

Walton C. Koemel, age 58; married; studied Electrical Engineering at Texas Tech. U., 1956-1960; farmed, 1962-1980; began designing Extremely Low Frequency radio receiver, 1983; observed ELF radio emissions produced by flying insects, 1988; research published in *Annals of the Entomological Society of America, 87*(5); observed Very Low Frequency radio emissions produced by flying bats, 1993.

Dr. K. N. Prasad, a former Director of the Geological Survey of India, is a noted paleontologist who has worked extensively on the mammalian fauna of the Siwalik. His study of Pleistocene cave fauna extended over several years. He was the recipient of the gold medal from the Watumull Foundation, Hawaii, for his exemplary contributions in the field of biostratigraphy, environment and science education.



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DEEPEST CAVES IN THE WORLD

	Cave Name	Country	Depth (m)	Length (m)
1.	réseau Jean Bernard *Caves & Caving 48*:35 - Summer 90	France	1,602.0	20,000
2.	Lamprechtsofen-Vogelschacht Taternik - 02/95	Austria	1,532.0	37,000
3.	gouffre Mirolda/Lucien Bouclier *International Caver 8*:33 - 1993	France	1,520.0	9,000
4.	Shakta Vjacheslav Pantjukhina *Caves & Caving 43* - 1989	Georgia	1,508.0	—
5.	Sistema Huautla Mark Minton - 12/95	Mexico	1,475.0	55,953
6.	Sistema del Trave (La Laureola) Laurent Anfrey - 01/92	Spain	1,441.0	9,167
7.	Boj-Bulok *Caves & Caving 58*:35 - Winter 92	CIS	1,415.0	5,000
8.	(Il)laminako Aterneko Leizea (BU56) *Caves & Caving 40*:40 - Summer 88	Spain	1,408.0	14,500
9.	Lukina Jama - Manual II *Spelunca 58* - 1995	Croatia	1,393.0	—
10.	Sistema Cheve (Cuicateco) *NSS News 53*(10):279	Mexico	1,386.1	23,500
11.	Sniezhnaja-Mezhonnogo *Atlas Des Grands Gouffres Du Monde* - 1986	Georgia	1,370.0	19,000
12.	Ceki 2 (Cehi) *International Caver 4*:40 - 08/92	Solvenia	1,370.0	—
13.	réseau de la Pierre Saint Martin *Atlas Des Grands Gouffres Du Monde* - 1989	France/Spain	1,342.0	53,800
14.	Siebenhengste-hohgant Höhlensystem (Muttsee.) *Spelunca 53*:27	Switzerland	1,324.0	135,000
15.	gouffre Berger - Gouffre de la Fromagere E.Elguero (Internet) - 05/94	France	1,278.0	26,467
16.	Cosanostraloch - Berger - Platteneck Höhle E.Elguero (Internet) - 05/94	Austria	1,265.0	30,000
17.	Torca dos los Rebecos E.Elguero (Internet) - 05/94	Spain	1,255.0	2,228
18.	Pozo del Madejuno mbrown,scmayo@rskp2.anu.edu.au - 1995	Spain	1,254.0	2,852
19.	Abisso Paolo Roversi Sherry Mayo - 1995	Italy	1,249.0	4,000
20.	Vladimir V. Iljukhina System *International Caver 12*:31	Georgia	1,240.0	5,870
21.	Sótano (Sistema) Akematl (Axematl) (Axemati) E.Elguero (Internet) - 05/94	Mexico	1,226.0	3,356
22.	Schwersystem (Batmanhole) *NSS News 42*(10):313-314 - 10/84	Austria	1,219.0	6,101
23.	Abisso Ulivifer (Olivifer) *Spelunca 59* - 1995	Italy	1,215.0	10,000
24.	Kijahe (Xontjoa) Shunthua (Kajahe Xuntua) Mark Minton - 12/95	Mexico	1,209.0	24,500
25.	Crnelsko brenzno *Caves & Caving 55*:7 - Spring 92	Slovenia	1,198.0	5,000

LONGEST CAVES IN THE WORLD

	Cave Name	Country	Length (m)	Depth (m)
1.	Mammoth Cave System CRF/CKKS - 01/95	USA	563,270	115.5
2.	Optimisticeskaja *International Caver 4*:4 - 08/92	CIS	183,000	20.0
3.	Jewel Cave Karen Rosga, NPS - 04/96	USA	170,821	212.1
4.	Hölloch MJR, *International Caver* - 02/94	Switzerland	165,500	872.0
5.	Lechuguilla Cave Dale Pate, NPS - 04/96	USA	143,773	477.9
6.	Siebenhengste-hohgant Höhlensystem (Muttsee.) *Spelunca 53*:27 - 1994	Switzerland	135,000	1,324.0
7.	Wind Cave Karen Rosga, NPS - 04/96	USA	125,983	172.2
8.	Fisher Ridge Cave System *Dug Scoops 13*(11) - 11/95	USA	125,529	88.4
9.	Ozernaja *International Caver 8* - 1993	Ukraine	111,000	—
10.	Gua Air jernih - Lubang Batau Padeng *International Caver 2* - 02/92	Malaysia	109,000	355.1
11.	Systeme de Ojo Guarena *International Caver 5* - 03/93	Spain	97,400	—
12.	réseau de la Coumo d'Hyouernèdo(e) E.Elguero (Internet) - 09/94	France	94,843	1,018.0
13.	Zoluška *Caves & Caving 28*:13 - Summer 88	Moldavioa	85,500	30.0
14.	Sistema Purificación Mark Minton - 12/95	Mexico	81,959	955.0
15.	Hirlatzhöhle *VDHK* - 01/95	Austria	79,000	1,041.0
16.	Easegill System *Caves & Caving 50*:26 - Winter 90	United Kingdom	70,500	211.0
17.	Raucherkarhöhle *Caves & Caving 44*:47 - Summer 89	Austria	70,000	725.0
18.	Friars Hole Cave System Doug Medville - 12/95	USA	69,997	188.4
19.	Toca da Boa Vista Pedro Nunes Baptista-*Cavers Digest* - 09/95	Brazil	64,000	—
20.	Organ (Greenbrier) Cave System *West Virginia Caver 10*(1) - 02/92	USA	63,569	148.1
21.	réseau de L'Alpe *Spelunca 56* - 1995	France	60,195	655.0
22.	Kazumura - Olaa Cave System Bob Richards-*Cavers Digest* - 10/95	USA	60,000	1,100.0
23.	Red Del Rio Silencio *Agvero 1* - 1995	Spain	60,000	542.0
24.	Sistema Huautla Mark Minton - 12/95	Mexico	55,953	1,475.0
25.	réseau de la Dent de Crolles *Spelunca 56* - 1995	France	55,000	668.0

Next — Special Topic Issue on:

CAVES AND KARST OF BELIZE

An Introduction to Cave Exploration in Belize
Nick Williams

The Value of Small Expeditions to Regional Cave Research:
A Reconnaissance to the Cayo District of Belize
Pete Hollings

Karstification on the Northern Vaca Plateau, Belize
Philip Reeder, Robert Brinkmann and Edward Alt

Geology and Hydrology of Belize Karsts:
Surface and Cave Development and Controls
Thomas E. Miller

Cave Archaeology of Belize
Logan McNatt

Biology of the Chiquibul Cave System, Belize and Guatemala
James R. Reddell and George Veni

Conservation of Karst in Belize
Michael Day

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