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CUEVA DE VILLA LUZ, TABASCO, MEXICO: RECONNAISSANCE STUDY OF AN ACTIVE SULFUR SPRING CAVE AND ECOSYSTEM

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Cueva de Villa Luz (a.k.a. Cueva de las Sardinas) in Tabasco, Mexico, is a stream cave with over a dozen H_2S-rich springs rising from the floor. Oxidation of the H_2S in the stream results in abundant, suspended elemental sulfur in the stream, which is white and nearly opaque. Hydrogen sulfide concentrations in the cave atmosphere fluctuate rapidly and often exceed U.S. government tolerance levels. Pulses of elevated carbon monoxide and depleted oxygen levels also occasionally enter the cave.

Active speleogenesis occurs in this cave, which is forming in a small block of Lower Cretaceous limestone adjacent to a fault. Atmospheric hydrogen sulfide combines with oxygen and water to form sulfuric acid, probably through both biotic and abiotic reactions. The sulfuric acid dissolves the limestone bedrock and forms gypsum, which is readily removed by active stream flow. In addition, carbon dioxide from the reaction as well as the spring water and cave atmosphere combines with water. The resultant carbonic acid also dissolves the limestone bedrock.

A robust and diverse ecosystem thrives within the cave. Abundant, chemoautotrophic microbial colonies are ubiquitous and apparently act as the primary producers to the cave's ecosystem. Microbial veils resembling soda straw stalactites, draperies, and "u-loops" suspended from the ceiling and walls of the cave produce drops of sulfuric acid with pH values of <0.5-3.0 ±0.1. Copious macroscopic invertebrates, particularly midges and spiders, eat the microbes or the organisms that graze on the microbes. A remarkably dense population of fish, Poecilia mexicana*, fill most of the stream. The fish mostly eat bacteria and midges. Participants in an ancient, indigenous Zoque ceremony annually harvest the fish in the spring to provide food during the dry season.*

Sulfur-rich waters of hypogenic origin formed Cueva de Villa Luz (a.k.a. Cueva de la Sardina, Cueva de las Sardinas, Cueva del Azufre) two kilometers south of the pueblo of Tapijulapa, Municipio de Teapa, Tabasco, Mexico. Small springs of thermal (+3°C above regional groundwater temperature), sulfur-rich water rise through the floor of the cave, joining the four small streams that flow into the cave from cracks too small to explore. Together, they form an active, anastomozing stream that flows through and out of the cave. Hydrogen sulfide concentration in the atmosphere varies and is frequently high enough to be a significant health hazard to visitors. In addition to the cave's fascinating hydrology and atmosphere, Villa Luz has a diverse and robust biological community that appears to be largely dependent on the mineral-rich waters.

The Cueva de Villa Luz stream flows at about 80 m msl and approximately 40 m above the regional hydrologic base level, which is represented by the Amatán and Oxocotlan rivers (Fig. 1). Lush vegetation and abundant rainfall of ~550 cm (Gordon & Rosen 1962) mark the overlying tropical hills.

The cave is ~65 km from the rich oil fields near Villahermosa, which suggests a possible migration of hydrogen sulfide from petroleum reservoirs. However, the cave is also only 10 km from a Tertiary andesitic flow and 50 km from the recently erupted (1982) El Chichón volcano, which has sulfur-rich waters in its caldera (Casadevall *et al.* 1984; Taran 1998). Consequently, the source of the sulfide-rich waters has not yet been identified.

EXPLORATION AND STUDY OF THE CAVE

Although indigenous Zoque groups visited Cueva de Villa Luz for centuries, the first systematic investigation of the cave was done by biologists Gordon and Rosen (1962). They focused on the larger organisms in the cave (fish, insects, spiders, etc.).

Cavers Jim Pisarowicz and Warren Netherton (Pisarowicz 1987) were unaware of the earlier work in this area when they started exploring and mapping caves near Teapa, Tabasco. While surveying Grutas de Cócona on the outskirts of Teapa, several people told Pisarowicz and Netherton that they should go look at "Azufre," which translates to sulfur. Pisarowicz and Netherton thought at the time that they were not interested in sulfur so put off investigating "Azufre" until the last days of their trip.

In February of 1987, just two days before Netherton was to catch a plane back to the United States, Pisarowicz and Netherton traveled to the village of Tapijulapa where they began asking about "azufre." They were directed toward a trail and told to follow it until they saw a white stream. Following the stream would lead to the cave entrance.

They found and followed the white stream until the odor of H_2S became strong and the stream emerged out of breakdown. After looking about the area, they found and descended an easier route into the cave. This entrance has been subsequently developed by the people of Tapijulapa by constructing concrete stairs into the cave.

Pisarowicz and Netherton immediately did a quick reconnaissance of the cave, wading both upstream and down. Since Netherton was to leave the next day, a discussion ensued about effectively using their time. Netherton favored beginning mapping the cave while Pisarowicz thought a photo survey of the cave should be done first. Pisarowicz's thoughts were that he had never seen similar cave features (sulfur, moonmilk-like stalactites [later dubbed snottites], ubiquitous gypsum crystals) in over 20 years of caving and that without photo documentation, few people would believe the things that they had seen. They returned to the cave with photographic equipment the next day and shot a series of pictures which were included in a presentation at the National Speleological Society convention in 1988 (Pisarowicz 1991).

In 1988, a larger expedition made a preliminary map of Cueva de Villa Luz (Pisarowicz 1988a). This expedition also began investigating the acidity of drips from snottites in the cave. Mark Minton, a caver and chemist at the University of Texas-Austin, provided Pisarowicz with several blocks of pH paper. Before entering the cave, individual pieces of pH paper were put into vials so that the acidic atmosphere of the cave would not react with all of the pH paper. During this expedition, pH of various water drops in the cave registered as low as 1.

The 1989 expedition began H_2S air sampling. A National Speleological Society grant provided a sampling pump and detector tubes to measure atmospheric H_2S. This expedition also collected elemental sulfur and gypsum samples for sulfur isotope analyses. Results indicated that the sulfur and sulfate from the cave were isotopically light and had been affected by biological processes (Spirakis & Cunningham 1992; Pisarowicz 1994).

The 1996-97 and 1998 expeditions resulted in a high-definition map of the cave (Fig. 1). The 1996-97 trip also collected, for the first time, "snottites" and wall, floor, and stream sediments for biological analysis including fixing samples for further investigation for microbes (Hose & Pisarowicz 1997a). These analyses yielded the significant finding of colonies of bacteria in extremely low pH environments. The January 1998 expedition brought a strong, interdisciplinary group of cavers, biologists, microbiologists, geologists, hydrochemists, and mineralogists to initiate detailed studies of the cave (Fig. 2).

CAVE DESCRIPTION

GROSS PASSAGE MORPHOLOGY

Total surveyed length of Cueva de Villa Luz is ~1900 m with only a few, difficult or miserable leads remaining in the cave. Total relief of the explored cave is only ~25 m. The main trend of the cave parallels the strike of the northeast trending bedrock (Fig. 3). The strike of the beds bends to a more eastward trend near the Main Entrance and the cave trend bends accordingly (Fig. 1). Passages enlarged where small, high-angle faults and joints cross them, but these minor structural features do not seem to affect the main trend of passage development. Passage upstream from the Main Entrance follows a low-angle fault.

The cave has at least 24 skylights, mostly vertical shafts with dissolution features such as natural bridges, boneyard, and rillenkarren walls. The floor is predominantly bedrock, commonly incised by the stream (Fig. 4) with only small amounts of breakdown.

STREAM

About 20 small risings of thermal (28°C), sulfur-rich water entering the cave through the floor have been identified. They join four small streams that flow into the cave from cracks too small to explore, and form an active, anastomosing stream that flows through and out of the cave. pH readings taken in early January 1998 at the springs were 6.6-7.3 (±0.1) (Palmer & Palmer 1998). The cave stream had values ranged from 7.2 upstream, near the risings, to 7.4 at the resurgence (Hose & Pisarowicz 1997b). Gordon & Rosen (1962) analyzed the water and their results are shown in Table 1.

Table 1. Analysis of stream water, Cueva de Villa Luz (Gordon & Rosen, 1962)

Temperature (April 1946)	28°C throughout
Temperature (December 1955)	30°C throughout
pH	7.0 - 7.2
Chloride	1.5×10^{-2} M
Sodium	2×10^{-5} M
Potassium	3×10^{-4} M
Calcium	6×10^{-3} M
Phosphate	None detectable
Sulfate	9×10^{-3} M
Hydrogen sulfide	Faint odor throughout

The Villa Luz stream is milky and translucent to opaque, probably due to suspended elemental sulfur. Stream discharge from the main resurgence in January 1998 was at ~290 L/sec and ~270 L/sec later in the dry season, April 1998. Prolonged exposure of skin to bottom sediments, which had slightly acidic (~6.4-6.8) pH readings, under the stream with a pH of 7.2 causes a mild burning sensation. Abundant white filaments about 2-3 cm long drift in the current. Perhaps most remarkable is the concentration of cave-adapted fish, which prompt two of the cave's alternative names, Cueva de la Sardina and Cueva de las Sardinas.

ATMOSPHERE

The odor of H_2S is apparent before entering the slightly thermal, 28°C cave. When Pisarowicz and Netherton (Pisarowicz 1987) first entered the cave in February 1987 they noted that they quickly became habituated to the "rotten egg" smell of H_2S. Fortunately, their initial reconnaissance of the cave was short as H_2S is toxic in high concentrations. In 1988, during a preliminary survey of the cave (Pisarowicz 1988ab) involving longer trips, several individuals complained about feeling ill after leaving the cave.

Starting in 1989, trips into the cave carried a Kitagawa pump to draw air samples through H_2S length-of-stain detector tubes (Kitagawa type SA and SB). Nine trips into the cave in 1989 during February and March, three trips in December 1996, and six trips in January 1997 took a total of 82 air samples for analysis at eight different locations in the cave. These results are summarized in Table 2.

In general, the atmospheric H_2S levels were higher further back into the cave, with the highest levels in the Sala Grande-Bat Room area. In areas near skylights (Main Entrance Room and Sorpresa de Jaime), H_2S concentrations were generally lower. This is presumably due to mixing of cave and outside air. Also notable is that H_2S measurements in the slightly higher, dry Fresh Air passages were the lowest throughout the cave.

Recent trips into Cueva de Villa Luz have used H_2S/SO_2 filtering respirators. When exploration of Villa Luz began in 1987, the threshold limit value (TLV) for H_2S established by the American Conference of Governmental Industrial Hygienists was 10 PPM (NIOSH 1994). Recently the Environmental Protection Agency has established a "no tolerance" limit for H_2S exposure.

We recently received an Enmet Quadrant Four-Gas Monitor (H_2S, O_2, CO, and flammable gases). In April 1998, the monitor recorded a carbon monoxide (CO) level of 48 PPM at stream level in Snot Heaven. Hydrogen sulfide concentrations at the same time measured up to 152 PPM and oxygen (O_2) dropped to 9.6% (Taylor 1999). The event lasted less than 30 minutes (the area was evacuated so the exact timing is unknown). We experienced a similar "burst" in the upstream part of The Other Buzzing Passage in January 1999 (CO at 85 PPM, H_2S at 120 PPM, and O_2 at 9.6%). The Other Buzzing Passage consistently registered the highest H_2S levels, except for occasional outgassing events elsewhere. Upstream Cueva de Villa Luz should only be entered by individuals prepared to deal with such conditions.

Table 2. Analyses of air samples taken in Cueva de Villa Luz. SD - standard deviation on data; N - number of samples at site; Range - concentrations in parts per million as determined by a Kitagawa pump drawing air samples through H_2S length-of-stain detector tubes (Kitagawa type SA and SB).

Location	Mean	SD	N	Range
Main Entrance Room	15.67	7.50	18	6-30
Big Room by Cat Box	19.22	5.81	9	10-27
End of Zoo-downstream	5.67	3.65	9	1-12
Sala Grande-Bat Room	40.00	10.72	10	25-55
Sala Grande	18.22	6.11	9	8-25
Fresh Air area	1.00	1.05	9	0-3
Entrance-Skylight	11.11	6.01	10	3-18
Zoo	9.89	4.38	9	3-16

LIFE IN THE CAVE

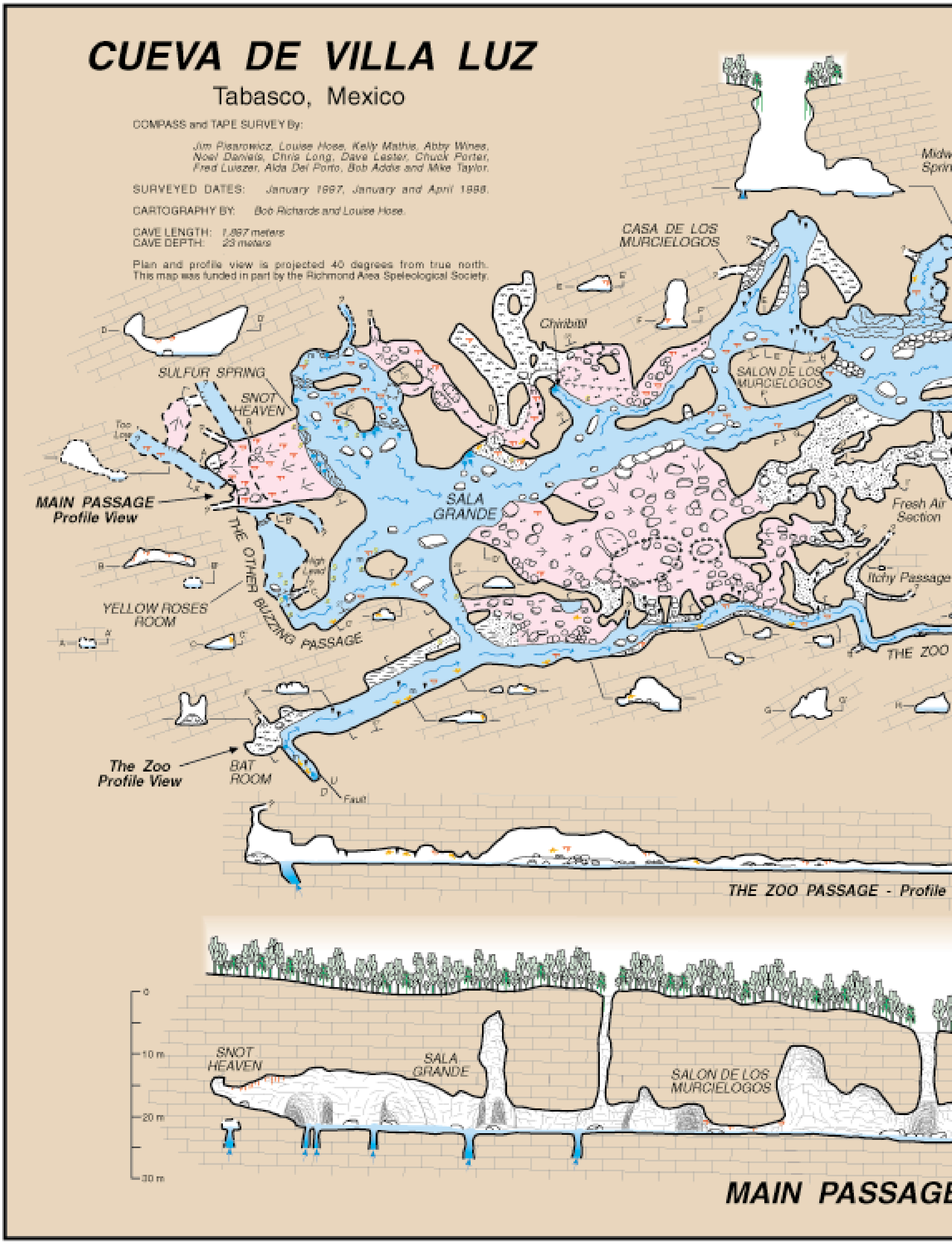
Life is abundant in the cave including plentiful bats and invertebrates. Various slimes and pastes coat the walls and floors throughout the cave. Unique to Villa Luz are growths of white, mucous-like soda straws, curtains, and "u-loops" up to 50 cm long suspended from walls and ceilings (Fig. 5). Original explorers referred to these deposits as "snottites" (Pisarowicz 1988c). Although they hang throughout the cave, they are most concentrated near the springs, particularly in Snot Heaven. Water drops from these growths had pHs of 0.0-3.0 (±0.1). The abundance of snottites was markedly greater in January 1997 than January 1998, a drier year, and even fewer hung in the cave in April 1998, further into the dry season. Atmospheric H_2S levels also declined over the three trips.

These phlegm-like materials were dyed with diamidinophenylindole (DAPI) stain, which causes material with DNA to fluoresce, and then examined under a 400x magnification with ultraviolet light. Inspection revealed that the "snottites" are communities of microbes similar to microbial mats commonly associated with sulfur-rich surface springs, but these colonies are suspended vertically. Mites, midges, worms, and various other invertebrates are commonly seen on these microbial "veils" despite the very low-pH environment (Fig. 6).

A green, slimy coating covers bedrock and breakdown immediately above water level throughout much of the cave, even in places beyond apparent visible light (The Other Buzzing Passage). Small, flying insects [probably the midge larvae] gather on these growths, apparently to graze. Spherical microbes larger than cyanobacteria mostly make up the green material.

A diverse variety of other organic and partially organic slimes coat the walls and floors. Slimy, brown, anastomosing and splotchy biovermiculations commonly coat the limestone walls. Microscopic examination revealed them as colonies of bacteria and fungi (Fig. 7). Many biovermiculation colonies were notably desiccated and represented by faint discolorations of the walls during the dry April 1998 trip. White, red, and black slimes are also abundant throughout the cave.

Figure 1 (next pages). Map of Cueva de Villa Luz, including location. Map by Bob Richards and L.D. Hose.


CUEVA DE VILLA LUZ
Tabasco, Mexico
COMPASS and TAPE SURVEY By:
Jim Pisarowicz, Louise Hose, Kelly Mathis, Abby Wines, Noel Daniels, Chris Long, Dave Lester, Chuck Porter, Fred Luiszer, Aldo Del Porto, Bob Addis and Mike Taylor.
SURVEYED DATES: January 1997, January and April 1998.
CARTOGRAPHY BY: Bob Richards and Louise Hose.
CAVE LENGTH: 1,867 meters
CAVE DEPTH: 23 meters
Plan and profile view is projected 40 degrees from true north.
This map was funded in part by the Richmond Area Speleological Society.
CASA DE LOS MURCIELAGOS
Chiribitil
SULFUR SPRING
SNOT HEAVEN
SALON DE LOS MURCIELAGOS
MAIN PASSAGE Profile View
SALA GRANDE
Fresh Air Section
THE OTHER BUZZING PASSAGE
High Lead
Itchy Passage
YELLOW ROSES ROOM
THE ZOO
The Zoo Profile View
BAT ROOM
Fault
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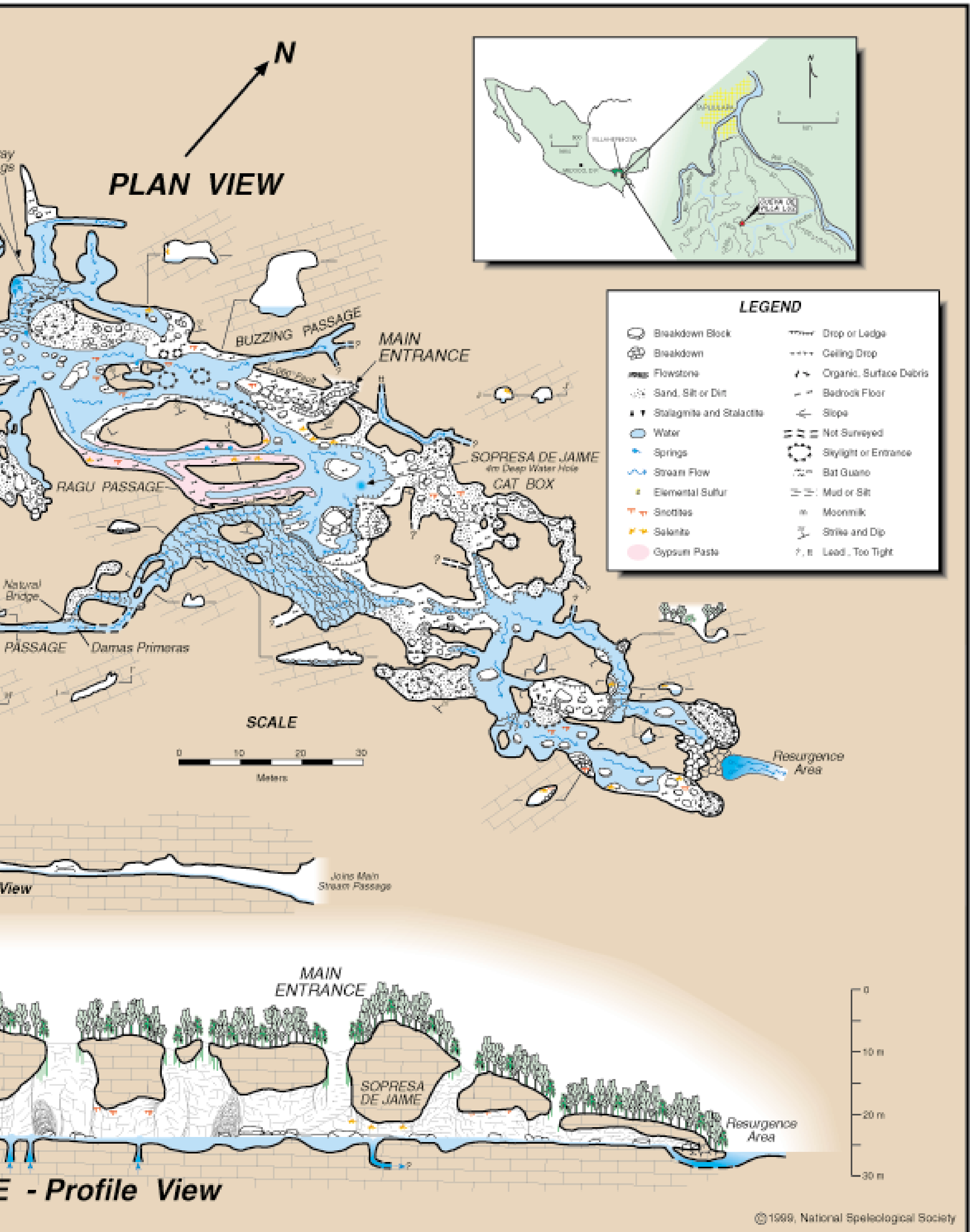
MAIN PASSAGE


N
PLAN VIEW
BUZZING PASSAGE
MAIN ENTRANCE
SOPRESA DE JAIME
4m Deep Water Hole
CAT BOX
RAGU PASSAGE
Natural Bridge
PASSAGE
Damas Primeras
SCALE
0 10 20 30
Meters
Resurgence Area
LEGEND
Breakdown Block
Breakdown
Flowstone
Sand, Silt or Dirt
Stalagmite and Stalactite
Water
Springs
Stream Flow
Elemental Sulfur
Snottites
Selenite
Gypsum Paste
Drop or Ledge
Ceiling Drop
Organic, Surface Debris
Bedrock Floor
Slope
Not Surveyed
Skylight or Entrance
Bat Guano
Mud or Silt
Moonmilk
Strike and Dip
Lead, Too Tight
View
Joins Main Stream Passage
MAIN ENTRANCE
SOPRESA DE JAIME
Resurgence Area
0
10 m
20 m
30 m
- Profile View
©1999, National Speleological Society

SECONDARY DEPOSITS

Calcite speleothems are sparse in Villa Luz. Travertine deposits form where spring waters mix with the cave stream in Snot Heaven and Midway Springs. Other poorly developed flowstone deposits are forming near Casa de los Murciélagos, at the northeast end of the Zoo, and at the entrance to The Other Buzzing Passage. A few, heavily corroded, stalactites and draperies hang from the walls of the main passage just upstream from the Main Entrance. Modest displays of stalactites and stalagmites occur in the fossil, Fresh Air section.

The most abundant speleothems in Villa Luz are splays of selenite crystals, common on the subaerial bedrock walls throughout the stream passages. Clusters and aggregates of selenite crystals are commonly located on the lower parts of ceiling pendants and on downward-facing ledges. The typically 2-4 cm long individual crystals are commonly associated with clusters of finely crystalline elemental sulfur and the microbial veils (snottites) (Fig 5). A small display of boxwork on the west side of Sala Grande was immediately adjacent to gypsum splays and elemental sulfur crystals.

White moonmilk and black, brown, orange, green, and red slimy coatings commonly cover the walls. A pasty covering of the floor in much of the cave, under 400x magnification, is mostly microcrystalline gypsum. pH of the gypsum paste is typically 1.0-3.0. Prolonged exposure to the gypsum paste (under a knee pad) resulted in a third-degree burn to one visitor.

LOCAL USAGE OF THE CAVE

For centuries, the local Zoque (a.k.a. Soque) people performed a religious ceremony, La Ceremonia de la Pesca, near and in the cave. The ritual, carried out at the end of the dry season, was believed to ensure a fertile summer growing season and provided a rich source of protein until the new crops matured. It was apparently prompted by an interpretation that the cave's unique fish population was a special gift from the Zoque gods, who inhabit the underground. Dressed in indigenous costumes, Zoque elders offered prayers and requested permission to enter the cave and harvest fish. When the "grandfather" and "grandmother" guardians of the cave gave permission, the Zoque went about 100 m upstream from the main entrance where they emptied packets of crushed roots of a barbasco vine and lime into the stream. The mixture placed in water, a traditional fishing technique in Central America, reportedly ties up oxygen and forces the anoxic fish to the surface and concentrated along the edges of the stream. The Zoque then easily scooped fish up in baskets. The fish were dried and helped nourish the people through the following months. The formal ceremony was discontinued in the mid-1940s as the indigenous religion and language in the area was lost to European culture.

In 1987, a local man named José Vasquez motivated some of the Tapijulapa men to re-enact the ritual. A troupe of mostly adolescents from Tapijulapa now perform the ceremony every spring with an adult leader speaking modern Maya (Fig. 8). Concern about the possible negative impact on the fish population has prompted a more conservative approach resulting in just a token harvest.

GEOLOGY AND HYDROLOGY

Cueva de Villa Luz is the only known cave within this small block of massive, micritic Lower Cretaceous limestone in a northwest-trending anticline truncated and uplifted on the south by an east-northeast-trending normal fault (INEGI 1989). The northeast-trending cave, as well as the surface and sub-surface springs, appears formed in the north-northwest-dipping strata along the downthrown side of this fault. At least nine other smaller sulfur-rich springs rise along the fault trend with similar temperature and pH values to the springs in the cave. Visible gas bubbles accompany only three of the surface springs and two of the subsurface (both in The Other Buzzing Passage) springs. Perhaps the other risings have already degassed in a previous chamber before entering the explorable cave or reaching the surface. The gas bubbles are suspected to be carbon dioxide (CO_2), but this suspicion is unconfirmed.

Other detached blocks of similar limestone contain caves nearby. Water rising into the swimming pools at El Azufre, a sulfur spring resort 27 km to the west-northwest, comes from a phreatic cave system. The temperature and chemistry of the waters are markedly similar to the cave water in Villa Luz. We are unaware of any attempts to explore the El Azufre caves. About 7km east of El Azufre, the commercial Grutas de Cócona appears to have mostly formed from hypogenic waters in the past. In a separate block of limestone only about 1 km east of Villa Luz, Grutas de Cuesta Chica appears to also represent a paleo-hypogenic cave.

SPELEOGENESIS

Cueva de Villa Luz is clearly forming from rising, sulfur-rich water with very little meteoric input. The cave looks to have originally formed while the bedrock was saturated with the rising, sulfur-rich water. We interpret the skylights as former vents for rising spring waters similar to the springs at El Azufre.

Downcutting by the nearby river and the accompanying drop in the local groundwater base level mostly drained the cave. The rising waters now emerge through the floor of the cave and form a stream that flows through the air-filled chambers. The rising water is slightly acidic and, combined with the highly acidic drip and condensate waters in the cave, probably causes the incised channels in the floor (Figure 4) and rillenkarren-lined stream shorelines.

As the water enters the oxygenated, sub-aerial cave environment, H_2S combines with O_2 to form elemental sulfur:

$$2\ H_2S + O_2 \rightarrow 2S^o + 2H_2O$$

Microbes may sometimes be involved in this reaction but this initial oxidation reaction can also proceed rapidly by abiotic processes.

Microbes, particularly in the microbial veils, further oxidize the sulfur to form sulfuric acid in the following reactions:

$$2S^o + 3O_2 + 2H_2O \rightarrow 2SO_4^{2-} + 4H^+$$

and

$$H_2S + 2O_2 \rightarrow SO_4^{2-} + 2H^+$$

The acid dissolves calcite in the limestone and the freed calcium ions then combine with the sulfate ions to form gypsum:

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2O + CO_2$$

$$Ca^{2+} + SO_4^{2-} + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O$$

Other biotic and abiotic reactions may achieve the same end result (Spirakis & Cunningham 1992). In addition, carbon dioxide and water undoubtedly combine to form carbonic acid that assists in the dissolution of the cave. Carbon dioxide comes from the atmosphere and rises in the hypogenic water as well as from the above reaction.

The current input of H_2S and the aggressive microbial communities promote active speleogenesis. Surely, passages are enlarging and, given the near-surface setting of the cave, Cueva de Villa Luz in its current vadose stage must be an ephemeral feature.

ECOSYSTEM OF THE CAVE

Preliminary investigations suggest a robust ecosystem in the cave that derives most its energy from chemoautotrophic processes. Downstream passages also receive energy input from bat guano and surface debris washing into the skylights.

Microbial communities, such as the microbial veils that oxidize reduced forms of sulfur create a base of the cave's food web. Sulfur-reducing microbes continue utilizing energy from the sulfur cycle. Fungi and other microbes derive further energy from the chemoautotrophs.

An extremely dense population of midges, *Tendipes fuvipilus* Rempel (Gordon & Rosen 1962; Langecker *et al.* 1996), is ubiquitous in the stream passages, particularly clustering on the green slime immediately above the stream. The midges, or perhaps their larvae, probably graze on the bacteria. Abundant spiders, beetles, mites, crickets, and other invertebrates presumably feed on either the microbes, midges, or each other.

The fish, *Poecilia mexicana* Steindachner 1863 (Gordon & Rosen 1962; Langecker *et al.* 1996), are the most striking inhabitants of the cave. Stomach analyses (Langecker *et al.* 1996) revealed a diet of dominantly bacterial filaments and midge larvae. Some downstream populations derive a minor portion of their diet from bat guano. Diana Northup and Kathleen Lavoie (personal communication, 1998) observed a diving hemipteran capture and devour a fish. Humans are the only other documented predators of the fish. A copious food supply and scarcity of natural predators facilitate the abundant fish population.

Several other vertebrates inhabit or frequent the cave. Several species of bats reside in the cave including four species of the Phyllostomid family (Gordon & Rosen 1962), a free-tail, and a vampire species. Some of the bats seem to be extraordinarily active during the day. Obvious questions for future research include whether they feed on the dense midge population in the cave and how they cope with the high toxic gas levels. (It is notable that several dead and dying bats hung from the walls in the stream passage during most visits). Sightings of eel, an accidental(?) turtle and abundant footprints of a probable tepeizcuinte (*Agouti paca*) make up the other evidence of vertebrates observed in the cave.

DISCUSSION

Cueva de Villa Luz is a striking example of sulfur-related speleogenesis and a chemoautotrophic ecosystem. Although not unique, its apparently robust ecosystem, high-energy environment, and easy access suggest that the cave will prove an excellent site for studies in both fields. The historic, and probable prehistoric, indigenous ceremonial use of the cave promises another intriguing field of investigation. We hope that the current, excellent relations with the local residents and officials will continue to facilitate work at the cave.

Other current studies at the cave include preliminary investigations into the hydrochemistry and related topics by Art and Peggy Palmer (SUNY-Oneonta), microbial biology by Diana Northup (University of New Mexico), Penny Boston (Complex Systems Research, Inc.), and Kathy Lavoie (SUNY-Plattsburg), invertebrate biology studies by José Palacios-Vargas (Universidad Nacional Autonoma de Mexico) and Carlos Blanco-Montero (Rohm and Haas Company, Agricultural Chemicals North America), sulfur mineralogy by Harvey DuChene (NSS), and a two-plus year aquarium study of the fish by Jakob Parzefall and colleagues at the University of Hamburg. With so much interest in the cave, it seems imperative that our next course of investigation be to improve understanding of the cave atmosphere, particularly the nature of the degassing events, and to improve safety procedures.

ACKNOWLEDGMENTS

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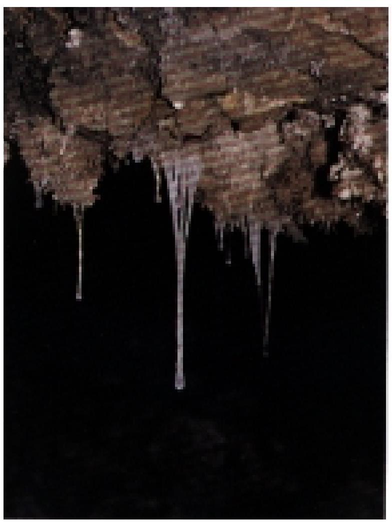

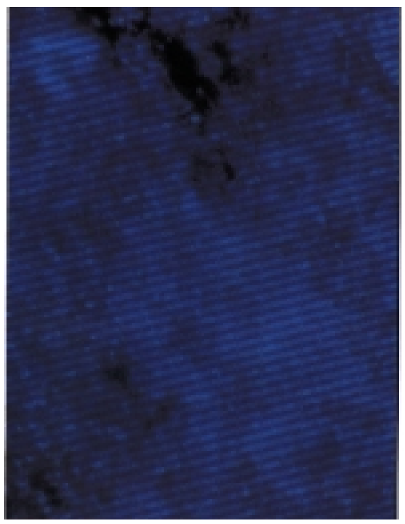

Figure 2 (top left). January 1998 group picture. Photo by Carl Snyder.
Figure 3 (center left). Looking upstream in Sala Grande. Note the stream is parallel to the strike of the beds in the ceiling over the caver. Photo by J.A. Pisarowicz.
Figure 4 (top right). Incised stream channel in down-stream portion of cave. Photo by J.A. Pisarowicz.
Figure 5 (bottom left). Snottites in Snot Heaven. Photo by L.D. Hose.
Figure 6 (bottom center). Photomicrograph of a DAPI-stained snottite—400x. Photo by L.D. Hose.
Figure 7 (bottom right). Photomicrograph of DAPI-stained bacterial and fungal colonies in graphic, brown slime deposits (biovermiculations)—400x. Photo by L.D. Hose.
Figure 8 (center right). Re-enactment of La Ceremonia de la Pesca at Cueva de Villa Luz. Photo by L.D. Hose.

Particular thanks are due to Alda Del Porto, who acted as translator, obtained most of the information we have on the Pesca ceremony, and established wonderful local relations on the January 1998 trip, and to Warren Netherton, who accompanied Pisarowicz on the first trip that led to the current investigations.

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