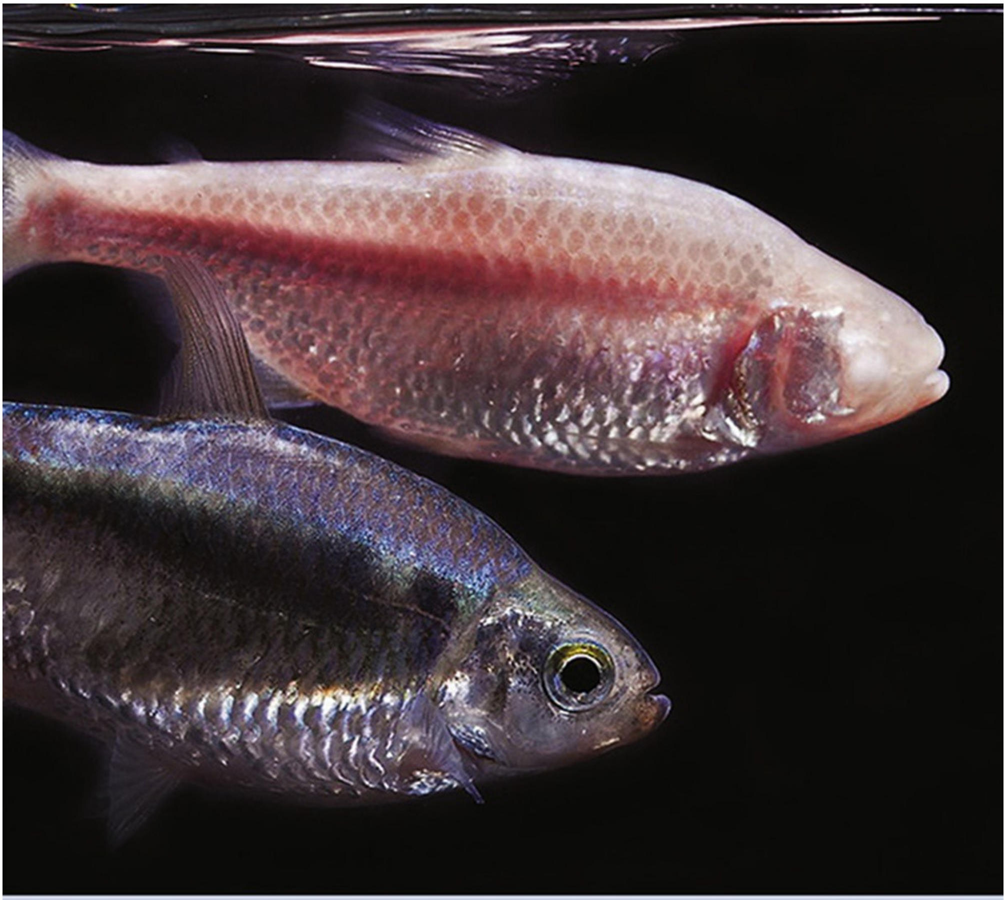

Biology and Evolution of the Mexican Cavefish

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Revised reprint:

Elliott, William R. 2015. Cave exploration and mapping in the Sierra de El Abra Region. Chapter 1, pp. 9-40 in: Keene, Alex C., Masato Yoshizawa, and Suzanne E. McGaugh (eds.), *Biology and Evolution of the Mexican Cavefish.* Academic Press (Elsevier), Amsterdam.

Chapter 1

Cave Exploration and Mapping in the Sierra de El Abra Region

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INTRODUCTION

Here I explore the worlds of biology and caving, and summarize what is known about the Mexican cavefish and its habitat. I will discuss the history of discovery, exploration, and mapping of caves in the Sierra de El Abra region (Figures 1.1 and 1.2). Much of this fieldwork was driven by an interest in the cavefish by about 200 biologists, geologists, and cavers (speleologists), who often worked together. Biologists and geologists made the first cavefish discoveries in the region. Only a few of the fish caves can be accessed on foot—vertical caving techniques and training are required in most. Many of the pit caves proved to be too challenging for academics. The cavers were younger explorers and adventurers, some of them graduate students excited by large, deep caves. Some of the professors became proficient in vertical caving, and some of the cavers became cave biologists. Americans, Canadians, Europeans, and Mexicans sometimes worked together in the field and laboratory. It also was a cultural phenomenon; the northerners learned more Spanish, fell in love with Mexico, and worked to create international goodwill. The teams found over 200 caves in the El Abra region, but just 29 of them are known to contain the Mexican cavefish.
Mexico is home to at least seven known species of cavefishes. These cavefishes have reduced or nearly absent eyes and pigment, and they have evolved from six families from widely separated areas: Characidae, Ictaluridae, Pimelodidae, Poeciliidae, Bythitidae, and Synbranchidae (Reddell, 1981). In this book, we refer to cavefishes of the species *Astyanax mexicanus*, which include the obsolete genus, *Anoptichthys*, as the "Mexican cavefish" (Figure 1.1). Whatever the Latin name may be, the Mexican cavefish is an evolving new species that is separating from its river form. The cave form can be purchased in aquarium shops and is easy to keep and breed. The aquarium breed came

Biology and Evolution of the Mexican Cavefish. http://dx.doi.org/10.1016/B978-0-12-802148-4.00001-3

FIGURE 1.1 *Asytanax mexicanus*, the Mexican cavefish from Cueva de El Pachón. *By Jean Louis Lacaille.*

FIGURE 1.2 Aerial photo looking south along the crest of the Sierra de El Abra. *By Robert W. Mitchell.*

from La Cueva Chica, described below; it is a hybrid between the river and cave forms (see the chapter on ecology and biodiversity).

A large technical literature exists in biology and speleology (caving) about caves and cavefishes in the Sierra de El Abra region of northeastern Mexico, also referred to as the "Huastecan Province." (The Huastecs are a group of native Americans in that area, whose language is related to Mayan.) Over 530 papers and reports have been published on the Mexican cavefish since 1936. A monograph on the cavefish was published by Mitchell et al. (1977). Another important study was John Fish's dissertation (1977, 2004) on karst (limestone cave) hydrology of the region. These monographs are available from the Association for Mexican Cave Studies (AMCS), Austin, Texas at http://www.mexicancaves.org, where thousands of cave maps from throughout Mexico are also available.

I can only present a few maps here and in the next chapter. For additional information and many maps, see *The Astyanax Caves of Mexico* (Elliott, in press). Figures 1.3 and 1.4 depict the northern and southern parts of the Sierra de El Abra region, about 200 km long and 60 km wide. See Table 1.1 for a listing of the 29 known fish caves, and Table 1.2 for a list of the larger nacimientos (large springs or resurgences). Another focus of cavefish evolution is in the state of Guerrero, about 400 km to the south of the El Abra, with two populations of *Astyanax aeneus* (Espinasa et al., 2001).

Physiography and Hydrogeology

Mexico is a land of complex geology and many rock types. About 7500 caves have been recorded by the AMCS, ranging through six major karst areas and lava flows with lava tubes (Mejía-Ortíz et al., 2013). Karst is a landscape formed by the groundwater dissolution of soluble rocks such as limestone, dolomite, and gypsum, with underground drainage systems, caves, sinkholes, dolines, and springs. The subject of this book is located in the karstic Sierra Madre Oriental of northeastern Mexico.

During the late Jurassic to early Cretaceous period about 146-100 mya (million years ago), a thick series of gypsum, anhydrite, and carbonate beds were deposited in shallow, warm seas in what is now northeastern Mexico. In the middle Cretaceous period, a widespread carbonate platform, or reef complex, grew on top, becoming what is now the El Abra limestone. The Sierra de El Abra is an elongated range along the eastern margin of that platform (Figures 1.3 and 1.4). During the late Cretaceous period (about 100-66 mya), the region was covered by thick deposits of shale, impermeable to infiltrating water, unlike limestone. During the early Tertiary period (starting 66 mya), the area was folded, uplifted, and subjected to erosion. The shales began to erode away, and the exposed limestone developed into a high-relief karst terrain, formed by the dissolving action of slightly acidic groundwater moving along joints (vertical fractures) and horizontal bedding planes (Fish, 2004). Later volcanic activity in the Gómez Farías area in the north created a ridge (Sierra Chiquita) that guided development of swallet (stream-capturing) caves in the karst valley immediately to the west.

Elevations in the region vary from 35 m above sea level at the Nacimiento del Río Choy in the south on the Gulf coastal plain, to 800 m in the Sierra Tanchipa portion of the Sierra de El Abra, and 269 m at Gómez Farías to over 2000 m in the Sierra de Guatemala. Annual rainfall in the region varies from 250 to 2500 mm and is strongly concentrated from June through October, when large tropical storms come in from the Gulf of Mexico. Hydrogeological studies carried out in the Sierra de El Abra show that large conduits (caves carrying water) have developed,
and that large fluctuations of the water table occur because of precipitation. The ancient caves on the eastern crest of the range were part of deep phreatic (below the water table) flow systems that circulated at least 300 m below ancient water tables and discharged onto ancient coastal plains that were much higher

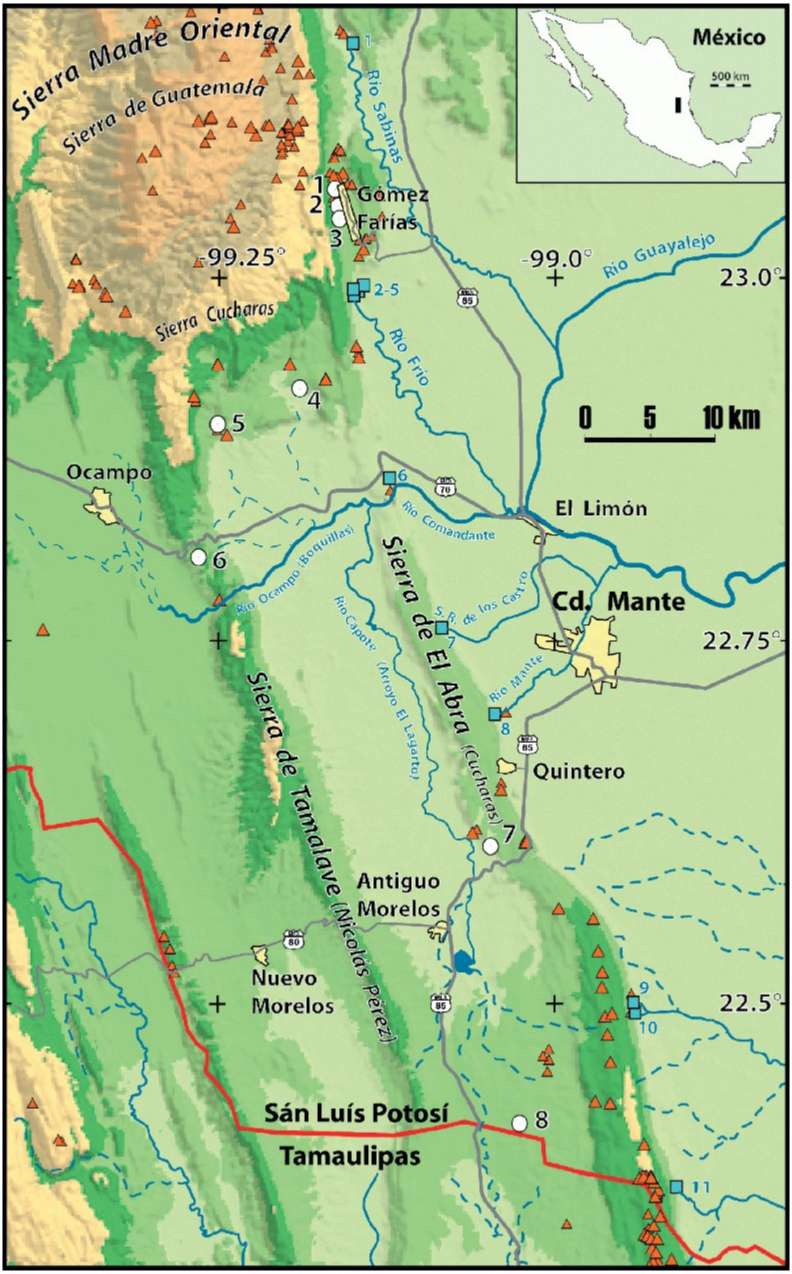

FIGURE 1.3 The Sierra de El Abra Region, northern map. Numbers for fish caves and nacimientos (springs) are in Tables 1.1 and 1.2. North is up, white dots are fish caves, triangles are other caves, and squares are nacimientos. By William R. Elliott based on INEGI 1:1,000,000 topographic map (San Luís Potosí sheet) and AMCS data. *Copyright © 2016 William R. Elliott. All rights reserved.*

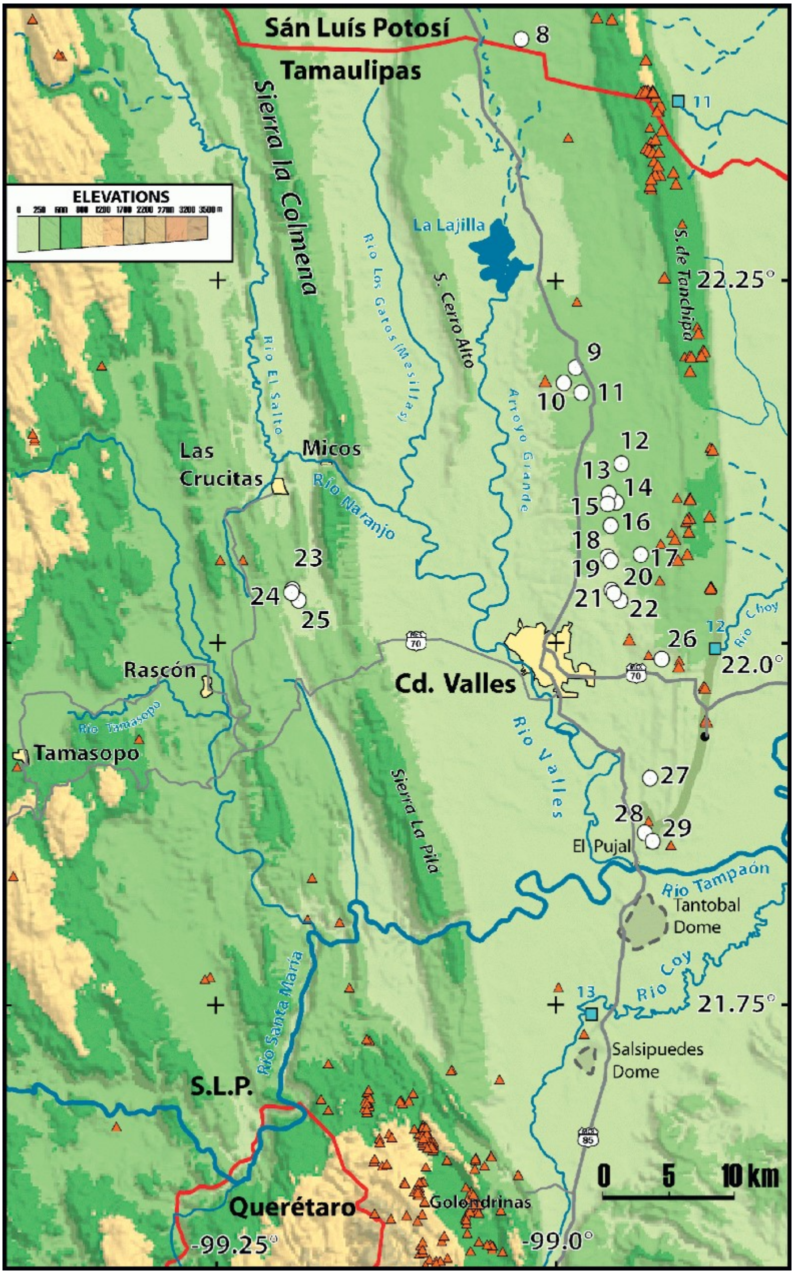

FIGURE 1.4 The Sierra de El Abra Region, southern map. See Tables 1.1 and 1.2. *By William R.Elliott.*

TABLE 1.1 The 29 Known *Astyanax* Caves of the Sierra de El Abra Region, with Label Numbers from Figures 1.3 and 1.4 and Dimensions in Meters

Label	Cave	Length	Elevation	Depth	Bottom
1	Sótano (Resumidero) de Jineo	302	292	144	148
2	Sótano del Molino	658	269	138	131
3	Sótano Escondido	100	303	150	153
4	Bee Cave	245	249	119	130
5	Sótano del Caballo Moro	285	320	211	110
6	Sótano de Vásquez	1500	422	277	145
7	Cueva de El Pachón	1000	211	8	203
8	Sótano de Venadito	3663	312	206	106
9	Sótano de Yerbaniz	2238	242	97	145
10	Sótano de Matapalma	1722	242	86	156
11	Sótano de Japonés	4500	243	140	104
12	Sótano del Tigre	3000	246	162	85
13	Sótano de la Roca	20	241	42	199
14	Cueva de los Sabinos	1502	239	96	144

15	Sótano del Arroyo	7202	192	134	58
16	Sótano de la Tinaja	4502	166	82	84
17	Sótano de Soyate	206	293	234	59 (6)
18	Sotanito de Montecillos	1741	190	92	99
19	Sótano de Pichijumo	1330	158	82	76
20	Sótano de Jos	338	176	85	92
21	Sótano de Las Piedras	405	145	47	99
22	Sótano de la Palma Seca	164	152	53	100
23	Cueva de Otates	269	220	15	205
24	Cueva del Río Subterráneo	475	239	32	207
25	Cueva del Lienzo	225	236	23	213
26	Cueva de la Curva	214	132	19	113
27	Sótano del Toro	66	92	5	88
28	Cueva Chica	320	68	19	49
29	Los Cuates (Cueva del Prieto)	400	62	22	40

The elevation at the entrance is in meters msl (above mean sea level), and is based on survey altimeter readings by Mitchell et al. (1977), at 27 caves. The elevations are within ±1 m of current INEGI topographic map elevations. Other cave elevations are based only on topographic maps and may be ±5 m. Cave depth is calculated from compass, clinometer and tape surveys. The bottom elevation (elevation-depth), is usually to the surface of the bottom-most pool.

TABLE 1.2 Thirteen Important Nacimientos (Springs) in the Sierra de El Abra Region, with Label Numbers from Figures 1.3 and 1.4 and Dimensions in Meters

Label	Nacimiento	Mean Flow (m^3/s)	Elevation
1	Nacimiento del Río Sabinas		160
2	Nacimiento del Río Nacimiento		85
3	Cueva del Nacimiento del Río Frío[a,b]		125
4	Nacimiento Florida		85
5	Nacimiento del Río Frío[c]	6	90
6	Nacimiento Riachuelo		110
7	Nacimiento de San Rafael de Los Castro[b]		95
8	Nacimiento del Río Mante	13	80
9	Nacimiento del Río Santa Clara		80
10	Nacimiento del Arroyo Seco		80
11	Nacimiento del Río Tantoán		80
12	Nacimiento del Río Choy	3	35
13	Nacimiento del Río Coy	19	31

The larger springs respond quickly to large storms, and water levels can rise by many meters.
[a]*May flow no longer.*
[b]Prietella lundbergi *site.*
[c]*Mean flow of springs #2, 4, and 5 gauged downstream.*

than the present one. These old caves may have formed by sulfuric acid speleo-genesis (cave development), caused by hydrogen sulfide from petroleum de-posits ascending and mixing with fresh groundwater, forming dilute sulfuric acid, a phenomenon now known in other karst areas (Palmer and Hill, 2005). Later the geochemistry evolved to the conventional mode of the dissolution of limestone, caused by CO_2 mixing with rain and groundwater to form weak carbonic acid. The western margin of the El Abra contains younger swallets of the floodwater type (Table 1.1). Stream capture began to occur wherever the overlying San Felipe and Mendez shales eroded to where streams could invade the underlying El Abra limestone at prominent joints. The El Abra limestone probably was exposed first along high ridges before the present-day swallets formed in the lowlands near Ciudad Valles (Fish, 1977, 2004). Stream capture dramatically isolated colonizing fish populations underground while eliminating them from surface arroyos (wet weather streambeds) at the same time, and this occurred repeatedly in different places over a long period. We do not know where the first Mexican cavefish evolved, and the original caves probably eroded away, but the fishes probably spread through subterranean connections to other sites. Many of the fish caves lie under arroyos that may have been perennial streams long ago, but are now subterranean floodwater conduits.

Large springs, or nacimientos (birthplaces), are located along the east face of the El Abra, which discharge huge amounts of groundwater from caves and even from longer connections to the higher ranges in the Sierra Madre Oriental to the west (Table 1.2). Through geologic time, the subterranean connections have grown in size and volume, causing some nacimientos to increase their discharge while others shrank. Karst is three-dimensional, even four-dimensional when one considers the dimension of time. Older, higher elevation connections may have ceased to carry flow except during very large storm events. Some cavefish populations may reconnect with each other during flood times, which can cause groundwater to rise into upper air-filled cave passages. When the water levels drop again, this can strand cavefishes in pools perched as much as 100 m above the usual water table. Some of these perched pools or lakes may become permanent bodies of water, like natural cisterns, such as in Cueva de El Pachón.

The Mexican cavefish is distributed over large distances in 29 known caves that are semi-isolated from each other, but it has not been found in the nacimientos. By semi-isolated, I mean that many caves may only have temporary hydrological connections during and after large storms. It is important to note that cavers and biologists have explored hundreds of caves in the region, so we have a good idea of where the cavefish are absent. So far, they do not occur in waters at elevations above 300 m above sea level, even when suitable habitat is found. As yet, none of the fossil caves on the eastern crest reach water, so they are not cavefish habitat either. Cave divers have not seen the cavefish in the nacimientos on the eastern face of the Sierras. A small, blind catfish, *Prietella lundbergi* (Walsh and Gilbert, 1995), was found in two springs on the eastern face by Hendrickson et al. (2001) (Table 1.2), hinting at a different history of isolation and evolution than *Astyanax*, which is found only in the western, swallet caves or in large sinkhole caves that penetrate to groundwater.

History of Exploration and Mapping

One might say that there have been three generations of cavers and biologists involved in the study of *Astyanax* cavefish. The first generation was from 1936 to 1954, and the second from 1963 to 1998. After 1989, it became increasingly difficult for cavers to access parts of the region with increasing private land development and the establishment of two large bioreserves, Reserva de la Biósfera El Cielo in the Sierra de Guatemala, and Reserva de la Biósfera Sierra de El Abra Tanchipa. These reserves are beneficial for wildlife, flora, and the preservation of many karst features. The former contains several fish caves near Gómez Farías. The latter does not include any caves housing *A. mexicanus*.

In the 1990s, the only field work was mapping in Sótano de Venadito and cave diving in the nacimientos. The *Astyanax* International Meeting (AIM) started in 2009. We are currently in the third generation of Mexican cavefish studies with the advent of modern DNA analysis and the consolidation and interpretation of cave mapping and karst studies.

The first Mexican cavefish was described by Hubbs and Innes (1936) as *Anoptichthys jordani*, based on specimens collected earlier that year by Salvador Coronado in Cueva Chica, a cave located about 1 km north of the village of El Pujal, about 12 km southeast of Ciudad Valles, San Luís Potosí. Álvarez (1946) described a second species, *A. antrobius*, from Cueva de El Pachón, located near the village of El Pachón (Praxedis Guerrero), Tamaulipas. Álvarez (1947) described a third species, *A. hubbsi*, from a large cave, Cueva de Los Sabinos, located 11 km northeast of Ciudad Valles, San Luís Potosí (Mitchell et al., 1977). It was these three "species" to which so much study was devoted by Breder and many others until the late 1960s. Now most biologists consider the Mexican cavefish to be part of the species *A. mexicanus* or *A. fasciatus*.

Cueva Chica probably was not the original site of cavefish evolution in the region, but initial work suggests it represents a younger cave that already contained cavefishes when it was intersected by the Río Tampaón (Mitchell et al., 1977). Originally mapped by Breder in 1940, Elliott and others remapped the cave more accurately from 1970 to 1974, and surveyed overland to locate the nearby tinajas (waterholes), the Los Cuates cave, and Cueva El Mante. More details are in the cave descriptions below, and in my chapter on ecology and biodiversity in this volume.

Sótano del Arroyo and Sótano de la Tinaja were located in 1946 by Benjamin Dontzin and Edwin Ruda, who were commissioned by the American Museum of Natural History (Breder and Rasquin, 1947) to collect additional eyeless characins. These two caves are located near the previously known Cueva de Los Sabinos (see Elliott, in press, and Fish, 1977, 2004, for maps).

Early fieldwork also was done by Mexican scientists like Bonet, Bolívar y Pieltain, Osorio Tafall, Peláez, Álvarez, and American biologists. Although some of the caves were known to local residents and some biologists, scientists were not equipped to explore the vertical caves that require single-rope techniques and training. In the mid-1960s, as a result of exploration and mapping by the Texas-based AMCS, new sightings of cavefishes were reported. These reports came at the same time that Robert W. Mitchell's interest grew in the Sierra de El Abra cave fauna.

Then cavers and biologists from the University of Texas at Austin, Texas Tech University, and other parts of the United States began visiting Mexico. A trip to Xilitla, San Luís Potosí in 1958 inspired Robert W. Mitchell and his associates, followed by others. They were intrigued by Federico Bonet's 1953 papers on the Sierra de El Abra caves and the Xilitla area. Following a trip to the Tequila, Veracruz area in 1962, T.R. Evans organized the Speleological Survey of Mexico, which soon became the AMCS. The emphasis was on publications to inform the world of the cavers' discoveries.

The *Association for Mexican Cave Studies Newsletter* began in 1965. The AMCS Bulletin series began in 1967 with the influential Bulletin 1, *Caves of the Inter-American Highway*, a general guide to caves of northeastern Mexico (Russell and Raines, 1967). In 1967, Sótano de las Golondrinas near Aquismón, the world's deepest pit at that time, was explored and mapped by Evans and others (Figure 1.4). The AMCS work was done mostly by American and, later, Canadian cavers at their own expense. Today, many Mexican cavers are proficient in cave exploration and mapping, and groups from overseas, notably France, Italy, England, and Australia, have made significant discoveries. Some expeditions are multinational.

By 1965, Ed Alexander, David McKenzie, John Fish, Terry Raines, and others were discovering, exploring, and mapping large caves like Sótano del Arroyo, Sótano de la Tinaja, Sótano de Pichijumo, and Bee Cave. Sótano del Arroyo, the most extensive fish cave at 7202 m long, required about 50 cavers to map from 1961 to 1971. John Fish, William R. Elliott, Don Broussard, Neal Morris, and many American and Canadian cavers worked intensively in the El Abra from 1967 to 1974, mapping many caves and studying hydrology and biology. In total, about 150 cavers were involved in mapping the fish caves and assisting scientists. This work culminated in Fish's dissertation at McMaster University, Ontario, Canada (Fish, 1977, 2004), and Mitchell, Russell, and Elliott's monograph on cavefishes (1977).

Robert W. Mitchell's research group at Texas Tech University worked closely with the AMCS (Figure 1.5). Supported by grants, in 1969, Mitchell, Richard Albert, William H. Russell, Francis Abernethy, Don Broussard, Tom Albert, and others made an extensive aerial survey of the Sierra de El Abra region, discovering seven new fish caves. This aerial reconnaissance ended when Albert's airplane crashed in the Sierra Cucharas (foothills of the Sierra de Guatemala). He and his two passengers, Tom Albert and Don Broussard, survived, but it took 2 days to find their way out of the jungle.

Bill Russell, David McKenzie, and other AMCS cavers located many caves by logging back roads, hiking through the thorn forest and the arroyos, and talking with locals. The AMCS and Mitchell's group discovered a total of 23 new fish caves, most of which were explored and mapped over the next 12 years. I was involved as a graduate student in this work from 1969 to 1974. Later, I independently focused on the Sierra de Guatemala from 1978 to 1981. Altogether, I mapped or drafted maps for 17 of the 29 known fish caves.

In 1970, Horst Wilkens and Jakob Parzefall found Cueva del Río Subterráneo near Micos about 16 km west of Ciudad Valles, based upon information from rabies control workers who were looking for bat caves. They visited a few other caves, finding aquatic troglobites, but no cavefishes. Mitchell and Russell found two more fish caves near Micos, Cueva de Otates, and Cueva del Lienzo, which Elliott and others mapped in 1974. These caves contain interesting "half-cavefishes" that are at an early stage of evolution to a cave-adapted fish (Wilkens and Burns, 1972). The Micos area has not been adequately explored for caves

FIGURE 1.5 Robert W. Mitchell's research group at Rancho del Cielo, January 10, 1971. Left to right: Masaharu Kawakatsu (Fuji Women's College), Suzanne Wiley, Mel Brownfield, Jerry Cook, Robert W. Mitchell, William H. Russell, James R. Reddell, Virginia Tipton, William R. Elliott, and Ann Sturdivant. *By Robert W. Mitchell.*

since then. One small pit cave north of the Micos caves, entered by Elliott in 1974, had dangerous "bad air" (high CO_2 and low O_2), and could not be explored.

Explorations in light airplanes over the crest of the El Abra range revealed many large, deep pits. In the mid-1970s, a campaign of "jungle chops" began in which teams of cavers used machetes to chop their way through the jungle to the pits. Long streamers were sometimes dropped from an airplane to mark a route. The opening of new back roads aided in this work, and many new caves were explored and mapped. But no fish caves were found on the crest of the El Abra. In 1977, cavers completed a 4-year campaign to "bottom" Cueva de Diamante on the El Abra crest. It had taken five expeditions and over 1500 man-hours to reach a depth of 621 m through an extreme obstacle course of tight canyons and razor-lined pits (Atkinson, 2004). At the time, Diamante was the fourth deepest cave known in the Western Hemisphere. The extreme difficulty of the cave has deterred anyone from returning, though several leads remain, including a major passage at −430 m that was taking water. Hoya de Zimapan, 320 m deep, is another major pit cave on the crest that does not go to water.

By the 1980s, the jungle chop era was over, although major pits are still unexplored; one can see them on Google Earth® today. Morris (1989) published an El Abra cave map folio. In 1989, the "Mexspeleo" caver convention was held at the Hotel Covadonga south of Ciudad Valles, and significant mapping was done in Sótano del Tigre (Figures 1.6 and 1.7). The only other significant expeditions since then were the trips led by Don Broussard to Sótano de Venadito (Figures 1.8 and 1.9). This extensive cave was mapped by 13 teams of 22 AMCS

FIGURE 1.6 Sótano del Tigre, Bill Farr on rope at the bottom of the entrance shaft, 1989. *By David Bunnell.*

cavers in 1968-1969, and then in 1989-1998, the longest effort for any cave in the El Abra. The Tigre and Venadito notes were recently drawn up for publication.

Cave divers explored nacimientos in the area from 1978 to 1989. Major dives by Bill Stone, Sheck Exley, Paul DeLoach, Jim Bowden, and others achieved depths to 55 m in Nacimiento del Río Sabinas, 264 m in Nacimiento del Río Mante (a world record at the time, Figure 1.10), 43 m in the Nacimiento del Río Choy against strong current (Figure 1.11), and 76 m in the Nacimiento del Río Santa Clara. These cutting-edge deep dives sometimes required special gas mixtures and long decompression times, and they demonstrated Fish's surmise that the springs had deep circulation under the Sierra, with some "B waters" gaining unusual chemistries from great depths (Atkinson, 2004). None of the divers reported seeing *Astyanax* cavefish in these places, but research dives in the 1990s found the new catfish species, *P. lundbergi*, "the phantom blindcat," at shallow depths in two springs on the eastern face (Table 1.2).

FIGURE 1.7 Jerry Broadus rigging rope in Sótano del Tigre, February 1, 1968. *By Robert W. Mitchell.*

MAPPING AND CARTOGRAPHY METHODS

Cave cartography is basic descriptive science. To explore a cave well, one must map it as one goes. A cave map is essential for route finding and understanding the hydrology, geologic history, and potential connections to other caves. A cave map is an important document in establishing a cave as an actual natural resource. Some of the early maps of fish caves were freehand sketches or compass and pace surveys, which are quite inaccurate in larger caves. Cave maps are used to note the locations of many points of scientific interest, including bat roosts and habitat. The special problems of speleology and cave biology are found in an extensive literature, but a good introduction may be found in Elsevier's 2007 *Encyclopedia of Caves and Karst*, in which Elliott discusses cave protection.

FIGURE 1.8 Sótano de Venadito aerial photo, with the shadow of the wing of Richard Albert's airplane, 1969. *By Robert W. Mitchell.*

FIGURE 1.9 James Reddell and John Fish at the low side drop of 46 m into Sótano de Venadito, 1969. *By Robert W. Mitchell.*

FIGURE 1.10 Nacimiento del Río Mante, 1969. *By Robert W. Mitchell.*

FIGURE 1.11 Nacimiento del Río Choy, March 2013. *By William R. Elliott.*

The 1940 expedition to Cueva Chica made the first published cave map from the region (Bridges, 1940; Breder, 1942). Charles Breder used a small plane table with a drawing sheet on a tripod, and an instrument for drawing lines and measuring distances optically to a stadia rod, which he sighted through a telescopic alidade. This method works well for outdoor surveys, but is not suited for dark caves with rugged terrain. Their map became increasingly inaccurate as errors in the drawing accumulated toward the lower end of the cave. The author remapped the cave from 1970 to 1974 using standard cave surveying equipment at that time: a steel survey tape and a Brunton pocket transit, which is a small magnetic compass with sights and a clinometer for measuring slopes. Similar equipment is still used by geologists, the military, and other field personnel. In the 1970s and 1980s, most cavers changed to the Suunto or similar liquid-filled compass and clinometer, which makes point-to-point, handheld surveying easier. In either case, meticulous notes are kept in a book with taped distance, magnetic azimuth (bearing), inclination, and LRUD (left, right, up, down) distances at each numbered station. Carefully scaled drawings are made in plan, profile, and cross-section views. Three or four cavers comprise a survey team, and multiple teams or trips may be needed to map the entire cave.

In the 1970s, cave survey data were still “reduced” to rectangular coordinates (x, y, z) using pencil, paper, and trigonometric tables, or plotted with a drafting machine. A slide rule or a calculator was used for calculations. AMCS cavers converted to the metric system in the 1980s, and cavers developed sophisticated mainframe computer programs for processing survey data from large caves, and plotting it on large plotters. Profiles, longitudinal sections of a cave, became easier to plot, and it became standard to depict caves in plan and profile views, especially pit caves requiring rope. Cave maps became better models of the caves, allowing scientific inferences to be made about hydrogeologic history. Today the author and many cavers use the *Walls* cave survey program, one of several that allows one to plot the plan and profile survey lines along with LRUD data, and send it to a vector drawing program like Adobe Illustrator for the final drawing

GEOGRAPHIC INFORMATION SYSTEMS

Seeing caves in their true relationship in a geographic information system (GIS) is important to understand how they formed and where groundwater may flow. Groundwater connections are usually elucidated with dye tracing, but there has been only one water trace in the Sierra de El Abra from Sótano de Japonés (Fish, 1977, 2004). Instead, we have relied on elevations, hydrographs, and water chemistry, but now from cave maps we can see structural trends of cave clusters and flow directions. Until the late 1970s, we had no topographic maps of Mexico, so we surveyed overland between caves and landmarks to accurately locate caves. Mitchell et al. (1977) used a precision surveying altimeter tied to Mexican government benchmarks to measure elevations at cave entrances. By the 1980s, DETENAL topographic maps from the Mexican government be-came publicly available, which improved our efforts to record cave locations long before the GPS (global positioning system) was available. In recent years, some cavefish researchers have used GPS receivers to obtain satellite-based co-ordinates for *Astyanax* caves. Even these precision instruments can get wrong data if the geographic datum and the position error are not recorded. Today we can download Mexican topographic maps from the Instituto Nacional de Estadística, Geografía e Informática (INEGI), the federal mapping agency, but they must be converted to a different datum and projection for use in most GIS programs.

Initially, I developed cave location data using Google Earth, then it was con-verted to *WallsMap* format. I developed cave area maps using INEGI base maps in *WallsMap* with shape files from the *Walls* program or *Quantum GIS®* (2014). Researchers may obtain limited cave location and GIS data from the author and AMCS. Such data are not posted in public because of potential conservation problems.

CAVE DESCRIPTIONS

Numbers correspond to labels in Figures 1.3 and 1.4. Maps may be found at AMCS online, in Fish (2004), Elliott (in press), and in other publications cited below.

Gómez Farías Area (Sierra de Guatemala)

The northern group of fish caves in the Sierra de Guatemala, Sierra Cucharas, and Sierra Tamalave may be separated hydrologically from the southern Sierra de El Abra fish caves by the large resurgences just south of Gómez Farías—Nacimiento del Río Nacimiento, Nacimiento del Río Frío, Nacimiento Florida, or at other resurgences farther south (Table 1.2). Some authors have debated whether or not the Cañon de la Servilleta of the Río Ocampo (Boquillas), which passes through the Sierra Cucharas, is a barrier to cavefishes. From the INEGI Loma Alta 1:50,000 topographic map, I found that the bottom of this Cañon runs west to east from 130 to 90 m msl (above mean sea level). Most of the nearby nacimientos are still below parts of the Cañon, but some are above it. An old cave, now dry, Cueva del Cañon de la Servilleta, is in the north wall of the Cañon. It is possible that water-filled caves still pass beneath the Cañon. The Cañon, per se, may not be much of a barrier in karst, which has three-dimensional flow paths that can change as water rises and falls after storms. Dye tracing studies during low and high water times might settle this problem, but it will be complex, owing to the many nacimientos in this area.

1. *Sótano* (*Resumidero*) *de Jineo* (Table 1.1, Figure 1.12) is the northernmost of three deep fish caves at Gómez Farías. Jineo corkscrews clockwise at −120 m, then bifurcates. The bottom pools are perched at 144 m deep (148 m msl), about 63 m above base level, which is about 85 m msl at the closest resurgence, Nacimiento del Río Nacimiento. Water flow apparently is west, and the end of the cave lies only 105 m from the end of Sótano de Molino, and I believe the two caves to be part of one system. A 1971 map showed a west-trending, muddy terminal passage, but a 2005 resurvey found mud blocking this route and a lower pool in another branch. An arroyo, lacking fishes, about 100 m long, drains a small area into the cave during wet weather. Some other nearby pit caves, checked in dry weather, had no cavefish pools, because they bottom above 200 m msl.
2. *Sótano de Molino* is the most extensive cave at Gómez Farías, with pools on four levels. Molino was mapped in 1971 (Elliott, 2002). Multiple trips by caving groups found cavefishes at the bottom, but sometimes cavefishes

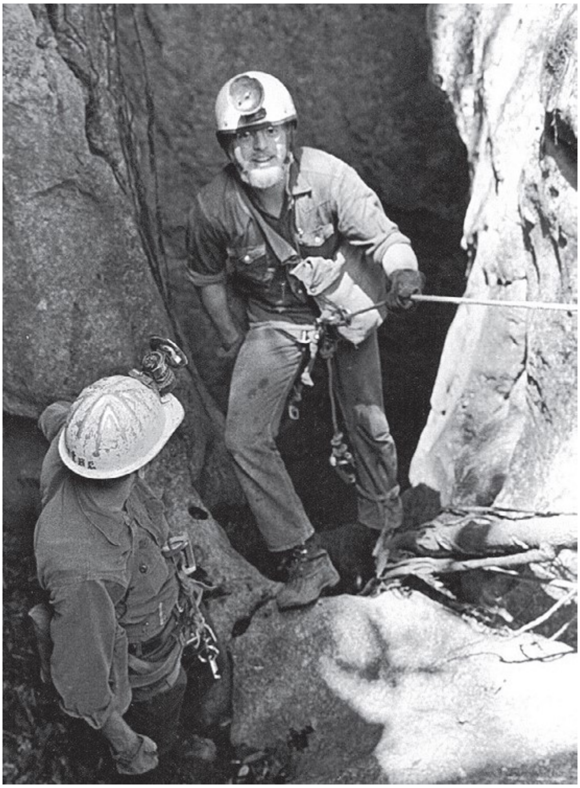

FIGURE 1.12 Bill Elliott rappels into Sótano de Jineo at Gómez Farías, Mel Brownfield looks on, May 18, 1971. *By Francis Abernethy.*

occurred in debris-laden upper level pools at −73 to −77 m. This indicates the dynamic nature of the aquifer, with cavefish carried at least 70 m upwards by rising groundwater during wet times. The arroyo to the cave receives runoff from fields and the western side of the Sierra Chiquita. The arroyo is several hundred meters long and is the largest captured arroyo in the area, but it is not inhabited by fishes. Erosion in the arroyo produced an entrance headwall 10 m high. The Molino-Jineo system probably flows south under the valley toward the nacimientos about 8 km away.

3. *Sótano Escondido*'*s* entrance is divided by a natural arch and is overgrown, hence the name Escondido (hidden). The 150-m-deep cave has seven pitches requiring equipment, with a counter-clockwise corkscrew leading to an east-trending terminal cavefish pool. This pool is perched well above the local base level at 153 m msl. Most of the fishes seen here were small and of uniform size, indicating that a few were transported upward by rising waters to be trapped in the pool, where they gave rise to the population. The shallow arroyo takes runoff, but it has no surface fishes. The cave runs to the east, but it could easily turn west again below the sump and join with the flow from the Molino-Jineo system.

Chamal-Ocampo Area (Sierra Cucharas and Sierra Tamalave)

4. *Bee Cave* (Sótano de las Colmenas) is a large collapse pit with a small pool at the bottom, with few cavefishes visible at any time.
5. *Sótano del Caballo Moro* is in a dolina (large sinkhole) in a saddle between two hills. The bottom is about 20 m above the Río Frío resurgences 14 km away to the northeast. The lake and stream at the bottom carries a large volume of water into a sump and toward the northeast. Sunlight hits a portion of the stream, where small-eyed fishes segregate from cavefishes (Mitchell et al., 1977; Elliott, 2002; Espinasa and Borowsky, 2000).
6. *Sótano de Vasquez* has the highest elevation entrance and is the deepest fish cave in the region. It has six levels, indicating a great age relative to other caves (Mitchell et al., 1977; Mothes and Jameson, 1984).

Northern El Abra (Sierra de El Abra or Sierra de Tanchipa)

7. *Cueva de El Pachón* is one of the three classic cavefish sites. It is the type locality, the place from which a new species is described, of Alvarez's *Anoptichthys antrobius*. The relatively high elevation and perched lake, 120 m above local base level at the Río Mante, may indicate a more ancient origin than most fish caves in the region. Additional upper-level water passage was mapped by Luis Espinasa et al. in 2003 (Espinasa, 2009).
8. *Sótano de Venadito* (Figures 1.8 and 1.9) is a large system developed on four levels at or near the groundwater divide between the northern and southern El Abra region. It flows southwest toward the La Lajilla lake and the headwaters of Arroyo Grande. It may also overflow into a north passage during high water, and thence possibly to small resurgences 12 km northeast, or to the Nacimiento del Río Mante on the east face of the range. A new map of the cave will appear in Elliott (in press).

Yerbaniz Cluster

The Yerbaniz cluster contains three hydrologically related caves: Yerbaniz Matapalma, and Japonés. Downstream are the older Sótano de Matapalma

FIGURE 1.13 Sótano de Yerbaniz entrance, 1969. *By Robert W. Mitchell.*

FIGURE 1.14 Francis Rose examines flood debris in Sótano de Yerbaniz, 1969. *By Robert W. Mitchell.*

(1.4 km away, straight line) and Sótano de Japonés (2 km away). Yerbaniz is the youngest and probably the most hydrologically active of the three fish caves. Heretofore, authors have assumed that the Yerbaniz cluster flows only to the east. I can hypothesize groundwater flow paths from these caves based upon known flow paths on the cave maps, cave morphology, and elevations (Figure 1.18). They may flow to unknown wet-weather resurgences or risings on the Arroyo Grande 4-8 km southwest of the cluster. Dye tracing is needed to delineate these flow paths. Other overflow paths could also connect to the Sabinos cluster about 5-8 km to the southeast.

9. *Sótano de Yerbaniz* (Figures 1.13–1.18) has three levels and floods violently. It has the largest catchment basin (area that captures runoff) of all the El Abra caves at 16 km^2. Eyed fishes are sometimes found on Levels 1 and 2, cavefishes and eyed fishes on Level 3. The cave has a rich fauna.
The name, *yerbaniz*, refers to an herb, the flowers of which are used in religious ceremonies on the Dia de Los Muertos. It is also spelled yerbanís or hierba anís.

Sótano de Yerbaniz is in the Arroyo Yerbaniz, about 22 km north of Ciudad Valles, San Luís Potosí (S.L.P.) Yerbaniz is described in detail here, as it is representative of a swallet cave that has captured a stream and its surface fishes, and is still capturing them. The cave was described in detail by Mitchell et al. (1977), and Elliott (2014) published a multi-colored map of the cave. That map is available on Elsevier's companion site and in the e-book. Figures 1.15 and 1.16 are simplified versions of the map for the printed volume of this book. Figure 1.17 is a legend of AMCS cave map symbols.

The cave was discovered from pilot Richard Albert's airplane on January 25, 1969 by Robert Mitchell, Richard Albert, Francis Rose, and Tom Albert. It was an accidental discovery after scouting for cavefish caves, as they

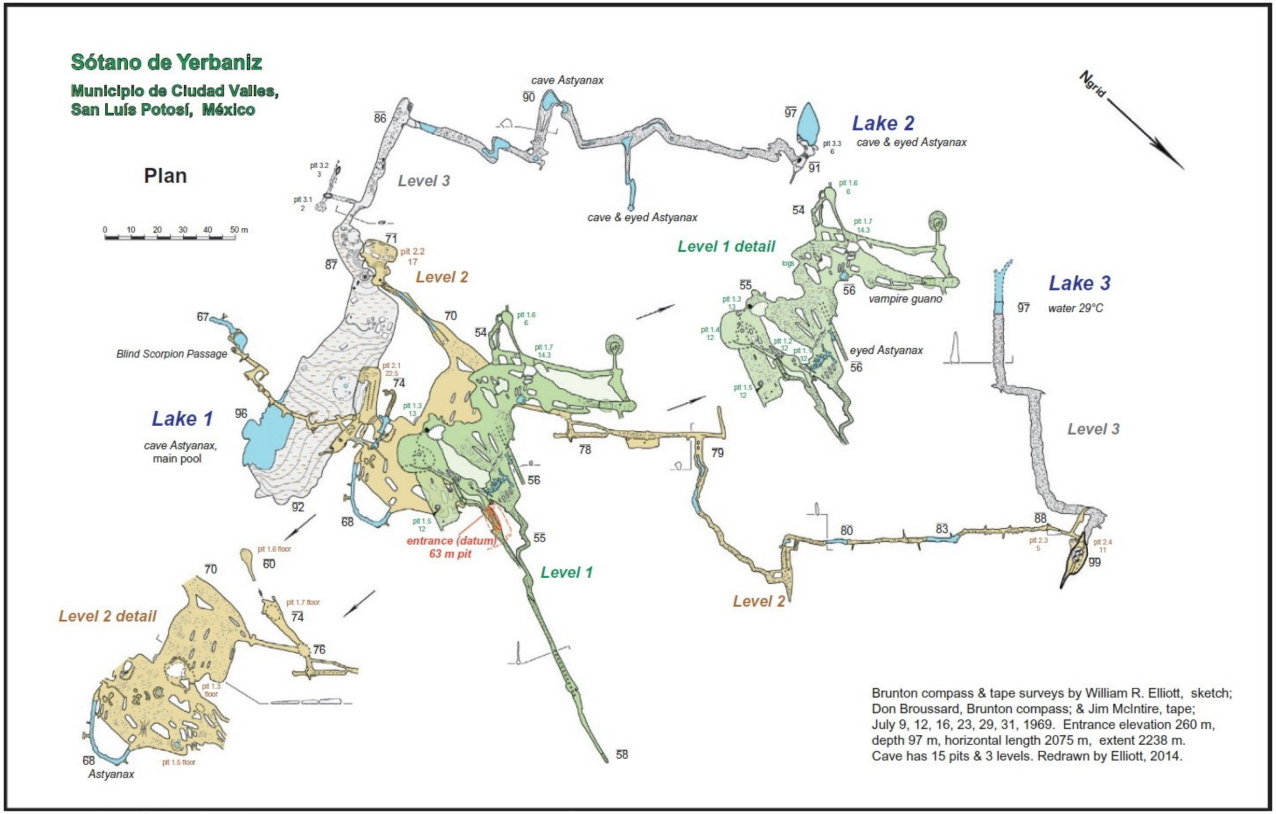

FIGURE 1.15 Sótano de Yerbaniz plan. By William R. Elliott. A detailed version of this map is available on the Elsevier companion site.

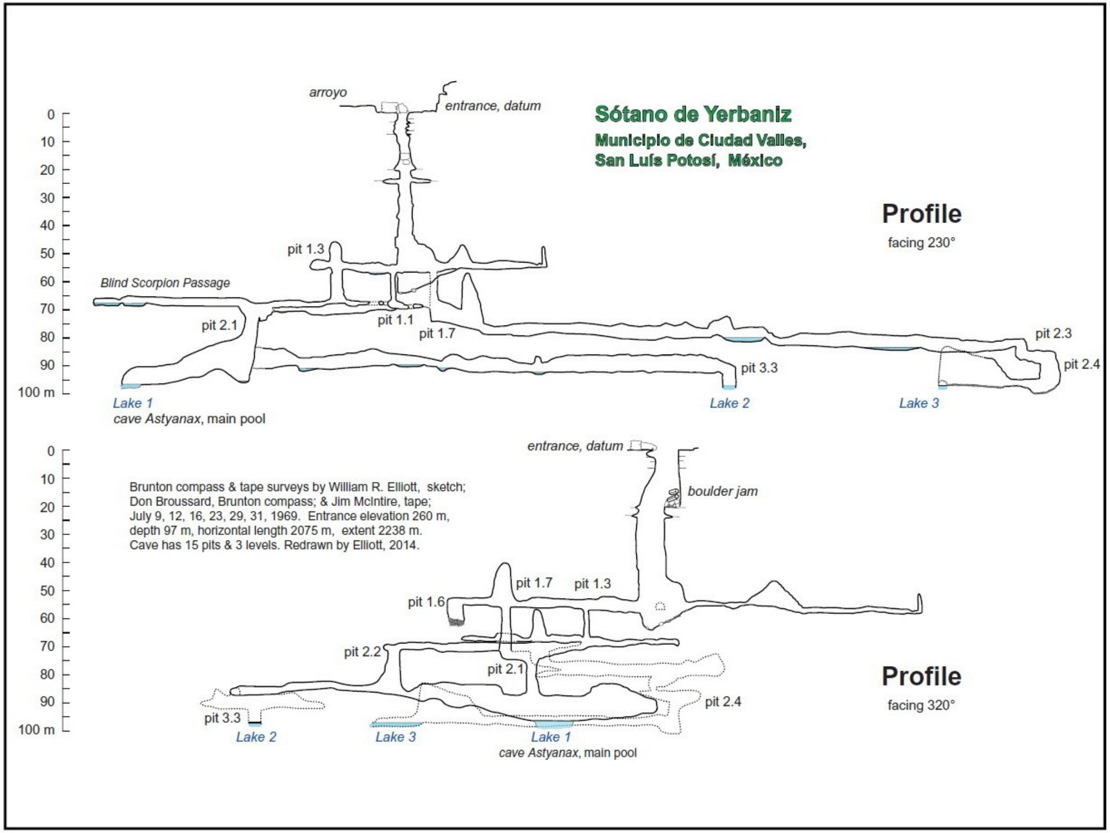

FIGURE 1.16 Sótano de Yerbaniz profile. *By William R. Elliott. Copyright © 2015 William R. Elliott. All rights reserved.*

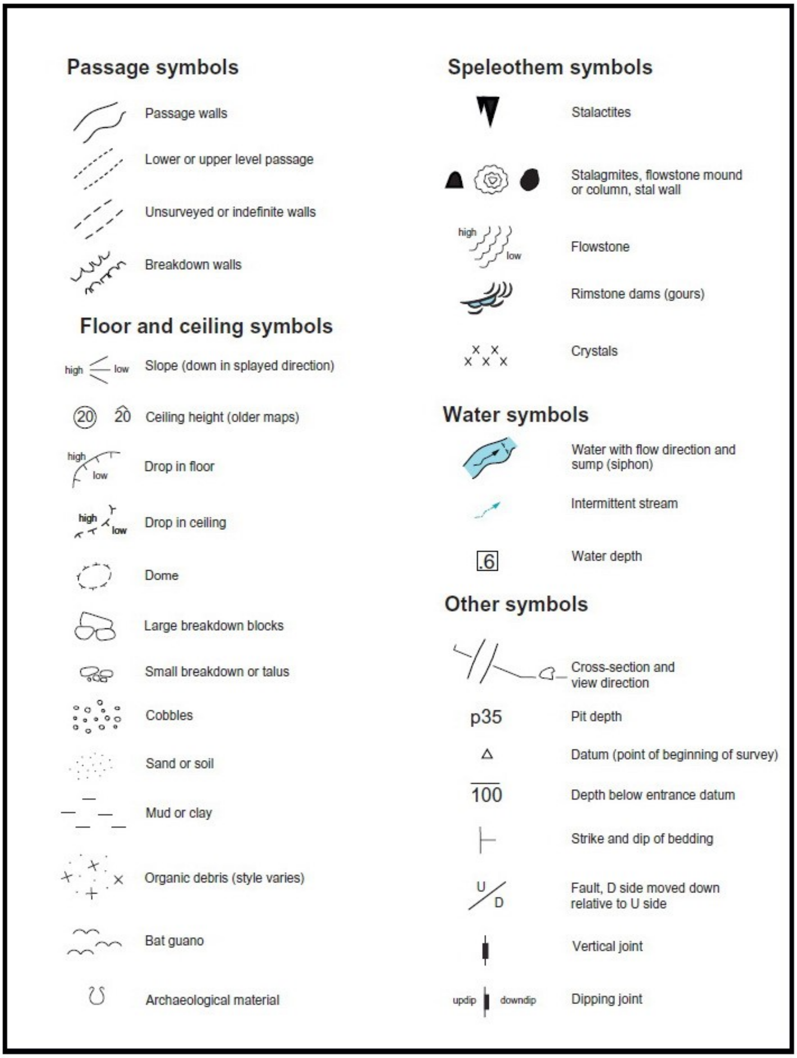

FIGURE 1.17 Legend of AMCS cave map symbols. *By William R. Elliott. Copyright © 2015 William R. Elliott. All rights reserved.*

searched at dusk for the landing strip at nearby Ponciano Arriaga. Little did they know they had found one of the most complex and biologically rich caves of Mexico.

Tony Mollhagen and Francis Rose, of Mitchell's research team from Texas Tech University, descended the 63-m entrance pit on January 28, 1969. On January 29, 1969, Mitchell, Rose, Richard, and his son Tom Albert entered the cave with more rope, explored parts of the first and second levels, and collected eyed, surface

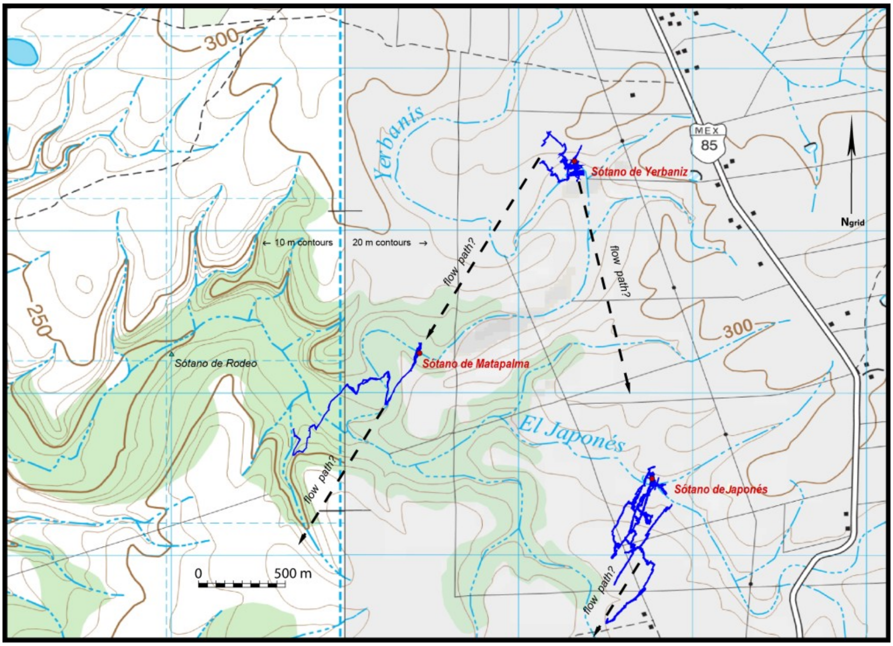

FIGURE 1.18 Map of the Yerbaniz cluster: Sótano de Yerbaniz, Sótano de Japonés, and Sótano de Matapalma, showing hypothesized groundwater flow paths based on cave morphology and elevations. *By William R. Elliott based on 1:50,000 INEGI topographic maps and AMCS data. Copyright © 2015 William R. Elliott. All rights reserved.*

Astyanax in pools on Level 1. On January 31, 1969, the cave was explored to Level 3 by Jerry Broadus, David Honea, Ann Lucas, Russell Harmon, and Joe Cepeda, who collected several cavefishes in Lake 1 on Level 3, about 96 or 97 m below the entrance. On February 2, 1969, a sizeable collection of cavefishes was made from the same lake by Bob Mitchell and Bill Russell.

The map of Yerbaniz went unpublished for 45 years, but it was worth the effort to redraw the July 1969 survey by Don Broussard, Jim McIntire, and me. I originally drafted the inked map on two large sheets in 1969-1970, but a planned series of papers on the *Astyanax* caves was not completed. Fortunately, I archived my survey notes and the two map sheets with the AMCS. Yerbaniz is the most complicated cave map I have ever drawn; it took 6 days to map and months to draw using a computer.

Surface fishes inhabit Arroyo Yerbaniz in abundance. The arroyo does not, however, support a permanently flowing stream, but in its course, there are pools in which the fish populations are maintained, some of which may be unseen deep within the bed of the arroyo.

Yerbaniz has 15 pits including the entrance, connecting three levels and three lakes on Level 3, which is in two parts. This is a challenge to represent on a two-dimensional map. I rendered the new map in three translucent colors to depict the overlapping levels, and I labeled the pits in three series. Pits from

Level 1 to Level 2 are numbered as pit 1.1 through pit 1.7. Level 2 pits are pit 2.1 through 2.4. Pits on Level 3 are pit 3.1 through 3.3.

The entrance of the cave is an elliptical slot about 10 m long by 1-4 m wide (Figure 1.13). It lies in the northern edge of the Arroyo Yerbaniz at an elevation of about 263 m. Although a relatively young opening, the entrance is of sufficient size to capture all the water flowing down the Arroyo Yerbaniz except at high flood stage. Water can move past the entrance at such times, as demonstrated in September 1969 when Bill Russell visited the cave entrance immediately after a very heavy rain. So much water was being carried in the arroyo that the entrance could not take all of it. Water about 1 m deep was flowing by the entrance, where a large whirlpool took water down, and at another point, mist shot up about 12 m as air was exhausted from the cave. The results of such violent flooding are seen within the cave, with cobble piles, large palm trunks wedged into corners, and log jams scattered in the floodwater mazes of Levels 1 and 2 (Figure 1.14).

The cave is a joint-controlled, three-level, floodwater maze with one major flow path (to Lake 1) and two overflow paths (to Lakes 2 and 3). The entrance pit drops to Level 1, which has joint sets trending at about 25° and 330°, witnessed by bedrock pillars in wide rooms and in narrow passages. Level 1, consisting of several large rooms, small intersecting passages, and one long northeast-trending passage, lies at 54-56 m beneath the datum (point of beginning of the survey at the entrance).

Level 2 at about −68 to −88 m has two large rooms (depending upon one's perspective), many small intersecting passages, one long northwest-trending passage to a second Level 3 and Lake 3, and a shorter south-trending passage (Blind Scorpion Passage). Joint sets trend at 0°, 45°, and 75°, with pillars trending along those joints.

Level 3, consisting of the Lake 1 Room the size of a football field and two long overflow passageways, lies about 91-97 m beneath the entrance. Joint sets trend at 45°, 75°, and 330°. The deepest points in the cave (surfaces of three lakes on the third level) lie 96-97 m beneath the entrance. Based upon mapping, these three lakes are all at about 145 msl and probably are connected via submerged passages. They are about 11 m above the bottom of Sótano de Matapalma, and probably are near local base level. The water in Lake 3 of Yerbaniz is warm, about 29 °C in July 1969. Sótano de Japonés, in a different arroyo, has a deeper bottom at 104 m msl.

I entered Yerbaniz 14 times over 3 years. On July 31, 1969, the last day of the survey, I was fortunate to discover a delicate blind scorpion on Level 2 (see Blind Scorpion Passage on map). Or rather the tiny, translucent scorpion found me, on my right thigh! I had been brushing off little *Brackenridgia* isopods as we surveyed the tubular passage, crouching against the wet walls. I was about to brush another one off when I looked down and saw what was to become the holotype specimen of a new species to science. I swore out loud and jumped up and down three times, then I collected it! Dr. Mitchell later described it as *Typhlochactas elliotti*. He found that it was similar to two other blind cave scorpions in Mexico, which he had published. Return trips found only three specimens total. Years later, it is still considered the world's most troglomorphic (cave-adapted) scorpion, and it has been moved to the genus *Sotanochactas* as the only known species in that genus. This was an exciting find, but especially since we did not know that blind scorpions could occur in the lowland tropics—the others were from montane areas. This began to change our ideas about cave animal evolution in the tropics, and now we understand that troglobites are often common in the tropics.

Some of us also found a new genus and species of cave schizomid, *Agastoschizomus lucifer*. Schizomids are tiny arachnids, relatives of the whipscorpions, but this one is large by comparison. In 1970, Suzanne Wiley and I witnessed something strange on Level 2 while we were checking fish pools in the cave for her master's thesis. We found an *Agastoschizomus lucifer* sitting in a tiny rimstone pool on the wall. We thought it must have drowned, but when we gently poked it, the creature walked up out of the pool onto the wall. They are not supposed to be amphibious, but maybe in that environment, the scorpions and schizomids have become amphibious. The air is so saturated that it may not matter to the animal. On a return trip to the cave, Suzanne's carefully documented fish pools had been totally blown out by a flood. That told us how tough it is for fish in upper-level pools. Her thesis study was wrecked, so she ended up doing one on respiratory rates of *Rhadine* cave beetles in Texas.

10. *Sótano de Matapalma* (Figure 1.18) is a large cave with one level. It now lacks much arroyo runoff, because of the more recent upstream capture at Sótano de Yerbaniz, but it probably conveys deep groundwater to the southwest via a major unexplored stream passage.

11. *Sótano de Japonés* (Figure 1.18) is a large, complex cave on four levels. Its map shows that it conveys water to the southwest, and that may continue to Arroyo Grande. It captures runoff from the Arroyo Japonés, and the subterranean flow path would be on a similar, southwesterly flow path as Yerbaniz and Matapalma. John Fish conducted a *Lycopodium* spore water trace from Japonés with inconclusive results (few spores recovered) at the Nacimiento del Río Choy. Perhaps those results could be explained if most of the water flowed to the Arroyo Grande via risings in the streambed or wet-weather resurgences, although none are known to me at this time (Figure 1.18).

Sabinos Area

12. *Sótano del Tigre* (Figures 1.6 and 1.7) is a deep, biologically rich pit cave with three levels. Cavefish occur on Levels 2 and 3. Its direction of flow is to the south or southwest, and it probably feeds to the Los Sabinos cluster of caves 3 km to the south. The "Bats and Ricinuleids Passage" is a fossil stream passage that now contains bats and a thriving population of the rare arachnid, *Cryptocellus osorioi*, in copious bat guano. A new map will appear in Elliott (in press).

13. *Sótano de la Roca* is a small pit cave 800 m upstream of Sótano del Arroyo and the Sistema de Los Sabinos.
14. *Cueva de los Sabinos* is a classic cavefish cave and type locality of Álvarez's *Anoptichthys hubbsi*. It is a large, complex cave on one level, with a sump connecting to Sótano del Arroyo. It is part of the *Sistema de Los Sabinos*, comprising Cueva de los Sabinos, Sótano del Arroyo, and Sótano de la Tinaja.
15. *Sótano del Arroyo*, a major cavefish site and the longest cave in the El Abra region. A complex, dendritic cave on three levels, it receives flow via its arroyo pit entrance and via a sump from Sabinos, thence conducting flow to the east.
16. *Sótano de la Tinaja* may be the oldest cave in the *Sistema de Los Sabinos*, as it is farthest downstream and its surface pit has been eroded to a walk-in entrance. It is developed on two levels. The upper level Water Passage to the left of the entrance receives water flow from the west and transmits it to the north to a large lake passage. Another Lake Passage in a different branch may also connect. These two lake passages probably connect via sumps to the south end of Sótano del Arroyo. The lower level of Sótano del Arroyo, the Downstream Canyon, ends in a sump, the Lake Room Siphon, at −82 m, or about 84 m msl.
17. *Sótano de Soyate* is the deepest cavefish site in the southern Sierra de El Abra. Its 195-m entrance pitch leads to two short pitches to a large, clear lake at −234 m. In the lake resides a large population of cavefishes, studied by Elliott (Elliott, 1970; Mitchell et al., 1977). In Soyate, the surface of the lake was at 59 m msl, and the bottom of the lake was at 6 m msl, 29 m below the surface outlet of the Nacimiento del Río Choy. No flow direction was observed, but because of its deep bottom, the cave likely is a major conduit to the south and the Nacimiento del Río Choy. See further discussion of the cave's ecology in Chapter 2.
18. *Sotanito de Montecillos*, the northern half of the Sistema de Montecillos, connecting via a sump to Sótano de Pichijumo.
19. *Sótano de Pichijumo* (*Montecillos*), the eastern half of the Sistema de Montecillos. Three levels and three flow paths exist in the system. Floods captured at the sotanito entrance go two directions; the lower route flows north to a sump pointing east, meeting subterranean water that flows from the northwest. An overflow route connects to Pichijumo via another sump, and is carried east via the Lake Passage to the deepest sump at −82 m in Pichijumo, which points east.
20. *Sótano de Jos*, a young floodwater cave on one level, from its initial orientation, it turns 180° under the arroyo and drains to the north-northeast, possibly converging with flow from Soyate.
21. *Sótano de Las Piedras*, about 290 m downstream from Jos, is developed on two levels. Like Jos, it drains to the north-northeast.
22. *Sótano de la Palma Seca* is about 740 m from Piedras. It is developed on two levels, with a perched lake on Level 1 and a sump that is oriented to the east-southeast.

Micos Area (Sierra San Dieguito)

23. *Cueva de Otates*, one of the three known "Micos caves," was mapped in 1974 by Elliott, Prentice, and Walker. Its pit entrance is on the north valley margin, 250 m northeast of Cueva del Río Subterráneo. It probably is hydrologically connected to Subterráneo, coming underground within 160 m of its entrance.
24. *Cueva del Río Subterráneo* is about 250 m southwest of Otates entrance. It is the largest cave in the area, formed on two levels, but it needs to be re-mapped. It is the original site of the "Micosfish" (Wilkens and Burns, 1972), an evolving population with somewhat reduced eyes and pigment.
25. *Cueva del Lienzo* is a small pit cave on a hillside with a tiny cavefish pool at the bottom. It is across the valley, about 800 m southeast of Cueva del Río Subterráneo. Elliott, Prentice, and Walker mapped the cave in 1974.

Southern El Abra

26. *Cueva de la Curva*, near a curve in the rail line, is a shallow stream cave oriented north-south. It is just north of the ancient, dry river valley, the southern El Abra pass. The cave originally may have drained to an active river valley before the Nacimiento del Rio Choy captured this flow underground. The perched stream is 70-80 m above base level, and may rarely receive rising groundwater, if at all.
27. *Sótano del Toro* is a small fissure cave with a small cavefish pool near the north end. Its north-south orientation is like that of Cueva Chica and Los Cuates about 4 and 5 km, respectively, to the south.
28. *Cueva Chica* is an important fish cave, the original Mexican cavefish site from which Hubbs and Innes described *A. jordani* in 1936. It is an atypical fish cave, not far from the Río Tampaón, which backfloods into the lower cave pools via three pools near the river. The cave has a succession of pools stepping down from the entrance, with cavefish in Pool 1 and successively more hybrids with eyed fishes as one travels downstream to Pool 4. Eyed *Astyanax* enter the lower cave from the river during times of high water. See my chapter on ecology and biodiversity for a full discussion.
29. *Los Cuates* (the twins), also known as Cueva del Prieto, was mapped by John Fish et al. in 1971. Elliott, Morris et al. mapped it more extensively in 1974 when water levels were low. It has two entrances, and like Cueva Chica and Sótano del Toro, the cave is oriented north-south, following a joint along a structural fold associated with a ridge. Like Chica, the cave contains cavefishes and hybrids. The nearby Cueva El Mante only contains eyed *Astyanax*.

GLOSSARY OF MEXICAN, GEOGRAPHIC, AND GEOLOGIC TERMS

anticline a fold in geologic strata in the form of an arch
arroyo a wet weather streambed

Cañon de Servilleta the river canyon NW of Cd. Mante, through which flows the Río Ocampo (Boquillas), which becomes the Río Comandante
carbonate platform a flat-topped reef with limestone-forming marine life
Ciudad or Cd. Mante a city near the northern Sierra de El Abra and the Nacimiento del Río Mante
Ciudad or Cd. Valles a city near the southern end of the Sierra de El Abra
cueva a walk-in cave as opposed to a sótano or pit (vertical) cave
Cretaceous the geological period from about 145-100 mya (million years ago)
dolina or doline a large sinkhole
El Abra literally "the opening" or pass, refers to two, now-dry river passes at the northern and southern ends of the Sierra de El Abra
Gómez Farías a small town at the northern end of the region
gruta a large cave
karst landscapes formed by the dissolution of soluble rocks such as limestone, dolomite, and gypsum, with underground drainage systems, caves, sinkholes, dolines, and springs
joint a more-or-less vertical crack in bedrock, along which caves often form through dissolution by groundwater
Micos caves three fish caves south of Micos and Las Crucitas, S.L.P.
Huastecan Province synonymous with "Sierra de El Abra region"
msl or amsl above mean sea level
nacimiento literally "birth," a large spring (manantial) or resurgence (see Table 1.2)
ojo de agua literally "eye of water", synonymous with nacimiento or manantial
poza a pool
poo a well or deep pit cave
resumidero a swallet cave that takes much runoff
río a river
San Luís Potosí or S.L.P. a northeastern Mexican state containing the southern half of the Sierra de El Abra
sierra a mountain range (literally "saw")
Sierra Cucharas literally "spoons," a local name for the northern Sierra de El Abra and the foothills of the Sierra de Guatemala
Sierra de El Abra a low range in the eastern Sierra Madre Oriental, between Cd. Mante and El Pujal
Sierra de El Abra region the subject of this chapter, including the El Abra, lower parts of Sierra de Guatemala (Cucharas), northern Sierra de Tamalave, and the Micos cave area
Sierra de Guatemala a higher range north of Ocampo and Gómez Farías, Tamaulipas, originally called "Mateguala."
Sierra de Tamalave a range west of the Sierra de El Abra, also called Nícolas Pérez
Sierra de Tanchipa a local name for the Sierra de El Abra from south of the northern El Abra pass to the southern El Abra pass near Ciudad Valles
Sierra Madre Oriental the large mountain range in eastern Mexico, continuous with the Rockies
sima a chasm or abyss
speleogenesis cave development
sótano literally "cellar," commonly applied to a deep pit cave in Mexico
sumidero a sinkhole or pit cave that may not take runoff
swallet stream-capture cave
Tamaulipas or Tamps. the northeastern Mexican

Tertiary the geological period from 66-2.58 mya
tinaja a water jar or water hole
type locality the place from which a new species is described

ACKNOWLEDGMENTS

I am grateful to Sharon Mitchell, Linda Mitchell, David Bunnell, and the late professors, Robert W. Mitchell and Francis Abernethy for photographs. Thanks to Gayle Unruh, Gerald Atkinson, and Luis Espinasa for reviewing the manuscript, and to David McKenzie, who for many years has supported cavers with excellent programs such as *Walls* and *WallsMap* for cave cartography. Logan McNatt and Bill Mixon helped me many times in gathering up and scanning old survey notes and maps. Thanks to the AIM and the Association for Mexican Cave Studies for their support and for encouraging me to write these chapters.

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