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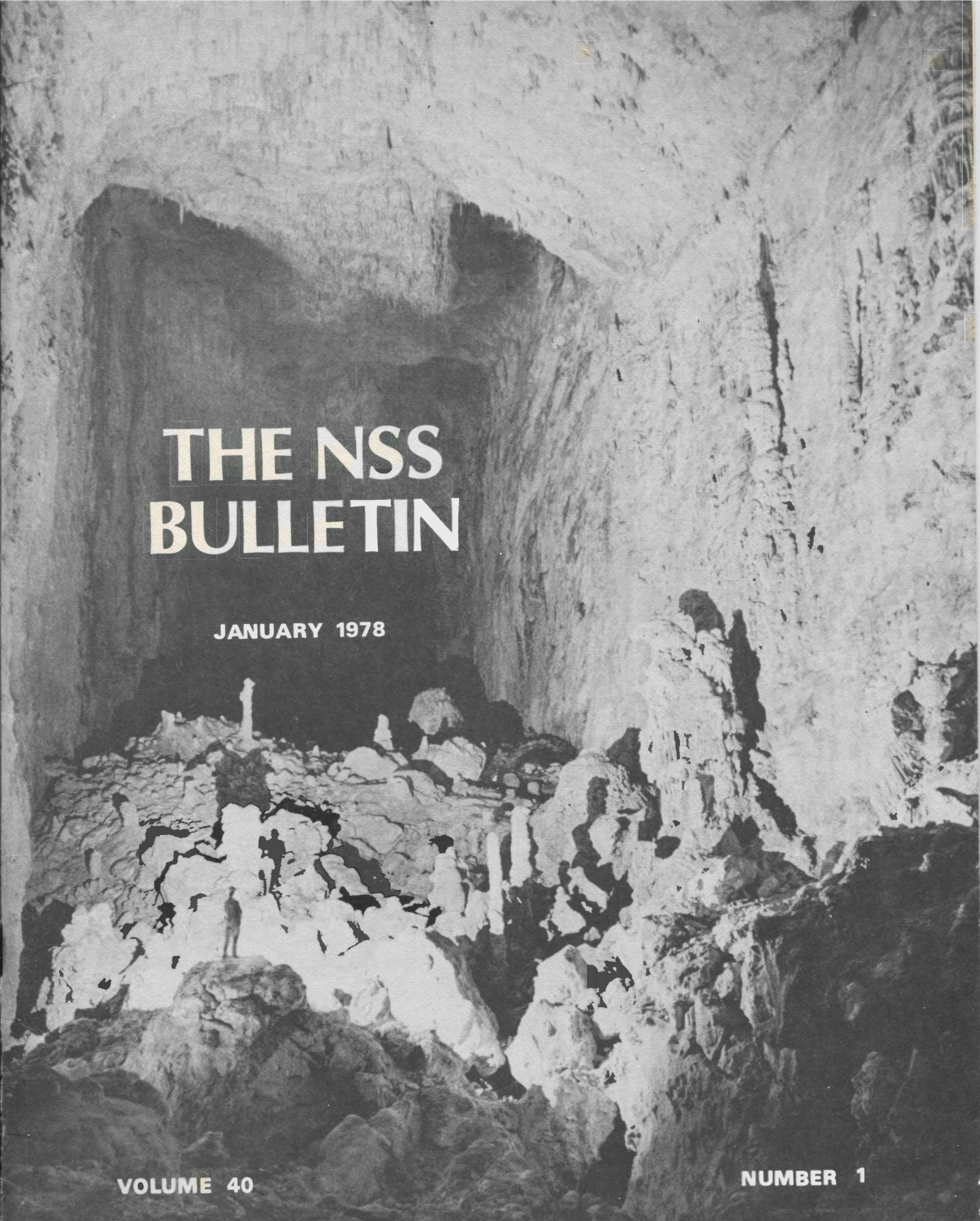

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Cover Photo: View south into Ogle Cave from approximately "OM12" illustrates the strongly joint-controlled walls trending N20°W. Pete Lindsley photo. See Figure 8, Jagnow.

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Geologic History of the Guadalupe Mountains Region

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ABSTRACT

Ogle Cave, in Carlsbad Caverns National Park, is developed in the (Permian) Capitan Reef complex. The origin of this and other caverns in the area is related to the tectonic history of the region. Events ranging in age from Precambrian to Tertiary influenced the location of structural and sedimentary features that directly affected the location and growth of the caves of the Guadalupe Mountains.

The Guadalupe Mountains are part of a north-northwest trending group of fault block uplifts and basins bordered on the northeast by the continental craton and on the southwest by the Sierra Madre Oriental orogenic belt. Orogenies in Precambrian, Pennsylvanian, and Tertiary time influenced structure in the area.

Precambrian orogeny caused development of a regional, northwest-trending structural grain, which influenced Pennsylvanian diastrophism and sedimentation. Monoclines developed along old zones of weakness in response to Pennsylvanian sedimentation. These monoclines appear to establish the margins of the western part of the [Permian] Delaware basin. The monoclines may also have helped to localize reef-building organisms by providing shallow platforms suitable for reef growth.

Tertiary deformation related to the development of the Sierra Madre Oriental orogenic belt in northern Mexico began in Late Cretaceous or Early Tertiary time and continued intermittantly until Late Tertiary time. This episode began with regional arching of the Guadalupe area and culminated in block faulting. The Late Tertiary surge of diastrophism created the Basin and Range structural elements of the Guadalupe Region.

THE GUADALUPE MOUNTAINS of southeastern New Mexico and west Texas are the site of many spacious and beautiful caverns, many of which are included within Carlsbad Caverns National Park. These caves are renowned for their great volumes and the size and beauty of their speleothems. The largest of these are Carlsbad Caverns, New Cave, and Ogle Cave. The last is the subject of the reports included in this issue of *The NSS Bulletin*.

The purposes of this report are briefly to summarize the geologic history of the region and to describe the major features associated with the Guadalupe Mountains, thus providing background information for the reports on the geology, mineralogy, biota, and history of Ogle Cave that follow.

INTRODUCTION

The Guadalupe Mountains region is located in southeastern New Mexico and adjacent western Texas (Fig. 1). The region can be broken into two areas, on the basis of their tectonic characteristics. A line running diagonally from northwest to southeast across Figure 2 separates the stable craton on the east from the fault block mountains of the Basin and Range Province to the west. Cratonic rocks are generally undisturbed, except for vertical deformation related to subsidence of sedimentary basins. The craton is characterized by the Delaware basin. The Basin and Range area includes the fault block Guadalupe, Delaware, Apache, and Sierra Diablo mountains and the Salt Basin graben.

CLIMATE AND VEGETATION

The climate of the Carlsbad Caverns area is semi-arid and continental, characterized by mild winters, warm summers, and summer showers. Precipitation averages 35.6 cm annually (Houghton, 1967). Carlsbad Caverns National Park lies on the northern fringe of the Chihuahuan Desert and contains a wide variety of flora. Plants characteristic of the canyon bottoms are creosote bush, catclaw, senna, goatbean, walnut, ocotillo, soapberry, barberry, Mexican buckeye, lechuguilla, sotol, yucca, and a variety of cacti. Canyon walls may support one-seed juniper, gray oak, walnut, hackberry, apache plume, sumac, saltbush, mimosa, beargrass, century plant, yucca, and many types of cacti. Many plants of the canyon bottoms may also be found on the canyon slopes and lower ridges (Spangle, 1960). These flora are typical of Slaughter Canyon, where Ogle Cave is located.

The tectonic map (Fig. 2) was compiled from geologic maps in reports by King (1948, 1965), Hayes (1964), Kelley (1971), and Wood (1968).

TECTONIC SETTING

Tectonic Features of the Region

Delaware Uplift. The Guadalupe Mountains, with the Delaware and Apache Mountains, form the Delaware uplift. Wood (1968) describes the uplift as a "...north-northwest trending...fault block, which is tilted to the east and flanked by a broad homocline dipping gently eastward toward the Pecos Valley." This uplift developed during Tertiary time, when Basin and Range topography was formed. Tectonically, the three mountain ranges behaved as a unit, being first uplifted as part of a broad regional arch and then faulted along the axis of the adjacent Salt Basin (Fig. 2).

Guadalupe Mountains. The Guadalupe Mountains are located on the Texas-New Mexico border. The highest point is in Texas. The mountains are wedge-shaped in map view, being bounded on the west by a steep, faulted escarpment and on the south by a pronounced erosional escarpment. From the western escarpment, the mountains slope eastward toward the Pecos River valley.

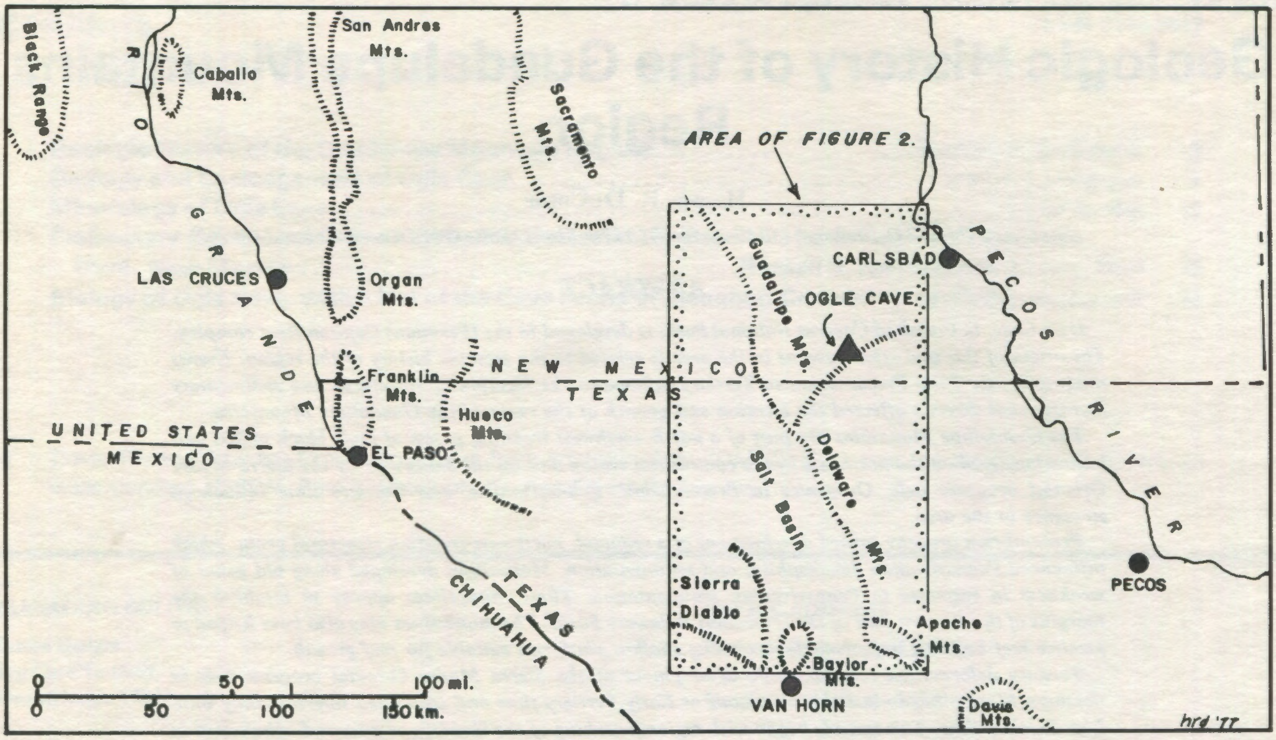

Figure 1. Index map of the Guadalupe Mountains region. Modified from Hayes, 1964, Figure 2.

The western escarpment is developed along a series of arcuate and en echelon, high-angle normal faults. Displacement on larger faults was estimated at 610 to 1220 m by King (1948).

The southern escarpment of the Guadalupe Mountains is formed along the exhumed core of the (Permian) Capitan Reef complex (Fig. 3). The escarpment is an erosional feature left after removal of less resistant evaporitic and clastic sedimentary rocks from the adjacent Delaware basin.

The eastern limit of the Guadalupe Mountains is the north-northwest trending Huapache monocline (Fig. 2). This flexure dips to the northeast and is best defined in its central part. It becomes obscure both north of the map area (Fig. 2) and to the south, where it intersects the erosional escarpment. Both Hayes (1964) and Kelley (1971) present evidence that the monocline crosses the escarpment and extends into the Delaware basin. The significance of the Huapache monocline to the development of Ogle Cave is discussed by Jagnow (this issue).

Delaware Mountains. South of the Guadalupe Mountains and several hundred meters topographically lower, are the cuesta-like ridges of the Delaware Mountains. Strata of the Delawares dip gently eastward toward the Delaware basin and are cut off on the west by a series of parallel, high-angle faults. This fault zone is continuous with the zone that borders the west side of the Guadalupe and Apache mountains.

Apache Mountains. The Apache Mountains are the southern-most component of the Delaware uplift. They are bounded on the west by the southern part of the Guadalupe-Delaware marginal fault zone and are separated from the Delaware Mountains by the Stokes fault. Wood (1968) observed displacement along the Stokes fault in excess of 457 m.

Delaware Basin

The Delaware basin is a structural low bounded on the west by the Guadalupe, Delaware, and Apache mountains. The sedimentary section in the basin is over 8230 m thick. It consists mostly of Permian and older rocks (Adams, 1965).

In the part shown on Figure 2, the surface of the basin is a relatively flat gypsum plain containing numerous subparallel linear scarplets trending east-northeast to east. Olive (1957) attributes these scarplets to subsidence along fracture zones where solution of gypsum has taken place in the subsurface.

The Delaware basin is nearly surrounded by the Capitan Reef complex. In the report area, the reef is exposed in the Guadalupe and Apache mountains.

Sierra Diablo

The Sierra Diablo is a tilted fault block range that slopes gently west. It is bounded on the north and east by high angle, range-marginal faults that form the boundary between the Salt Basin and the mountains. The adjacent Baylor Mountains are a part of the Sierra Diablo uplift separated from the main range by a concave-eastward normal fault. The Baylor Mountains are cut by numerous northwest trending faults that probably are similar to faults buried in the Salt Basin graben.

Salt Basin

The Salt Basin is a complex graben 8 to 24 km wide and 160 km long that lies between the Delaware uplift and the Sierra Diablo uplift (Fig. 2). According to King (1948), the northern and southern ends appear to be downwarps while the long central section is controlled by faults. Wood (1968) describes the basin as a "...half-graben, a gravity sag phenomenon in the early stage of basin subsidence."

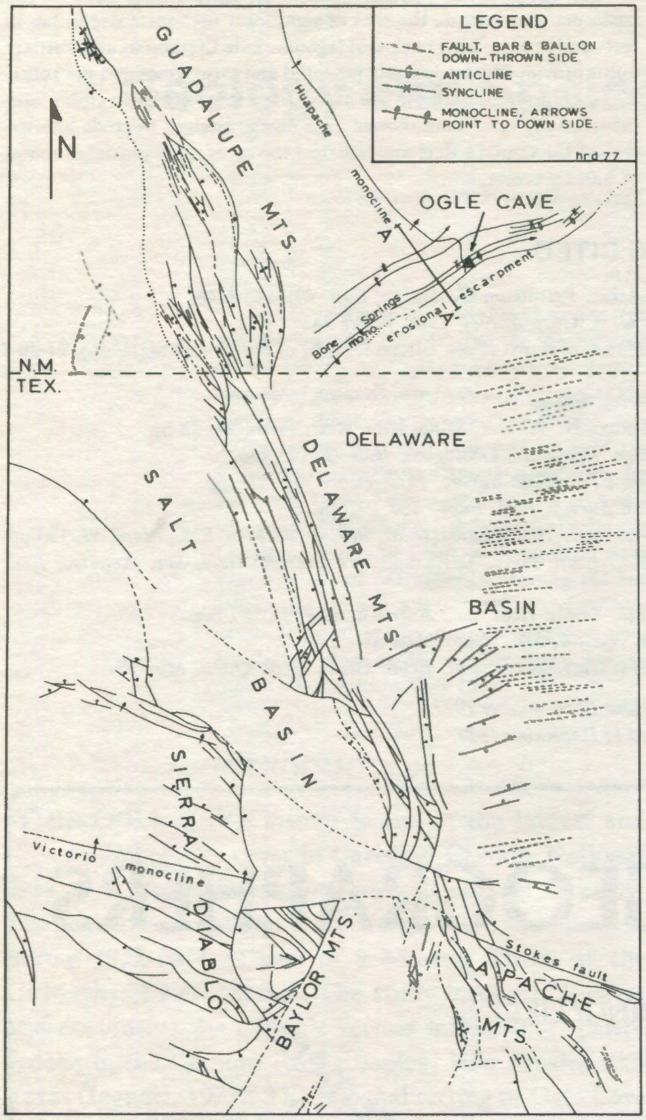

Figure 2. Tectonic map of the Guadalupe Mountains region.

TECTONIC HISTORY

Tectonic events of Precambrian age have been recognized in west Texas by King (1940, 1965). Among the features he noted as being of probable Precambrian age are a series of northwest-trending faults in the Sierra Diablo (Fig. 2). These high angle faults appeared to King to have lateral offset, and to establish a regional grain that influenced later orogenic events in the region.

After the Precambrian, the Guadalupe Mountains region remained essentially undisturbed by major orogenic events until Pennsylvanian time. During the Late Pennsylvanian, folding and faulting occurred together with renewed movement along the Precambrian faults of the Sierra Diablo. Part of the movement along the old faults may have been adjustments in response to sediment accumulation in basins north and east of the Sierra Diablo (Meyer, 1966).

In Early Permian time, the Sierra Diablo area was stable and subsided less than the adjacent Delaware basin. The basin margin was probably nearly coincident with the Capitan Reef complex in the Apache and Guadalupe mountains. The basin margin (shelf margin) is marked by the Bone Springs monocline in the Guadalupe Mountains and the Victorio monocline (or its eastward extension) in the Apache Mountains. These monoclines probably influenced the location of Permian reefs. The flexures face toward the basin center, where deeper water could have provided nutrients. They also provide shallow areas where organisms requiring light could grow and flourish.

The Permian was a time of tectonic stability and major carbonate accumulation in the Guadalupe Mountains. This sedimentation resulted in the great thicknesses of limestone that now contain the caves of the region.

The rock record for most of Mesozoic time is absent from the Guadalupe Mountains region due to non-deposition and/or erosion. At the close of Cretaceous time, however, major orogenic events took place throughout western North America. The Guadalupe Mountains area was strongly affected by the development of the Sierra Madre Oriental orogenic belt in northern Mexico (Smith, 1940). This orogeny caused broad arching of the crust in the Guadalupe region in Late Cretaceous or Early Tertiary time (King, 1948).

Deformation related to the Sierra Madre Oriental orogenic belt continued intermittantly through the Tertiary, reaching a climax in Late Tertiary time. Arching, probably in response to deep seated compression within the crust, reached the point of rupture and the horsts and graben were formed. Compressional forces directed toward the craton from the southwest are responsible for the north-northwest orientation of the structural elements (Fig. 2). Present topographic features are due to this period of deformation and to subsequent erosion.

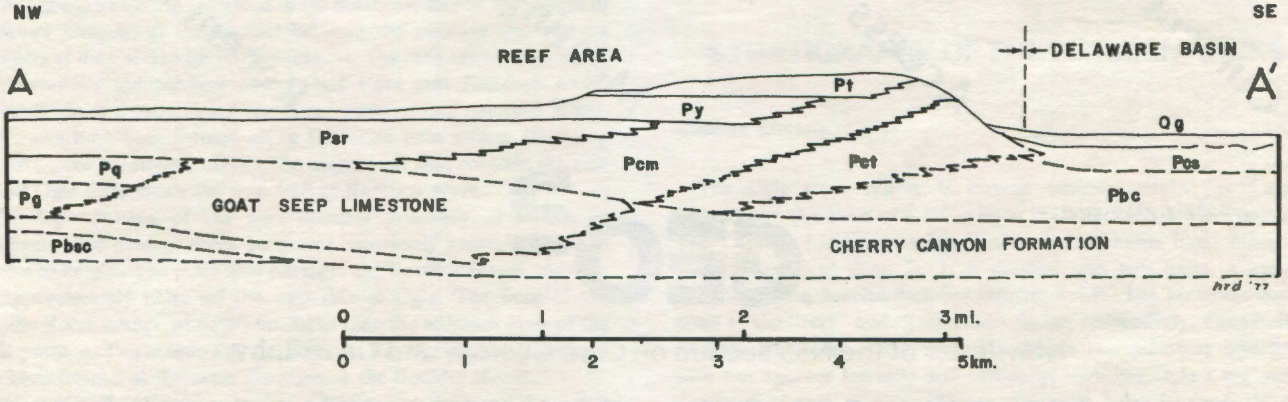

Figure 3. Cross section A-A' through the Capitan Reef complex (see Figure 2). Modified from Hayes, 1964, Plate 3. Units are: Qg = Quaternary Gravel; Permian units are: Pt = Tansill Formation; Py = Yates Formation; Psr = Seven Rivers Formation; Pq = Queen Formation; Pg = Grayburg Formation; Pbsc = Bone Springs Formation, Cut Off Shale Member; Pcm = Capitan Limestone, Massive Member; Pct = Capitan Limestone, Reef Talus Member; Pcs = Castile Formation; Pbc = Bell Canyon Formation.

SUMMARY

Cavern development in the Guadalupe Mountains occurred as a result of a sequence of complex tectonic and sedimentary events that can be traced from Precambrian time to the present. The regional structural grain established in Precambrian time helped control the location of basin margins in Pennsylvanian and Permian time. These basin margins became the sites of significant carbonate deposition in reefs and in associated back-reef lagoons. Late Cretaceous and Tertiary uplift provided hydrodynamic potential and, also, fractured the rocks, allowing ground water to excavate the caves. Tertiary uplift also provided the relief that allowed high energy streams to erode into the core of the Capitan Reef and intersect the caves, thus providing routes of human access.

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Geology and Speleogenesis of Ogle Cave

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ABSTRACT

The Ogle Cave system developed by preferential solution at the intersection of major vertical joint swarms, trending N20° W, and the sloping geologic contact between the breccia and massive members of the (Permian) Capitan Limestone. Impermeable siltstones in the overlying Yates Formation channeled groundwater from as far away as the Guadalupe Ridge anticline into vertical joints and 15 sandstone dikes directly over Ogle Cave.

The author proposes that sulfuric acid played a major role in the solution of the Guadalupe Mountain caves. Finely disseminated grains, large crystals, and massive concentrations of pyrite in the overlying Yates Formation provided a sulfide source. Late Pliocene faulting and uplift of the Guadalupes initiated pyrite oxidation, releasing sulfuric acid down dip into the more soluble Capitan Limestone. Episodic uplift, and resultant drops in base level concentrated shallow phreatic solution near 1390m and 1417-20m asl. During the last stage of cavern development, ponded waters high in sulfate and calcium precipitated varved gypsum on the floors and ledges of Ogle and other Guadalupe caves. Beds of massive gypsum were commonly redissolved under vadose conditions, or covered by breakdown from exfoliation [spalling]. Displays of massive carbonate speleothems developed under vadose conditions in Ogle Cave.

INTRODUCTION

THE OGLE CAVE system is one of the largest and most impressive caves in Carlsbad Caverns National Park. It is second in volume only to Carlsbad Caverns. The geology and speleogenesis of Ogle Cave were studied during 1972-1974 as part of a Masters Thesis at the University of New Mexico. The study involved 52 caves and documents the geologic factors influencing speleogenesis in the Capitan Reef complex, New Mexico and Texas (Jagnow, 1977). The regional setting of Ogle Cave is discussed by DuChene (this issue).

GENERAL DESCRIPTION

The Ogle Cave system is formed in the northeast wall of the mouth of Slaughter Canyon, at the contact between the massive and breccia members of the Capitan Limestone (Fig. 1). The cave system consists of two essentially independent parts, Ogle Cave and Rainbow Cave, connected by a narrow, joint-controlled passage (see enclosed map). Both caves have been formed along the same joint swarm (trending N20°W), but are slightly offset. The major joint that controls the east wall of Ogle Cave forms the west wall of Rainbow Cave.

The Ogle portion of the cave consists primarily of one large joint-controlled passage 488m long, and commonly averaging 30m in width and height. The main side passage, the Boulder Room, extends for approximately 122m off the west side of Ogle. The floor of the Boulder Room is approximately 6m lower than the adjacent floor of the main passage. Two minor side passages on the east side of Ogle have also been formed at the same elevation as the Boulder Room.

Entrance to Ogle Cave is gained by a 49m drop (minimum) through a natural shaft near the north end of the main passage. At the bottom of this drop is a cone of debris approximately 24m high. From the base of the debris slope, at 1396m elevation, the floor of the cave gradually rises to 1432m at the south end of Ogle. This sloping floor roughly parallels the geologic contact between the massive member and breccia member of the Capitan Limestone (see map profile).

The Rainbow portion of Ogle Cave is located immediately south of Ogle. The large walk-in entrance, 17m wide and 4.6m high, faces the gypsum plains in front of the Capitan Reef Escarpment. From the entrance, the passage slopes downward at approximately 25 degrees, following the same geologic contact as the Ogle portion. Rainbow Cave is 131m long, and averages 18m wide and 24m high.

Rainbow Cave is connected to Ogle Cave only by one tight joint passage at ceiling level. The connection, Blood Fissure, is along the major joint that forms the west wall of Rainbow and the east wall of Ogle. Blood Fissure is 46m in length and is entered by a difficult 12m climb at the apparent "end" of Rainbow Cave. The fissure requires a 43m rappel into the "end" of Ogle Cave.

Thus, the Ogle Cave system consists of two essentially independent caves, dissolved en echelon along a major joint trending N20°W. The cave system contains 670m of linear, joint controlled passage plus approximately 152m of side passages.

STRATIGRAPHY OF THE PERMIAN ROCKS

Capitan Limestone

The Ogle Cave system is formed entirely within the Capitan Limestone—the heart of a 250 million year old Permian reef complex. The Capitan Limestone crops out in a continuous band along the Reef Escarpment (Fig. 2). It is divided into two units, a massive member and a breccia member (Hayes, 1964). The members correspond to the "reef" and "reef talus" facies, respectively, described by Newell and others (1953, Fig. 24). These two members interfinger with one another laterally and vertically, with the Ogle Cave system dissolved at this contact. This gradational zone between the two members rises in stratigraphic position from the northwest to southeast (Fig. 3). The following stratigraphic summary has been prepared from descriptions by Hayes (1964).

Massive Member. The massive member of the Capitan Limestone is

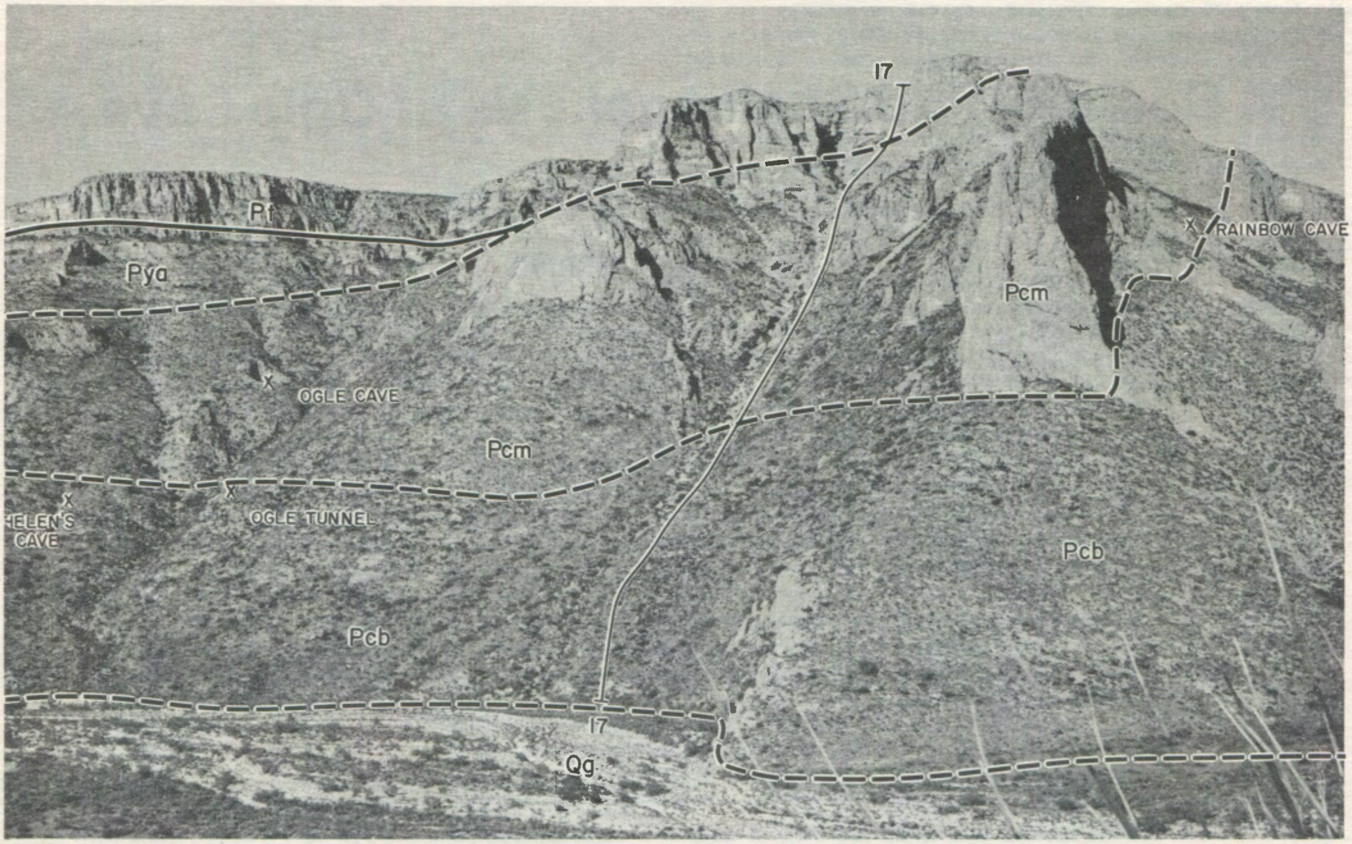


Figure 1. Northeast wall of Slaughter Canyon, showing entrance locations of Ogle Cave, Rainbow Cave, Helen's Cave, and the Ogle tunnel. Lateral transitions of the Yates (Pya) and Tansill (Pt) formations into the massive member of the Capitan Limestone (Pcm) occur directly over Ogle Cave. Ogle and Rainbow caves formed by preferential solution along the transition of the massive member into the breccia member of the Capitan (Pcb). Hayes' stratigraphic section No. 17 (Fig. 4) was measured directly over the cave. Pete Lindsley photo.

characterized by a virtual absence of bedding planes. It forms nearly vertical cliffs in canyon walls from Big Canyon to Slaughter Canyon. It is composed almost entirely of very light gray to yellowish-gray, fine-textured limestone which weathers light olive-gray. Isolated aggregates of white, coarsely crystalline calcite are locally common. Sandstone dikes and isolated pockets of sandstone are common at many localities, and the origin and importance of these deposits will be discussed later. At Ogle Cave, Hayes' measured section (#17) of the Capitan Limestone indicates 133m of massive member overlying 213m of exposed breccia member (Fig. 4).

Breccia Member. The breccia member of "reef talus" of the Capitan Limestone is distinguished from the massive member by differences in bedding, composition, and erosion. The breccia member is composed of thick beds that dip southeastward 20° to 30° or more. These beds contain coarse angular cobbles and boulders of limestone and dolomite derived from the massive member, and bedded dolomites derived from the Tansill and Yates formations (Fig. 5). The breccia member generally forms ragged slopes, as opposed to the nearly vertical cliffs of the massive member (Fig. 1). The maximum measured vertical thickness of the breccia member is about 533m, and its average thickness is about 381m. The breccia member comprises about two-thirds of the total bulk of the Capitan Limestone (Hayes, 1964, p. 22).

The contact between the two members of the Capitan is vague and is mapped where indistinct bedding planes of the breccia member steepen upward and fade out into the massive member. The contact rises stratigraphically toward the southeast and appears to be the major stratigraphic control for solution of the Ogle Cave system.

Artesia Group

The Capitan Limestone is overlain by the Artesia Group, named by Tait and others (1962, p. 511) to include, in ascending order, the Grayburg, Queen, Seven Rivers, Yates, and Tansill formations (see Fig. 3 and DuChene Fig. 2). This group includes a carbonate facies adjacent to the basin-margin facies and an evaporite facies farther shelfward (northwest). Immediately above Ogle Cave, the Capitan Limestone is overlain by the Yates and Tansill Formations, which grade southeastward into the massive member of the Capitan. Only these two upper members of the Artesia Group will be discussed.

Yates Formation. The Yates is underlain by the Seven Rivers Formation (approximately 1.6 km northwest of the Ogle entrance) and overlain by the Tansill Formation with sharp, comformable contacts. The Yates is characterized by very persistent siltstone and very fine sandstone beds which make up one-third to two-thirds of the formation, with the remainder of the section being primarily pisolitic dolomite. The adjacent Seven Rivers and Tansill formations are predominately dolomite.

The quartzose siltstone and sandstone units in the Yates are less resistant to erosion and generally weather into slopes between cliffs and ledges of dolomite. The laminated siltstone and sandstone beds range in thickness from less than 2 cm to 9 m. The color of the weathered rock is mostly very pale orange and grayish-orange near the Capitan and is reddish-orange and reddish-brown farther northwest. This conspicuous color results from limonite or goethite staining. Within 4.8 km of the Capitan, the siltstone and sandstone beds locally contain abundant limonite or goethite pseudomorphs after pyrite, as large as 6

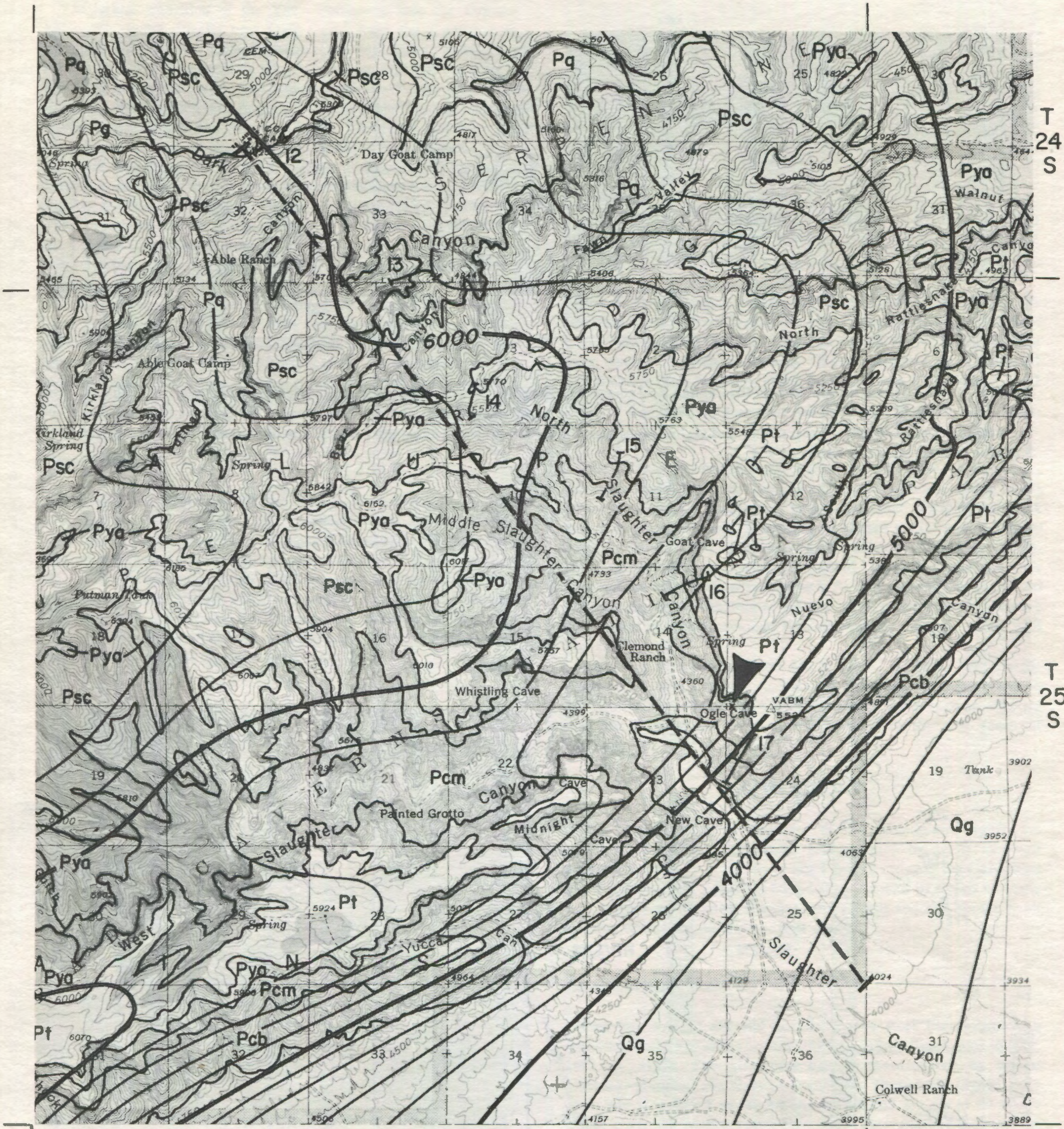
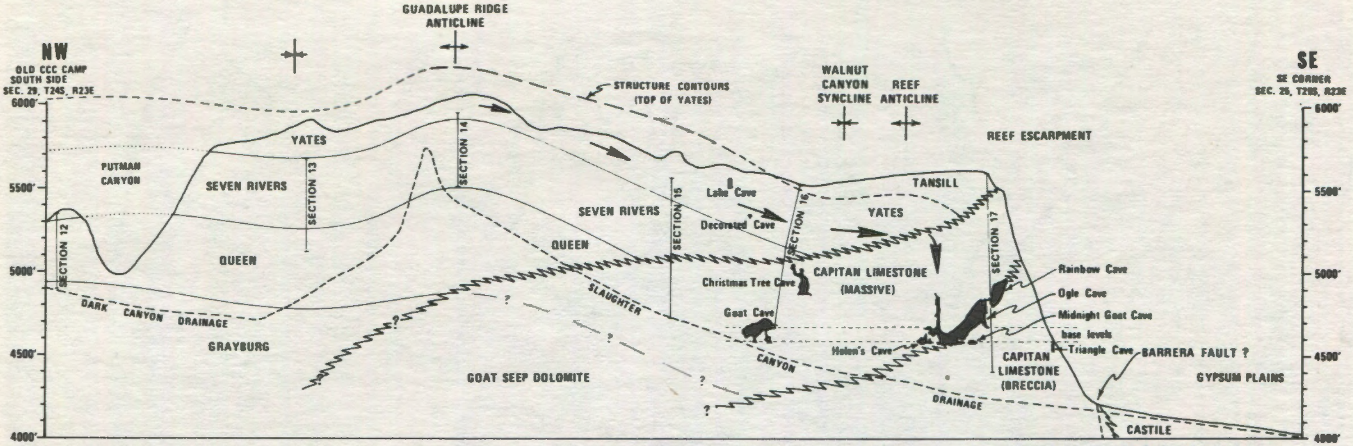


Figure 2. Topographic and geologic map of the Guadalupe Mountains in the Slaughter Canyon area. Geology from Hayes (1964), showing Quaternary gravel (Qg), the massive (Pcm) and breccia (Pcb) members of the Capitan Limestone, and the Tansill (Pt), Yates (Pya), Seven Rivers (Psc), Queen (Pq), and Grayburg (Pg) formations. Structure contours are on the top of the Yates Formation (Contour Interval = 200'). The map also shows the location of the structure cross section (dashed line) (Figure 3), and measured sections by Hayes (Figure 4).



(Caves near the mouth of Slaughter Canyon were projected horizontally onto the line of section.)

Figure 3. Structural cross-section through the Capitan Reef complex at Slaughter Canyon, showing stratigraphic location of several Slaughter Canyon caves. The profile of New Cave has been omitted because it would be superposed on that of Ogle Cave. Arrows indicate groundwater flow along impermeable Yates siltstones. Canyon floor and skyline topography have been projected along dip onto the line of section. Vertical exaggeration = 5.2. Line of cross-section is shown on Fig. 2.

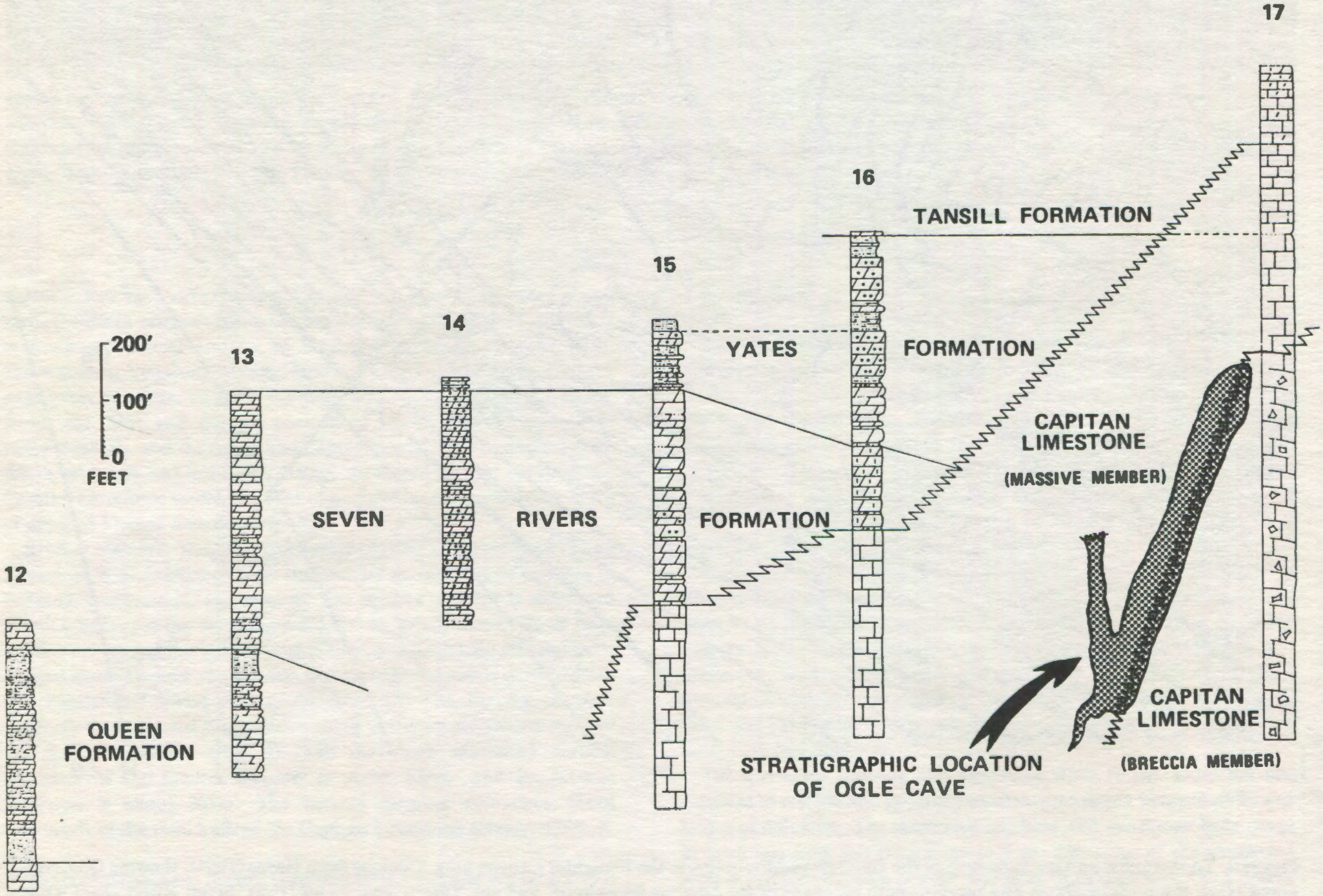


Figure 4. Graphic sections (from Hayes, 1964, Plate 3) in the Slaughter Canyon area, showing stratigraphic location of Ogle Cave and location of impermeable Yates siltstones.

cm in diameter (Fig. 6).

The lateral transition of the Yates Formation into the Capitan Limestone occurs directly over Ogle Cave. Near the transition in Slaughter Canyon, the Yates thickens to at least 114m, owing to a thickening of the dolomite beds (Hayes, 1964, p. 35). The dolomite is very thick bedded, bioclastic, and contains abundant fusulinids. At the transition, the dolomite beds thicken, become calcitic, and the bedding planes disappear into the massive Capitan Limestone. Likewise the siltstone and sandstones grade abruptly downdip into limestone.

Tansill Formation. The Tansill Formation is the youngest formation in the Artesia Group. Within the study area, the Tansill forms outliers capping the Reef Escarpment. The Tansill comformably overlies the Yates Formation and the Yates equivalents in the massive member of the Capitan Limestone. To the southeast (directly over the Rainbow portion of Ogle Cave) the Tansill grades into the uppermost part of the massive Capitan.

The Tansill is composed mainly of dolomite which is nearly identical to the dolomite in the Seven Rivers and Yates formations. It also contains minor beds of siltstone similar to the siltstones of the two underlying formations. The lower portion of the Tansill grades into the massive Capitan Limestone. The upper portion of the Tansill has been removed by erosion. Approximately 91m of Tansill overlies Ogle Cave.

Castile Formation

Following the deposition of the Tansill Formation, or perhaps contemporaneously with the upper portion of the Tansill, marine conditions in the Delaware Basin changed dramatically. The encircling Capitan Reef restricted the basin to such an extent that evaporites of the Castile Formation complete filled the basin and buried the Reef Escarpment. Late Tertiary uplift and erosion have removed the soft evaporites from the resistant Reef Escarpment. However, the uniquely laminated Castile anhydrite was once deposited within a few hundred feet of what is now the Rainbow entrance.

Figure 5. Excellent outcrops of Capitan limestone breccia along the west wall of Ogle Cave 30m beyond "F." Crude bedding planes steepen upward into the massive member 15m above this site. Pete Lindsley photo.

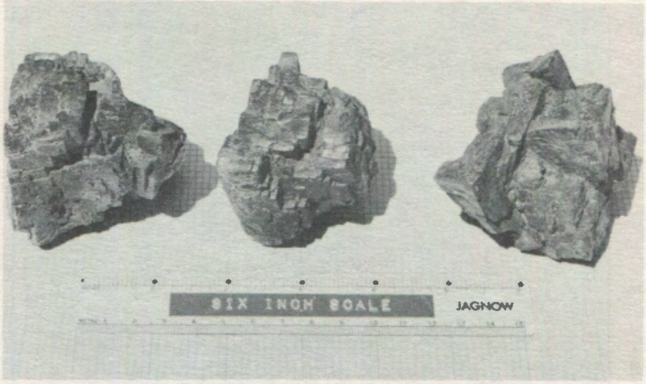


Figure 6. Large limonite pseudomorphs after pyrite indicate that the overlying Yates Formation once contained extensive deposits of sulfide. Uplift, and resulting oxidation, released sulfuric acid down dip into the more soluble Capitan Limestone. These specimens were collected 2.4km east of Dark Lookout, along the Guadalupe Ridge Road. David Jagnow photo.

The Castile Formation originally contained 550m of anhydrite, delicately laminated on the scale of millimeters with alternating bands of white anhydrite (weathered to gypsum) and fine-grained, dark brownish-gray limestone. According to Udden (1924) about 300,000 cycles of the varve-like structure occur in a complete core of the Castile. He suggested that the cycles are annual, indicating that the time spanned by the Castile is comparable to that spanned by individual glacial stages in the Pleistocene. Adams (1944, p. 1619) thinks the dark layers are probably summer deposits—yearly marine floods and plankton blooms.

According to Björkland and Motts (1959, p. 122), "the Castile Formation acts as a barrier to eastward movement of groundwater in the Capitan Limestone. The Castile Formation forms such an effective seal that little or no water moves eastward in the area south of Carlsbad."

STRUCTURE

The major structural features of the Guadalupe uplift are summarized in Fig. 7. The area is dominated by gentle eastward regional dip, formed primarily by late Pliocene tilting of the Guadalupe block. This structural block is bounded on the west by a zone of nearly en echelon normal faults; the Guadalupe Fault and the Border Fault forming two of the most prominent scarps.

Guadalupe Ridge Folds

Crossing regional dip and paralleling the Reef Escarpment is a structural belt 8 km wide known as the Guadalupe Ridge folds (Kelley, 1972, p. 2197). This structural belt is characterized by several northeast-plunging anticlines and synclines. These folds plunge 19 to 28 m/km (1°—1½°) to the east-northeast and are about 40 km in length. Structure contours on the top of the Yates Formation depict the broad Guadalupe Ridge anticline, paralleled to the southeast by the Walnut Canyon syncline, which in turn is paralleled by the Reef anticline at the brow of the escarpment. It is important to realize that the Reef anticline and the Walnut Canyon syncline are relatively minor structural features, mappable only at the top of the Yates Formation (and above). Due to the stratigraphic thickening of the Yates toward the Capitan (Fig. 4), the lower portion of the Yates Formation discharged groundwater directly into the massive member of the Capitan (Fig. 3). Thus, prior to the present erosion cycle,

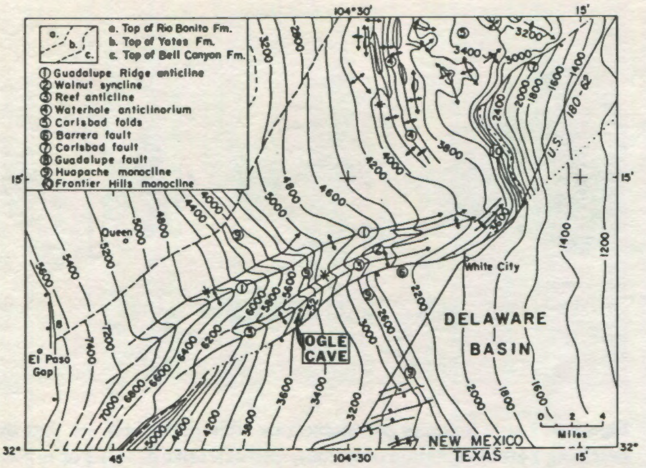


Figure 7. Structural map of the Capitan Reef and adjoining areas (Kelley, 1972, Fig. 3).

impermeable siltstones in the Yates Formation directed groundwater from the Guadalupe Ridge anticline downdip into the more soluble Capitan Limestone. Ogle Cave, Carlsbad Caverns, and New Cave underlie areas of Yates discharge into the Capitan Limestone.

Huapache Monocline

The Huapache monocline trends north-northwest, crossing the Reef Escarpment between Slaughter and Rattlesnake Canyons. This flexure, approximately 6.4 km wide, contains dips of 4 to 5 degrees to the northeast. The Huapache monocline appears to shift to the east as it approaches the Reef Escarpment. The same, or a similar monocline, appears to be offset to the east in the Delaware Basin (Fig. 7, feature no. 9).

Drilling along the Huapache monocline indicates it consists of sediments passively draped over an older structure. Hayes (1964, p. 1) shows a thrust fault of Pennsylvanian or post-Pennsylvanian age beneath the Huapache monocline. He suggests that minor Tertiary movement has probably taken place along this old zone of weakness (1964, p. 42).

As is true of most monoclines, the bottom or synclinal bend at Rattlesnake Canyon is sharper than the upper or anticlinal bend at Slaughter Canyon. The anticlinal bending of sediments results in an upward widening of joints which enhances solution along those joints. The Huapache monocline is thus a major structural control, in part responsible for the concentration of caves in the Slaughter Canyon area along major joints swarms trending N20°W.

Barrera Fault

The other major structural feature in the Slaughter Canyon area is the Barrera fault (Kelley 1971, p. 48-51). The Barrera fault lies along the base of the Capitan Reef Escarpment and it is traceable in outcrop expression for 30 km. The fault dips moderately to steeply toward the basin, with throw for shallow beds ranging up to a few hundred meters. The fault surface has been found in two places. At the mouth of Rattlesnake Canyon, in the west bank of the arroyo, the dip is 65°S on a carbonate footwall. The other exposure is near U.S. Highway 62, 3.8 km east of White City, where the dip is about 80°S. The fault dies out beneath alluvial fans somewhere between Slaughter and Double Canyons.

Offsets of the Salado and Rustler formations indicate a post-Ochoan time of movement on the Barrera fault. The most likely age of the fault is Late Tertiary, accompanying the rise of the Guadalupe Mountains. Slight amounts of recent movement on the Barrera fault are indicated by Holocene fan scarps at the base of the northern end of the Guadalupe Mountains (Kelley, 1971, p. 38). The Barrera fault has no major influence on the speleogenesis of the area other than perhaps being related to the pronounced northeast-trending fracture zone that parallels the Reef Escarpment.

GEOLOGIC FACTORS CONTROLLING SPELEOGENESIS

The major geologic and hydrologic factors controlling the speleogenesis of Ogle Cave are joints, stratigraphic position, solution via sulfuric acid, sandstone dikes, and the influence of base levels.

Joints

Most caves of the Guadalupe Mountains are strongly joint controlled, and Ogle Cave is no exception. The lack of bedding planes in the massive member of the Capitan Limestone makes the joint control even more pronounced. Groundwater flow along joints and fractures commonly produces fissures that exhibit linear, angular, or rectilinear patterns. The Capitan Reef complex contains a conspicuous system of nearly vertical joints. One set of joints parallels the Reef Escarpment, while a second set is approximately perpendicular. These joints will be referred to in terms of "major" and "minor" joints, dependent on the amount of solution that has occurred along each. In several areas of the Guadalupe Mountains, the major and minor joints are reversed due to the influence of local structure or a particular geologic formation (Jagnow, 1977). Another type of jointing peculiar to the Capitan Limestone is exfoliation (spalling), a breakdown process that modifies the original solutional passage during vadose conditions. These three types of jointing are prominent in Ogle Cave.

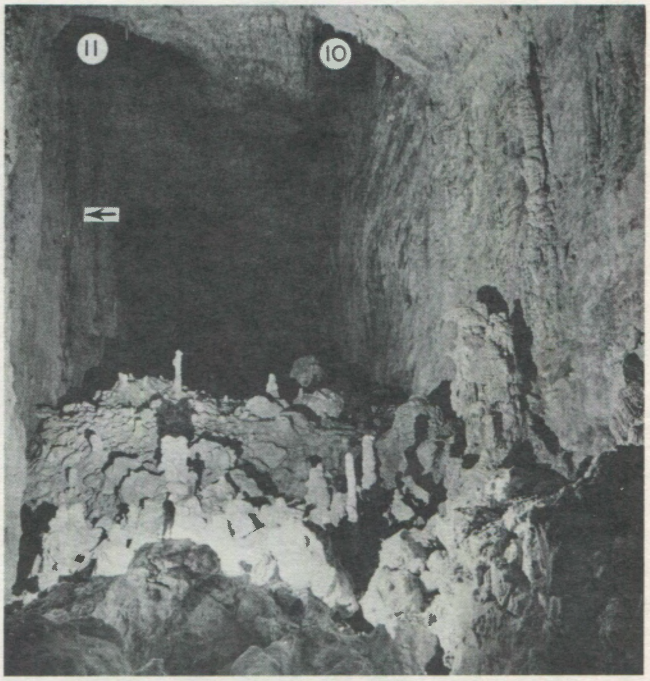


Figure 8. This view south into Ogle Cave from approximately "OM12" illustrates the strongly joint-controlled walls trending N20°W. Elongate ceiling domes are present where sandstone dikes nos. 10 and 11 intersect the cave. Arrow marks dark streaks of sand-impregnated flowstone beneath sandstone dike No. 11. Pete Lindsley photo.

Major joints. The major joint swarm controlling solution of Ogle Cave trends N20°W, paralleling the Huapache monocline and perpendicular to the Reef Escarpment. The linear nature and nearly vertical walls of Ogle Cave are two of the cave's most striking features (Fig. 8). The walls of Ogle Cave are defined primarily by three major joints. The central joint forms the east wall of the Ogle section, the west wall of the Rainbow section, and provides the only connection (Blood Fissure) between these two essentially independent caves. Approximately 30m west of the central joint, a second major joint controls the west wall of the Ogle section. Between these two bounding joints are other major joints spaced irregularly at roughly 6 m intervals. This joint swarm roughly parallels the major bounding joints and forms domes, linear ceiling irregularities, and rows of speleothems (see Fig. 8 and map cross-sections). The "Sequoias" in the Sequoia Room are a row of columns over 20m tall and up to 2m in diameter aligned along a major joint.

Near the entrance to Ogle Cave, the central joint ends at an alcove in the Sequoia Room. At this point the wall jogs inward for 6m along a minor cross joint, then follows another major joint toward the entrance. Similar jogs occur on the west side of the passage. Approaching the entrance, the passage narrows until at the entrance shaft solution has occurred along one major joint striking N20°W and dipping 85°E.

As stated earlier, in the Rainbow Cave section, the central joint bounds the west wall and continues all the way to the Rainbow entrance. This portion of the cave averages 18m in width. The third major bounding joint controls the east wall, dying out in a small alcove 12m inside the Rainbow entrance. Other major joints, spaced roughly 6m apart, give the ceiling cross sections their step-like appearance.

In general, the ceilings of both Rainbow and Ogle cave slope away from the central joint. This probably indicates that the earliest and/or greatest amount of solution occurred along this central "life-line" of the cave.

Minor joints. Close inspection of the massive Capitan Limestone reveals two kinds of minor joints that contributed less to the solution of the cave. Paralleling the major joints is a swarm of minor joints about one meter apart. These minor joints are best observed in an alcove on the west wall of Ogle between cross sections G and H. Their strike parallels the major joints and their dips average 80°E at this location.

The other set of minor joints is conjugate to the major joint swarm. This set parallels the Reef Escarpment and is approximately perpendicular to the Huapache monocline. The Slaughter Canyon area is unique in its relationship to the Huapache monocline. Elsewhere along the Reef Escarpment, solution in the Capitan Limestone was primarily controlled by the joints paralleling the escarpment. However, the Slaughter Canyon caves (Ogle, Helen's, New, Wen, Goat, and Longlegs) are all developed parallel to the Huapache monocline. The only known exceptions are minor caves that parallel the Reef Escarpment in the overlying Yates Formation (Lake Cave and Decorated Cave) (see Fig. 3).

There are three good locations in Ogle Cave to observe the effects of minor cross joints. The natural entrance shaft of Ogle Cave formed at the intersection of a major joint and a sandstone-filled minor cross joint. In the Sequoia Room, several minor cross joints control the alignment of speleothems and the abrupt jog in the cave wall. These joints also control the major drainage directly over this area (see map profile). The third location is near the end of Ogle Cave, where three cross joints are partially sandstone-filled.

For the most part, the minor cross-joints did not contribute significantly to the solution of the cave. However, when these joints have been tectonically opened and filled with sandstone, they become important aquifers for channeling acidic waters directly down to zones of solution.

Exfoliation. Another type of jointing that is peculiar to the Capitan Limestone is exfoliation—sheeting parallel to the present erosion surface. Hayes (1964, p. 46) states that "sheeting occurs locally along the Reef Escarpment and on the walls of some of the canyons which cut through the escarpment. The sheeting can be easily confused with the crudely developed bedding in the breccia member, which is subparallel to the surface of the Reef Escarpment. The type of sheeting or exfoliation noted in the Capitan Limestone is often well developed in granitic rocks, but is rarely observed in sedimentary rocks". Bradley (1958, p. 1724) described similar jointing in massive sandstones of the Colorado Plateau.

Figure 9. Examples of inward exfoliation, paralleling the original solutional void. The 15mm scale is resting on a block of gypsum deposited at the extreme end of the Main passage in Cottonwood Cave.

Exfoliation also occurs in the caves of the Capitan Limestone. The void of the cave serves as the erosion surface, and inward exfoliation occurs parallel to the wall of the original solutional void (Fig. 9). The actual mechanism for exfoliation probably results from the rocks having experienced pressure "relaxation" due to removal of the adjacent rock (over-burden), or from chemical weathering. The exfoliation slabs (spalls) may range in thickness from 1 to 60 cm. Thus, exfoliation is a breakdown process resulting in modification of the original solution cave.

To a certain extent, Ogle Cave has been modified by exfoliation jointing. The floor of the entire main passage is covered with spalls, except where more recent deposits of guano cover the breakdown. As a result, the position of Ogle Cave has shifted upward and slightly outward from its original solutional position—perhaps on the order of 6m. The Boulder Room is one of the few areas of Ogle Cave that has not been modified by exfoliation. This broad solutional room is approximately 6m lower than the breakdown floor of the adjacent main passage and probably represents one of the original base levels of cave formation. In support of this argument, there are two minor side passages off the east wall of Ogle that are reached by climbing down through breakdown to approximately the same elevation as the Boulder Room. Other side passages have probably been completely hidden by the breakdown. Figure 10 diagrams some of the modifications due to exfoliation.

Stratigraphic Position

The three largest caves in Carlsbad Caverns National Park occupy the same stratigraphic position. Carlsbad Caverns, Ogle Cave, and New Cave are each formed primarily in the massive member of the Capitan Limestone, at its contact with the breccia member, and directly below the southeastern limit of the Yates Formation. This unique combination of structure and stratigraphy (Fig. 3) has provided optimum conditions for speleogenesis.

Bedding planes. The contact between the massive and breccia members of the Capitan Limestone is important because, at the contact, the bedding planes of the breccia member interrupt the downward movement of groundwater in the vertical joints of the massive member. This intersection of vertical joints and joint swarms with bedding planes allows solution and erosion to take place more readily than in surrounding localities.

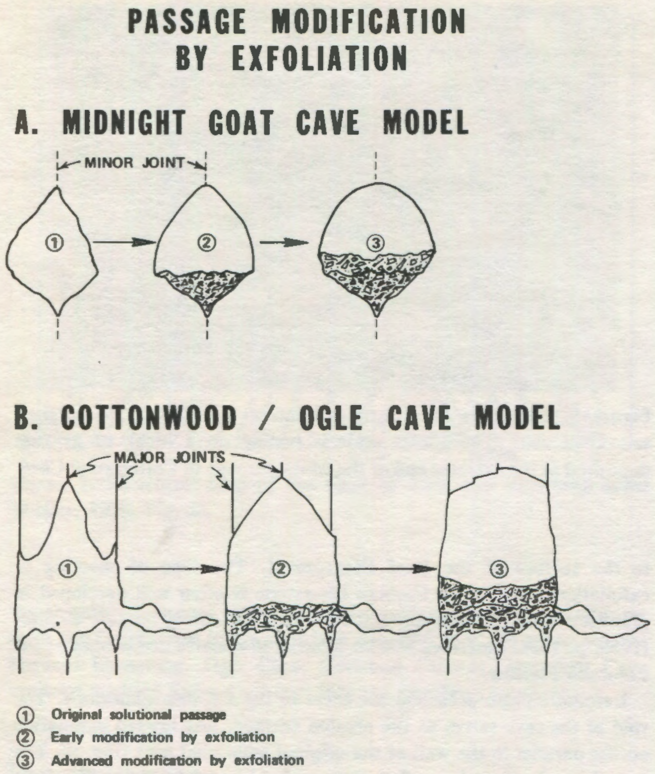


Figure 10. Diagrammatic examples of passage modification by exfoliation.

In Ogle Cave, the breccia member is best exposed at the southeastern end of the cave, where nearly 15m of breccia is exposed (Fig. 5). Bedding planes are indistinct, but can be observed extending upward into the massive member in some places. Isolated pockets or beds of breccia occur elsewhere in the cave walls. However, the present floor of Ogle Cave, which locally is underlain by more than 15m of breakdown, is roughly coincident with the geologic contact of the two members. The Boulder Room, which is lower than the main passage, is probably formed in the breccia member, although massive flowstone masks most of the bedrock. In Rainbow Cave, the bedrock is also masked by flowstone, moss, and green algae; however, the entrance is immediately above the breccia contact.

Yates discharge. The Yates Formation played an equally important role in the development of Ogle Cave. As discussed earlier, the lateral transition of the Yates Formation into the Capitan Limestone occurs directly over Ogle Cave (Fig. 3). The upper two-thirds of the Yates Formation contains numerous impermeable siltstones up to 2m thick. These impermeable siltstones act as groundwater barriers, collecting groundwater from as far northwest as the Guadalupe Ridge anticline. The oxygen-rich groundwater flows down dip and is dumped into the massive member of the Capitan directly over Ogle Cave. The groundwater follows vertical joints and joint swarms until it intersects the more permeable bedding planes at the contact of the breccia member.

Solution Via Sulfuric Acid

In recent years, cave development via sulfuric acid and the origin of sulfate minerals have been well documented in other areas of the country (Morehouse, 1968; Pohl and White, 1965). To the author's knowledge, this mechanism has not previously been proposed for the origin of the caves in the Guadalupe Mountains. Several lines of evidence support the hypothesis that the solution reaction during the development of Ogle Cave involved sulfuric acid in addition to carbonic acid.

Overlying source of sulfides. Pyrite in the overlying Yates Formation provided a widespread source of sulfide for the reaction. Because of their rapid weathering rate, sulfide minerals are not normally observed in outcrop. However, limonite pseudomorphs after pyrite are a common occurrence in the Yates Formation. Most ridges southeast of Guadalupe Ridge are capped by the Yates and commonly contain limonite pseudomorphs up to 6 cm in diameter (Fig. 6). Slabs and polished sections of several large pseudomorphs indicate only 1% of the original pyrite remains unaltered.

Pyrite also occurs disseminated in the upper two-thirds of the Yates Formation. Most of the disseminated pyrite has been altered to limonite or goethite, resulting in the pale orange to reddish-orange color characteristic of the Yates siltstones and sandstones.

Evidence for massive concentrations of pyrite are present at Queen of the Guadalupes 18.5 km WSW, where a 70m deep series of pits formed directly beneath a former deposit of massive pyrite, now altered to limonite. The small resistant knob immediately over the cave is a gossan, or "iron hat", consisting principally of hydrated oxide of iron. The outcrop at the pit entrance and thin section analysis confirm gossan texture. Minor occurrences of malachite, azurite, and barite also indicate the former presence of a sulfide mass. The fact that Queen of the Guadalupes formed directly beneath a gossan, provides direct evidence for cavern development via sulfuric acid.

Massive gypsum. Sulfate minerals, especially beds of massive gypsum, are present in large quantities in many Guadalupe caves; however, the origin of these deposits has remained obscure. A maximum thickness of approximately 8m is observed where the Talcum Passage of Carlsbad Caverns overlooks Lower Cave. New Cave, Cottonwood Cave, Black Cave, Hell Below Cave, Pink Panther Cave, and the McKittrick Hill caves are a few of the caves containing massive gypsum. The gypsum is best preserved in isolated dry alcoves and passages with inactive drainages. The only known gypsum crust in Ogle Cave occurs in the Welbourn side passage at SL3-SL4; however, there may be some beds of massive gypsum beneath the breakdown floor.

These beds of massive gypsum, characteristic of the Guadalupe caves, are the end product of cavern development via sulfuric acid. During the last stage of cavern development, ponded waters high in sulfate and calcium precipitated calcium sulfate on the floor of the lake. A tunnel through the gypsum in the Big Room of Carlsbad Caverns clearly shows varved gypsum draped over bedrock knobs. Thousands of years were probably required to precipitate the gypsum, most of which was later dissolved by vadose streams and/or recrystallized, destroying the 1-2mm varves.

Sulfuric acid reaction. The sulfuric acid solution reaction, as suggested by Howard (1960), is as follows:

Step A: $4FeS_2 + 15\,O_2 + 2H_2O \rightarrow 2Fe_2(SO_4)_3 + 2H_2SO_4$
Step B: $2Fe_2(SO_4)_3 + 12H_2O \rightarrow 4Fe(OH)_3 + 6H_2SO_4$
Step C: $4Fe(OH)_3 \rightarrow 2Fe_2O_3 \cdot nH_2O$
Step D: $8H_2SO_4 + 16CaCO_3 \rightarrow 16Ca^{++} + 8SO_4^{=} + 16HCO_3^{-}$
Step E: $8Ca^{++} + 8SO_4^{=} \rightarrow 8CaSO_4$
Steps A+B+C+D+E: $4FeS_2 + 15\,O_2 + 14H_2O + 16CaCO_3 \rightarrow$
$2Fe_2O_3 \cdot nH_2O + 8Ca^{++} + 8CaSO_4 + 16HCO_3^{-}$

The pathway given for the sulfuric acid reaction is a standard inorganic mechanism. However, there is the possibility that the reaction is partially or completely organic. Iron bacteria, common in the subsurface around Carlsbad, gain their energy by the oxidation of ferrous iron to ferric iron. Therefore, the bacteria could produce the sulfuric acid by the following reaction:

Step A+B (alternate): $4FeS_2 + 15\,O_2 + 14H_2O \rightarrow 4Fe(OH)_3 +$
$8H_2SO_4$

The ferric hydroxide is then excreted by the bacterium and undergoes the same rearrangement and dehydration as occurs in Step C of the inorganic mechanism (Cotton and Wilkinson, 1962).

Considering the foregoing evidence, I have concluded that the sulfuric acid reaction (inorganic, organic, or both) was a major solution reaction during the development of the Guadalupe caves and is responsible for the numerous occurrences of thin crusts and beds of massive gypsum.

Sandstone Dikes

No fewer than 15 permeable sandstone dikes cutting Ogle Cave provided direct pathways for acidic waters discharged from the Yates to enter Ogle Cave. Sandstone dikes, ranging in thickness from a centimeter to 3m across, are relatively common in and immediately adjacent to the Capitan Limestone. Resulting from tectonic opening of joints and sand being washed in from above, they have been described by Hayes, 1964, p. 37 and 46; Newell, *et al*, 1953, p. 130; Dunham, 1972, p. II-77; and many others. Lower Cave and the Big Room of Carlsbad Caverns contain "numerous sand domes, conical piles of quartz sand which sifted in through cracks and which were later covered with carbonate. Many of these domes were breached for trail-building material during the early part of the century" (Bullington, 1968, p. 23). Most of these conical piles of quartz sand accumulated beneath weathering sandstone dikes.

In Ogle Cave, preferential solution has occurred at sandstone dikes, resulting in ceiling domes (Fig. 8) and minor wall alcoves (Fig. 11) where the dikes are exposed. Five of the dikes consist of buff to pale-orange fine quartz sandstone infilling major vertical joints; four dikes infill minor vertical cross joints; 2 dikes infill high angle cross joints (see N-S Profile and Fig. 11); and 5 exposures appear as irregular sandstone plugs at the top of domes. The appendix* summarizes the observed sandstone dikes.

Although ceiling heights are commonly 30m or more, the sandstone dikes were mapped with the aid of a 6-volt flashlight. Sand-impregnated flowstone (Fig. 12) often betrays the presence of a sandstone dike high above. The upper surfaces of the white flowstone are coated with calcite-cemented pale-orange sandstone that has washed or fallen from the easily weathered sandstone dike. Flowstone is common beneath the sandstone dikes, indicating that the same solutions that dissolved the cave under phreatic conditions, later deposited massive speleothems under vadose conditions.

Four hand specimens of the sandstone dikes were collected from the entrance shaft area for thin section analysis. Petrographic analysis shows two distinct lithologies characteristic of two different ages of emplacement. The petrographic description and the age conotations discussed by previously mentioned authors, are summarized in Table 1. The most diagnostic parameters are color, grain size, and minerals. Black chert pebbles in the post-Permian sandstone dikes are similar to the black chert in the Pliocene Ogalalla Formation. Hayes (1964) suggests an early Cretaceous age for the sandstone dikes. The cement in the samples collected appears to be nondiagnostic. However, Dunham cites dolomite cement for Type A sandstones; quartz or quartz and calcite cement for Type B sandstones. He also records abundant kaolinite as typical of Type A.

The entrance shaft of Ogle Cave resulted from preferential solution at the intersection of at least three sandstone dikes. Figure 13 shows two sandstone dikes exposed at the east rim of the entrance shaft. Arrows indicate small solution cavities formed immediately below the sandstone dikes. The east wall of Slaughter Canyon exposes numerous sandstone dikes immediately above Ogle Cave. Inside the cave, the main joint connecting Ogle and Rainbow Caves contains at least five areas of sandstone fill. The sandstone dikes accelerated the solution of Ogle and Rainbow Caves, allowing vast quantities of rock to be dissolved at or immediately below base level.

TABLE 1. Petrographic Description Of Ogle Cave Sandstone Dikes

Parameter	**Type A: (Permian Age)**	**Type B: (Post-Permian) (Pliocene)**
Color (fresh)	Buff to pale orange	Lt. gray, salt and pepper
Grain size	V. fine to medium	Generally coarse sand to gravel
Sorting	Moderately to well sorted	Poorly sorted
Roundness	Subrounded to subangular	Subangular to well rounded
Grain constituents	∿95% clean quartz sand 1-5% Limonite 1-3% kaolinite	∿60% clean quartz sand 20% lt. gray chert sand-pebbles 10% black chert sand-pebbles 10% Kaolinite occasional euhedral quartz xl.
Grain texture	Surface etching	Common quartz overgrowths
Staining	Minor limonite staining	None
Cement	Primarily calcite with 20-40% patchy, porous, granular dolomite.	
Porosity	Estimated 2-10% ø — primarily in the granular dolomite cement. Local solution (weathering) removes calcite cement, resulting in friable sandstone with 25% ø.	

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* A copy of the Appendix is available free on request to: NSS Library, Cave Avenue, Huntsville, Alabama.

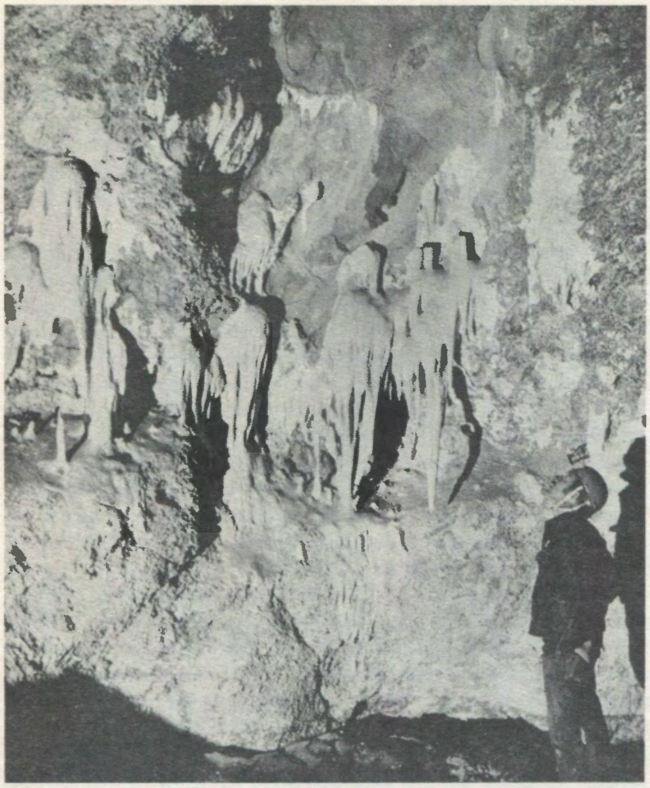

Figure 11. Dissected remnant of sandstone dike No. 15, exposed in the west wall 18m beyond "F." Fifteen sandstone dikes cutting Ogle Cave provided direct pathways into the cave for acidic discharge from the Yates Formation. Under vadose conditions, flowstone is commonly deposited beneath the dikes. David Jagnow photo.

Figure 12. Sand-impregnated flowstone (dark colored areas) beneath sandstone dikes nos. 13 and 14 in the alcove near "F." Such clues often aided in locating sandstone dikes 30m above. Pete Lindsley Photo.

Base Level

The speleogenesis of Ogle Cave was initiated by phreatic solution, with preferential solution occurring where the vertical joint swarm and sandstone dikes first intersected the bedding planes of the breccia member. Deep phreatic solution may have started as early as late Cretaceous as a result of broad epeirogenic uplift and tilting to the northeast (Bullington, 1968). It was probably well advanced by late Pliocene or early Pleistocene when most of the uplift of the Guadalupe Mountains occurred (Hayes, 1964). This uplift resulted in abrupt drops, followed by periodic stability, of the nearly horizontal water table. The greatest phreatic solution takes place at or directly below the zone of saturation, developing horizontal cave levels.

Carlsbad Caverns, 13 km northeast, contains at least five distinct levels of passageways. These levels suggest stable base levels for long periods at elevations of 1282m (Bat Cave), 1227m (Upper Guadalupe Room), 1212m (Lower Guadalupe Room), 1114m (Big Room and Left Hand Tunnel), and 1090m (Lower Cave). Detailed leveling of a distinct water mark from the Big Room to near the end of Left Hand Tunnel indicates an apparent dip to the east of 3.2m/km (17 ft/mile) (Jagnow, 1977). Thus, minor tilting of the Guadalupe Mountains followed, and probably accompanied, the drainage of the main level of Carlsbad Caverns.

Ogle Cave lacks the extensive, well-defined base levels of Carlsbad Caverns. However, evidence inside the cave and from other caves in the immediate area suggest that two former base levels intersect Ogle Cave. The most prominent horizontal development occurs around 1390m, the elevation of the Boulder Room and East Chambers. Both walls of the cave contain solutional boneyard at this elevation. Other side passages probably exist at this level, but their entrances are sealed with breakdown (Fig. 10-B3). Solution pockets and minor passages at the north end of Ogle Cave suggest a second base level near 1417-20m.

Table 2 summarizes the elevations of key levels in other caves near the mouth of Slaughter Canyon:

TABLE 2. Base Level Data From Nearby Caves

Cave name	Lower level elevation	Upper level elevation
New Cave	1399.3m at N-6 (Level of Chinese Wall)	1418.5m at N-2 & N-3 (level of side passages in center of cave), distinct waterline at 1421.3m
Wen Cave (dissected portion of New Cave)	———	1426.5m at bottom of drop
Midnight Goat Cave (dissected portion of New Cave in Midnight Canyon)	Floor = 1399-1400m	(small solution cavities above Midnight Goat Cave)
Triangle Cave	Approx. 1402m	———
Helen's Cave	Approx. 1402m	———
Goat Cave	Est. 1402m	Est. 1417m

These caves provide further evidence for a prominent base level near 1390m and a less pronounced level at 1417-20m. It is interesting to note that the vertical separation between these two levels is nearly identical to that between the Big Room and Lower Cave in Carlsbad Caverns. It is my hope that a CRF network of theodolite surveys will accurately tie down a series of tilted base levels throughout the Guadalupe caves in the years to come.

Speleogenesis Summary

The geologic history of Ogle Cave began 250 million years ago with the growth of the Permian Capitan Reef. The complex stratigraphy

Figure 13. Two tabular exposures of sandstone dikes (No. 1) at the east lip of the Ogle Cave entrance shaft. Arrows point to small solution cavities beneath each dike. Below the skyline is the lateral transition of the Yates and Tansill formations into the massive Capitan Limestone. Note person (right) for scale. David Jagnow photo.

later focused preferential solution near the front of the depositional reef escarpment. The core of the reef, the massive Capitan Limestone, was highly soluble, with especially great solubility near the bedding planes of the breccia member. Impermeable siltstones in the overlying Yates Formation formed barriers to ground water migration. Slight initial dips, increased by later structural deformation, allowed groundwater to move down-dip along the siltstones and discharge into the massive Capitan Limestone directly over Ogle Cave. The Yates Formation also contained finely disseminated grains, large crystals, and massive concentrations of pyrite—the sulfide source of sulfuric acid which aided solution. Finally, nearly 610m of anhydrite in the Castile Formation filled the Delaware Basin and buried the Reef Escarpment, forming a groundwater barrier along the front of the reef. Thus, the original depositional setting established conditions for preferential solution near the front of the reef escarpment.

In late Guadalupian time, settling of the reef on the unstable forereef breccia produced two prominent sets of near vertical joints. One set parallels the reef escarpment, and a second set is approximately perpendicular to the escarpment. This second set trends N20°W and parallels the Huapache monocline in the vicinity of Slaughter Canyon. These intersecting joints formed avenues for solution, controlling the development and orientation of Ogle Cave. Differential settling of the

TABLE 3. Chronological Summary of Ogle Cave Speleogenesis

Geologic Periods	Tectonic Events	Sedimentation Events	Speleogenetic Events
Precambrian (570 mybp)	Regional NW-trending wrench and thrust faults.	Unknown	None
Late Pennsylvanian to Early Permian (Wolfcamp) (300-270 mybp)	Regional folding and faulting along old faults (Victorio monocline, Babb flexure, Bone Springs (?) and Huapache monoclines.	Basin sedimentation.	None
Late Permian: Guadalupian epoch (260-240 mybp)	No major events.	Deposition of the reef margin facies (Capitan Limestone) and back reef facies (Seven Rivers, Yates and Tansill Formations).	(Possible early karst development, not discussed in this paper. See Dunham, 1972, pp. II-97-99.)
	Possible tectonic activity or settling of reef on unstable fore-reef breccia forms two prominent sets of nearly vertical joints.	Sand infills some joints, producing type A sandstone dikes.	
Ochoan epoch (240-225 mybp)	No major events.	Capitan Reef dies out as the Delaware Basin is filled with Castille evaporites, then Rustler and Salado elastics and evaporites.	
Late Cretaceous (100-65 mybp)	Broad regional uplift continuing into Micene.	Broad peneplain with minor erosion and minor Cretaceous sedimentation.	Possible minor deep phreatic solution.
Late Tertiary: Late Miocene, Pliocene and Pleistocene epochs (10-1 mybp)	Periodic faulting and uplift of the Guadalupe Mountains along NNW-trending faults; regional tilting to the NE; folding of the Guadalupe Ridge anticline; movement along the Barrera fault; and flexing of the Huapache monocline causing widening of the NNW-trending joints in the Slaughter Canyon area.	Deposition of Pliocene Ogallala gravels over broad Pecos River Valley are and upper surfaces of Guadalupe Mountains. Coarse sand infills some opened joints, producing type B sandstone dikes.	Uplift resulted in oxidation of the Yates pyrite, releasing sulfuric acid down dip into the more soluble Capitan Limestone. Periodic uplift cause shallow phreatic solution to concentrate along nearly horizontal water tables. As uplift continued, higher cave levels were drained, tilted, and began to fill with speleothems and cave breccia from exfoliation. Ogle Cave probably developed in Early Pleistocene.

reef opened many joints and sand from the overlying Yates Formation washed in, forming sandstone dikes up to 3m wide. The 15 permeable sandstone dikes cutting Ogle Cave provide direct pathways into the cave for the acidic discharge from the Yates Formation.

Post-Permian history of the Guadalupe Mountains is somewhat sketchy. Broad epeirogenic uplift and tilting to the northeast during late Cretaceous may have initiated deep phreatic solution in the Capitan Reef. By Pliocene time, shallow phreatic solution had probably developed caves near the top of the reef complex.

Late Pliocene uplift of the Guadalupe Mountains initiated development of most of the Guadalupe caves. Folding of the Guadalupe Ridge anticline increased the dip of the Yates siltstones. Uplift also resulted in oxidation of the pyrite in the Yates Formation, releasing sulfuric acid down dip into the more soluble Capitan Limestone. Folding, movement of the Barrera fault, and possible flexing of the Huapache monocline opened new joint swarms—some being filled with coarse sand and gravel possibly of Pliocene age.

Periodic faulting and uplift continued into the early Pleistocene, resulting in abrupt drops, followed by periodic stability, of the local base level with shallow-phreatic solution immediately below it. Increased precipitation during the Pleistocene resulted in extensive cavern development. Preferential solution occurred where vertical joints and sandstone dikes intersected the sloping bedding planes of the breccia member. Horizontal development of passages and boneyard, as well as evidence from nearby caves, indicates that former base levels intersected Ogle Cave near 1390m and 1417-20m.

During the last stage of cavern development at any one level, gypsum from ponded waters high in sulfate and calcium was precipitated on the floors and ledges of many Guadalupe caves.

With the onset of vadose conditions, the beds of massive gypsum were commonly recrystallized, "drilled" by dripping water, and/or completely removed by periodic vadose streams. Exfoliation often modified the original solution passage, resulting in slight upward migration (Fig. 10). Vadose conditions in Ogle Cave were accompanied by deposition of massive speleothems. The flowstone beneath sandstone dikes is commonly impregnated with sand that has washed or fallen from above.

In recent times, the climate of the Guadalupe Mountains has become increasingly arid. Most speleothems currently are inactive. Although caves are probably still being developed in the Capitan Limestone at the present base level, the sulfuric acid mechanism is probably inactive, unless new sources of sulfide are present deeper within the Capitan Reef.

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Mineralogy of Ogle Cave

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ABSTRACT

Ogle Cave contains massive carbonate dripstone and flowstone speleothems such as stalactites, stalagmites, columns, draperies, flowstone, and bell canopies; it also contains maller carbonate speleothems such as shields, tower coralloids, rimstone shelves, helictites, rafts, rimstone dams, cave pearls, moonmilk, and popcorn. The columns in Ogle Cave reach 20 m in height. Cross sections of these columns indicate three separate growth periods. Evaporation, as well as CO_2 loss, appears to be a mechanism for calcite deposition in Ogle Cave and has produced the unusual speleothem morphology of bell canopies and tower coralloids. Popcorn growth is oriented toward the Ogle entrance and away from the Rainbow entrance. This orientation may be due to differential evaporation rates caused by a seasonal "chimney effect" within the cave. Brushite, a phosphate mineral, is found in great abundance in Ogle Cave and is a leached by-product of bat guano. Small amounts of calcite flowstone, coral, soda straw, and drapery deposits have grown within the cave in the 40 to 60 years since guano mining ended.

INTRODUCTION

Like most of the caves of the Guadalupe Mountains, New Mexico, Ogle Cave is well decorated with large speleothems. However, almost all of the decorations are "dead;" that is, they are inactive due to a regional climate of little rainfall, low humidity, and high evaporation. Very little research has ever been done on how different climates might produce different speleothem morphologies. Past work on the relationship of speleothem type versus climate has been limited to discussions of speleothem size (*e.g.*, wetter climate produces larger speleothems) and mineral type (*e.g.*, aragonite should be precipitated in warmer climates).

This paper has two main objectives: 1) to give an overview of the types of speleothems that exist in Ogle Cave and 2) to specifically discuss the role of evaporation as a depositional mechanism that influences speleothem morphology. Two speleothem types in Ogle Cave, the bell canopy and the tower coralloid, are believed to be produced by high evaporation rates. Also, entrance orientation of popcorn and flowstone and its relation to evaporation is discussed.

DESCRIPTION OF SPELEOTHEMS

Ogle Cave, Carlsbad Caverns National Park, New Mexico, contains a variety of large carbonate speleothems, among which are stalactites, stalagmites, columns, draperies, flowstone, and bell canopies (Fig. 1). The columns in Ogle Cave are especially distinctive; these colossal pillars reach over 20 m in height and are among the largest in North America. The main area of dripstone mineralization is in the Sequoia Room (between OM-5 and OM-6). "Snoopy" and various other extremely massive stalagmites and columns are located in the Sequoia Room. Their presence at this particular place is no coincidence, but is related to surface topography. Directly above the Sequoia Room is a surface topographic low (see Map). Drainage is pilfered from this low down into the cave along major joints and minor cross joints (see Jagnow, this issue). "*Was* pilfered" is probably a more correct phrase, because at the present time dripstone and flowstone deposition in Ogle Cave has almost ceased. Small amounts of dripping water are seen throughout the cave, but no massive carbonate buildup is occurring at the present time. In the Rainbow section of Ogle Cave, the dripstone and flowstone are all within the daylight zone. In a few places, moisture causes speleothems to be covered with algae on the daylight-facing surfaces.

Figure 1. Massive columns in Ogle Cave. Note standing figure on right. Pete Lindsley photo.

Columns

Many of the massive columns in Ogle Cave have broken along the column-ceiling contact and are either leaning against the cave wall or have collapsed to the floor. Upon collapsing, almost all of these columns have fractured, providing ready-made cross sections of their interiors. Three separate growth periods are indicated by the cross sections of the broken columns (Fig. 2). The inner core is quite macrocrystalline, with large, "blocky," rhombohedral crystals that are oriented concentrically around the center axis of the column.

Figure 2. Cross-section of an Ogle Cave column. The inner, ellipsoidal core consists of macrocrystalline calcite. The core is surrounded by alternating dark and light rings. The outermost part consists of many closely-spaced light rings and a final, weathered, surface. Ron Miller photo.

These cores are round or slightly ellipsoidal in shape and, in all of the columns examined, (20 to 30), the cores were 15 to 20 cm in diameter. The macrocrystalline cores have only a few distinguishable growth rings and may indicate an early uninterrupted growth cycle under moist surface and cave conditions, or, at least, under conditions of constantly infiltrating water. Surrounding the inner macrocrystalline core is a second growth region that shows typical radial crystal orientation. This section is variable in width, is less macrocrystalline than the inner core, and has alternating lighter and darker growth rings. Often, the light rings are fairly evenly spaced between the dark layers, perhaps indicating dry years alternating with wet years. The outer portions of the columns consist of many closely spaced, light-colored rings with light-colored, weathered outside surfaces. Light-colored rings are caused by a cessation of growth. Their surfaces are discolored by dust and, therefore, probably indicate dry, desiccating growth conditions. (For a discussion of the age of Ogle Cave stalagmites, see Harmon, this issue).

Bell Canopies

Bell canopies are abundant in Ogle Cave. These bell- or mushroom-shaped speleothems extend outwards as lateral protrusions from columns and other carbonate flowstone speleothems. Although absent in most other caves of the United States, bell canopies are conspicuous in many caves of Carlsbad Caverns National Park and the Guadalupe Mountains (Hill, 1973a, 1976). Bell canopies are believed to form when downward-flowing solutions cover a previously deposited flowstone layer, but do not extend past this layer. In this manner, a lateral rather than a predominantly vertical build-up of carbonate material occurs and this lateral growth creates the "umbrella-like" sides of the bell canopy.

Tower Coralloids

In one small, shallow, dry pool in the East Chambers Passage is a small "forest" of conical towers called "tower coralloids" (Fig. 3). These calcite deposits are spaced a few centimeters apart and vary in size from less than a cm in height and a few mm in diameter to almost 8 cm in height and 2 cm in diameter. A broken piece of one of these "tower" coralloids was cross-sectioned, revealing three radial layers of growth concentric around the long axis of the speleothem (see Figs. 4a and 4b). The outer crystalline layer consists of calcite crystals approximately 0.5 cm in length. The middle "dirty" layer consists of calcite crystals approximately 0.5 mm in length. The calcite crystals of the inner layer are about 0.5 cm in length. None of the cross sections examined showed any unusual structures or foreign material that might have acted as nuclei for growth. Similar speleothems are present in the Chinese Wall and Black Forest sections of New Cave, Carlsbad Caverns National Park. The New Cave tower coralloids are also composed of calcite and exist in a shallow pool environment. In both occurrences, there are no pool lines, shelfstone, rafts, or cave pearls coexistant with the tower corralloids. However, the tower coralloids in New Cave are associated with the "Chinese Wall" rimstone dams. Also, some of the tower coralloids in New Cave are bent concentrically away from points of water impact (Fig. 4c).

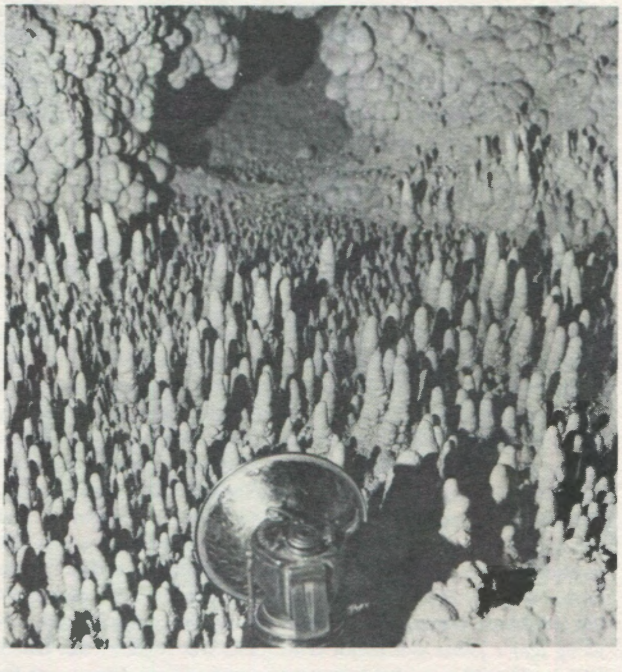

Figure 3. A small "forest" of tower coralloids. In the background are more typical subaqueous coralloids. Pete Lindsley photo.

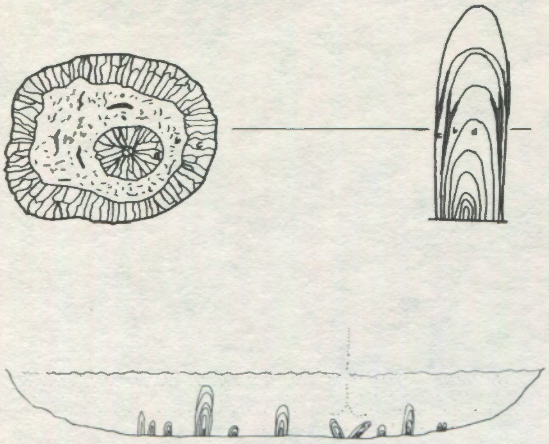

Figure 4. (a) Longitudinal section of a tower coralloid (actual size); (b) Transverse section of a tower coralloid (⅓ actual size); (c) Pool containing tower coralloids, including some inclined away from the point of impact of falling drops.

Entrance-Oriented Popcorn

Less abundant and less massive carbonate speleothems in Ogle Cave include shields, rimstone dams, cave pearls, rimstone shelves, rafts, helictites, moonmilk, and popcorn coralloids. Almost all of these speleothems are presently inactive, with the major exception of popcorn adorning the surfaces of other speleothems such as stalagmites and columns. The popcorn in Ogle Cave is produced mostly by splash from ceiling drips rather than from pool splash or from bedrock seepage.

Popcorn does not grow uniformly throughout Ogle Cave, but instead is oriented with respect to the two entrances. Popcorn in the Ogle section faces *toward* the Ogle entrance, while flowstone faces away from this entrance. Conversely, popcorn in the Rainbow section faces *away* from the Rainbow entrance, while flowstone faces *towards* that entrance. Popcorn and flowstone growth in the interior of the cave seems to be without regard to either entrance.

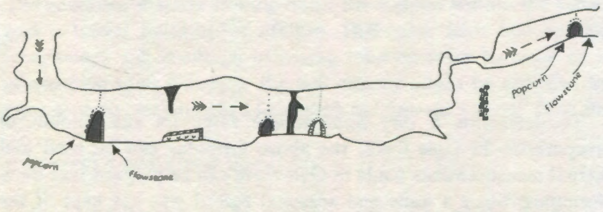

Figure 5. Profile of Ogle Cave, showing air flow in winter and entrance orientation of popcorn.

Other Carbonate Speleothems

Most of the other small carbonate speleothems are concentrated either in the East Chambers side passage or in the side passage between the Boulder Room and the Tunnel. In the East Chambers Passage, there is a rimstone shelf area near the end of the passage. The rimstone is composed of two tiers of shelves about 20 cm apart, vertically, which correspond to two former pool levels. Broken bits of rafts lie on the bottoms of these now dry pools. A well developed shield protrudes conspicuously from the wall in the rimstone shelf area. This shield extends to the floor of the dry pool, where it covers (postdates) the rimstone shelves. The shield is still intermittently growing from solutions seeping from the rim (medial crack.) The minor joint along which the shield is developed can be traced away from the shield along a travertine (dripstone-helictite) ledge (see Fig. 6). Moonmilk is also present on the walls of the East Chambers Passage near the tower coralloids; some of the moonmilk appears to have flaked to the floor after drying. The moonmilk was X-rayed and found to be aragonite. Small, desiccated helictites and cave pearls are located between the tower coralloid and shelfstone areas in the East Chambers: these speleothems are unimpressive in both size and beauty. Shields are also well developed in the side passage off of the Boulder Room. This area also contains actively growing "soda straw" tubular stalactites and small, beautifully fringed draperies (Fig. 7).

Figure 6. Shield at the end of the East Chambers Passage. The shield formed along a bedrock crack which can be seen in the upper left as a line of soda-straw stalactites and helictites. In lowermost left, two tiers of shelfstone indicate two former pool levels. Pete Lindsley photo.

Non-carbonate Mineral Deposits

Near the end of the Main Corridor of Ogle Cave (OM 18-19), mounds of dry bat guano cover the passage floor. Ivory-yellow nodular masses of a fine-grained powder overlie the bat guano in many places. This material was determined to be brushite ($CaHPO_4 \cdot 2H_2O$) by X-ray analysis (Hill, DuChene, and Jagnow, 1972). Brushite also occurs in the guano deposits near the mining equipment at OM-15. Mining of the guano deposits revealed a horizon of dark bat guano alternating with light, thin layers and pockets of brushite (Fig. 8). Brushite (which also occurs in other caves in the Guadalupe Mountains and elsewhere) is a leached deposit derived from decaying bat guano (Murray and Dietrich, 1956; Kaye, 1959; Hill, 1973b). The only sulfate mineralization in Ogle Cave is a small amount of gypsum crust along the Welbourn side passage at SL3-SL4.

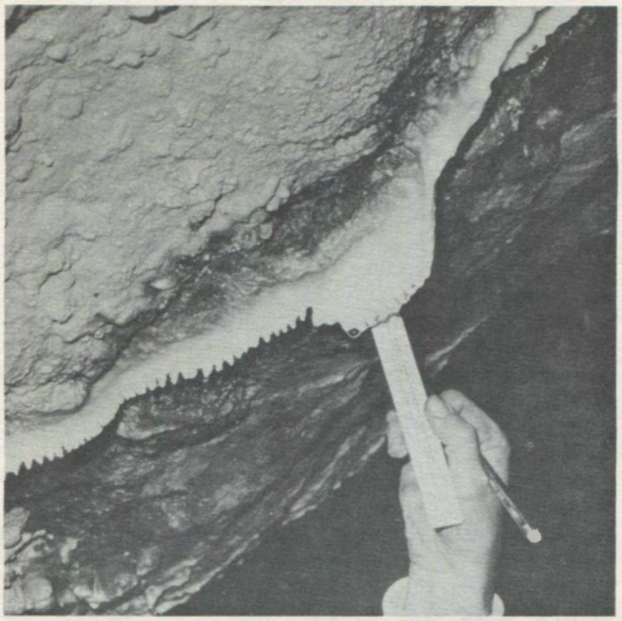

Figure 7. Fringed draperies in the side passage off the Boulder Room. Ron Miller photo.

DEPOSITIONAL MECHANISMS

Evaporation Model for Ogle Cave

In most caves, CO_2 groundwater equilibrium with cave air is the predominent mechanism which controls carbonate precipitation (Holland, *et al.*, 1964). However, in arid regions such as southwestern United States, evaporation can be an important control on precipitation and speleothem morphology. The growth of bell canopies, tower coralloids, and the orientation of popcorn in Ogle Cave may be directly related to high evaporation rates.

Evaporation from a water surface is a function of many variables, the most important of which are relative humidity of the cave air, wind velocity, temperature, barometric pressure, and the amount of dissolved solids in solution. Dalton's Law states that the rate of evaporation is proportional to the difference between the amount of water the air can theoretically hold at a given temperature and the amount that it actually does hold:

$$E = C(p_w - p_a) \qquad 1.$$

where E is the amount of evaporation, p_w and p_a are the theoretical and actual partial pressures, respectively, of water vapor at a given temperature, and C is a coefficient dependent on wind velocity, barometric pressure, and other variables. Rohwer's formula corrects for both wind velocity and barometric pressure:

$$E = 0.771\ (1.465 - 0.0186\ B)\ (0.44 + 0.118\ w)\ (p_w - p_a) \qquad 2.$$

where B is the barometric pressure (in inches of mercury at 32°F), w is the wind velocity (miles/hr), and E is evaporation (inches/day) from a small evaporative pan (Rohwer, 1931). Wind velocity is usually minimal near the ground surface and increases when measured up from the ground according to the formula:

Figure 8. Stratified bat guano with brushite deposits. The shovel was used by guano miners in the 1920's and '30's. Ron Miller photo.

$$\frac{w_h}{w_1} = \log h + 1 \qquad 3.$$

where w_h equals the wind velocity at any height h (ft) and w_l is the wind velocity at 1 ft above the ground. B, the barometric pressure, is a function of temperature and altitude and can easily be determined from a barometric chart (List, 1951). P_w and p_a are calculated, knowing the relative humidity and temperature:

$$\text{R.H.} = 100 \times \frac{p_a}{p_w} \qquad 4.$$

To determine a very approximate value for the amount of evaporation in Ogle Cave, the above formulas can be used and actual measurements made in Ogle Cave can be plugged into these formulas. Since a daily and seasonal record was not kept of the relative humidity, temperature, and wind velocity, the error in these calculations will be relatively high. However, such a hypothetical calculation is meaningful because it does point out the evaporation differences between humid Eastern caves and dry Southwestern caves. For example, in Table 1 it can be seen that, for a constant wind velocity, the amount of evaporation in a cave of 88% relative humidity is more than 10 times as high as in a cave of relative humidity 99%. The figures in Table 1 were calculated using a temperature of 58°F, a height h = 10 ft, and assuming that evaporation retardation due to dissolved minerals is slight compared to the error in the other parameters. The values T = 58°F and R.H. = 88% are representative of measurements taken in the Main Corridor of Ogle Cave in the month of October (see Welbourn, this issue); the corresponding evaporation loss at this time and place was therefore between 1.90×10^{-2} and 3.06×10^{-2} in/day (see Table 1.)

TABLE 1. The amount of evaporation *E* in inches/day for varying relative humidities and wind velocities.

Relative Humidity	Wind Velocity			
	3.0 in/min	1.0 mile/hr	5 mile/hr	10 mile/hr
88%	1.90×10^{-2}	3.06×10^{-2}	7.74×10^{-2}	1.36×10^{-1}
90%	1.58×10^{-2}	2.55×10^{-2}	6.44×10^{-2}	1.13×10^{-1}
95%	7.90×10^{-3}	1.28×10^{-2}	3.22×10^{-2}	5.66×10^{-2}
99%	1.57×10^{-3}	2.54×10^{-3}	6.42×10^{-3}	1.13×10^{-2}

The evaporation values thus calculated can be compared with the amount of evaporation recorded by McLean (1971) in Carlsbad Caverns. McLean reported a relative humidity of 88% for the month of October in the Lunch Room—Pump Room section of Carlsbad Caverns and an evaporation loss of 1.67×10^{-2} in/day from a small evaporative pan.

The wind velocity in this area of Carlsbad Caverns is somewhat less than 1 mile/hr. Thrailkill (1971), by a different approach, also concluded that evaporation was indeed a mechanism for precipitation in Carlsbad Caverns. Thrailkill used the constancy of the Mg^{++} ion in cave waters as his evaporation criterion. If $CaCO_3$ precipitation is due to CO_2 loss exclusively, then the Mg^{++} ion concentration remains constant, whereas if $CaCO_3$ precipitation is caused also by evaporation, the amount of solvent (water) decreases and the relative amount of Mg^{++} ion rises. Thrailkill found an evolution toward lower Ca^{++} and higher Mg^{++} concentrations in several areas of Carlsbad Caverns, indicating that about 40% of deposition is due to evaporation effects.

Evaporation and Bell Canopy Growth

The predominance of bell canopies in Ogle Cave and other caves in the Guadalupe Mountains can be logically explained in terms of high evaporation rates. If the source of incoming cave waters remains relatively constant and if evaporation rates are consistently high, then solutions will flow only a certain distance down a large column or stalagmite before all water content is lost by evaporation. The next film of water flowing down the column will do the same, and a lateral build-up of calcium carbonate with bell canopy morphology will result. If incoming solution rates increase or if evaporation rates decrease, the bell canopy might be engulfed by later deposits, resulting in a form such as "Snoopy's Nose" (Fig. 9).

Evaporation and Tower Coralloids

Tower coralloids may be another speleothem whose deposition and morphology is controlled by high evaporation rates. Evaporation may be high enough in Ogle Cave so that a concentration gradient is maintained between the surface and the bottom of small, shallow cave pools. According to this model, the top part of a pool would be more highly saturated than the lower parts and precipitation would be greatest on the top of any surface irregularity. As the coralloid grows, this preferred upward deposition of material would become even more pronounced and a "tower" shape rather than a "nodular" shape would be the result. Only a pool with a very high evaporation rate could maintain this concentration gradient. Pools with normally high carbon dioxide loss and low evaporation rates would experience supersaturation only at the pool surface and typical pool deposits such as rafts and shelfstone would form. Pool depth is probably critical for tower coralloid formation. If a pool is too deep, then the gradient would not be steep enough at the bottom of the pool for tower coral growth to get started. In all of the three tower coralloid locations, pool depth is very shallow.

Figure 9. "Snoopy." The laterally projecting "nose" is probably an engulfed bell canopy. Pete Lindsley photo.

Evaporation and Popcorn Orientation

Evaporation may also be responsible for the popcorn orientation at the entrances of the Rainbow and Ogle sections of Ogle Cave. Ogle Cave has two entrances, the Ogle entrance being approximately 30 m lower in elevation than the Rainbow entrance (see Map). The wind in Ogle Cave is caused by this entrance elevation difference combined with a temperature difference between the cave and the outside air. In winter, when cave temperatures are greater than surface temperatures, warm, moist cave air expands and flows out the upper entrance (Rainbow), thus bringing cold dry air into the lower entrance (Ogle) (see Fig. 5). In summer, the air flow reverses and brings warm, moist air into the cave via the Rainbow entrance. This process is called the "chimney effect." As the cold winter air equilibrates with the warmer cave walls, its ability to hold moisture increases. The only source of moisture in Ogle Cave are the solutions dripping into the cave through joints. What this means is that in the winter more evaporation takes place on the sides of speleothems that face the Ogle Cave entrance, or the direction of inward air flow. The reverse situation should take place at the Rainbow entrance in the summer resulting in less evaporation on the sides of speleothems facing this entrance. By the time the air reaches the interior of the cave, it has reached equilibrium with regards to humidity and evaporation is the same on all sides of a speleothem.

Thrailkill (1965) speculated that popcorn growth is inhibited by thick, fast-flowing films of water because, if the film is flowing, precipitation will take place evenly over the deposition surface and flowstone will be the type of speleothem deposited. Popcorn growth needs slow-moving, thin films of water because then deposition of $CaCO_3$ will be localized at points of surface irregularities (such as projections in the bedrock) where the surface area is greater and CO_2 or H_2O loss is more rapid. The evaporation model for Ogle Cave supports Thrailkill's theory: the side of the speleothem that has greater evaporative losses will be the side to first develop the slow-moving surface films of water critical for popcorn development.

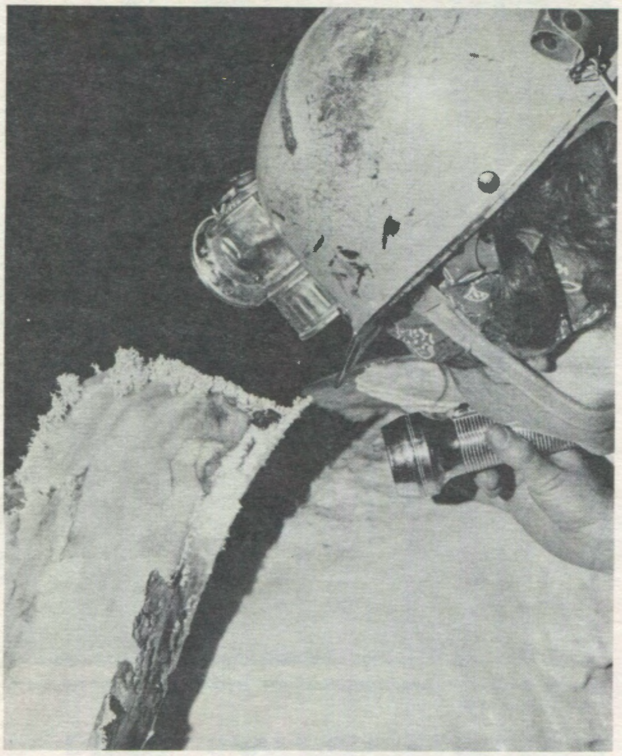

Figure 10. Flowstone and coral on a metal trough—this growth has occurred within the last 40 to 60 years. Pete Lindsley photo.

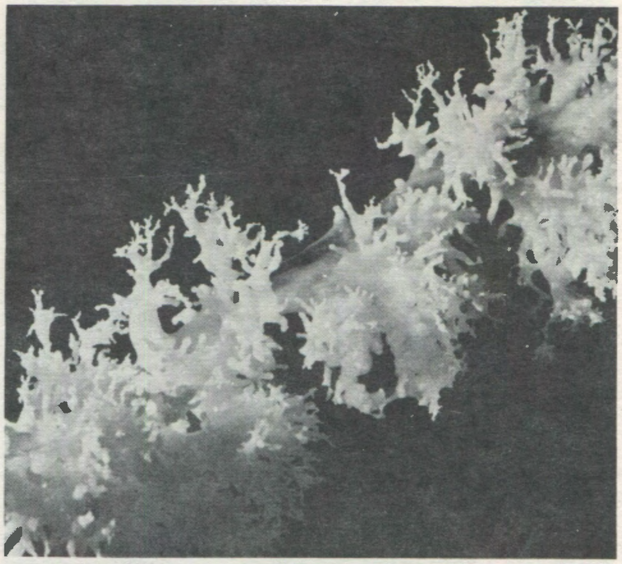

Figure 11. Close-up of the delicate coral growth in Figure 10. Length of the individual coral fronds is approximately 2 cm. Pete Lindsley photo.

CARBONATE GROWTH RATES

Guano mining in Ogle Cave took place from about 1913 to 1937. Since that time, flowstone and coral have accumulated on articles left by miners and other visitors. Approximately 1 mm of flowstone has been deposited on a cup left by miners under a drip in the Main Corridor. Also along the Main Corridor, near OM-6, are a rain barrel and metal trough used at one time for collecting water from a copious drip. Water now enters this spot at a rate of approximately 1 drop every 10 seconds and has caused a layer of flowstone on the trough approximately 0.5 cm thick. A delicate calcite coral has grown 2 cm high along the top of the trough (figs. 10 and 11). At the end of the Boulder Room side passage, white calcite has grown over speleothems broken by the miners. Soda straw stalactites up to 7½ cm long and a white, saw-toothed drapery (approximately 30 cm long, 5 cm wide, and 1 cm thick) have grown within the last 60 years.

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Preliminary Results on Growth Rate and Paleoclimate Studies of a Stalagmite from Ogle Cave, New Mexico

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ABSTRACT

^{230}Th/^{234}U dating and morphologic study of a portion of a stalagmite from Ogle Cave, New Mexico indicate continuous deposition from about 205,000 to 125,000 years B.P. This is the period to which is commonly assigned the penultimate glaciation in North America, suggesting that deposition of speleothems in arid areas of the western United States was more intense during the pluvial periods accompanying glaciation than at present.

INTRODUCTION

In March, 1975, an upper portion of a broken stalagmite estimated to have been 33 cm in diameter was collected from the floor of Ogle Cave, New Mexico. It is believed that the stalagmite was previously broken during guano mining in the cave, but this is not certain. The section of the stalagmite studied here is shown in Figure 1.

ANALYTICAL RESULTS

The top and bottom 2 cm of a 2.5 cm slab from the inner portion of the stalagmite section were dated by the ^{230}Th/^{234}U method using a procedure slightly modified from that described by Thompson (1973). The details, assumptions, and limitations of the method have been previously presented in Harmon, *et al.* (1975). Analytical data for the Ogle Cave stalagmite are given in Table 1.

The uncertainties in the isotope ratios are large, due to the low U content of the specimen and the small sample (40 g) used for each analysis. Nevertheless, we have confidence in the calculated ages because the ages are in correct stratigraphic order and no detrital Th was detected.

The detailed morphology and crystal growth of the stalagmite was also studied. There are no apparent internal discontinuities, and crystal growth appears to be quite uniform across the specimen from bottom to top. As well as can be determined, the growth layers are equally spaced parallel to the growth axis. This would imply growth under a nominally constant rate of water supply. The uppermost growth layer (about 1 cm at the apex—see Fig. 1) converges more rapidly than the others, indicating a final period of growth under conditions of reduced flow. The outer surface of cave "coral" suggests a period of increased dessication before the stalagmite finally stopped growing (or was broken naturally).

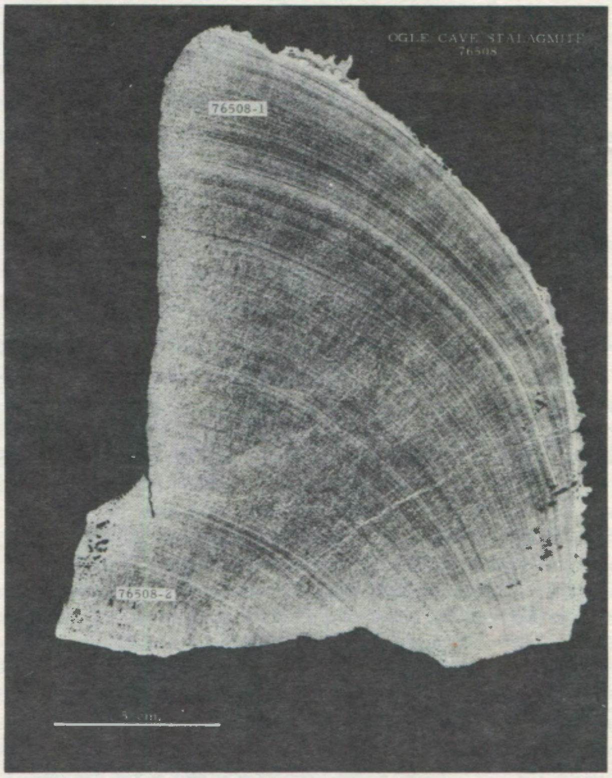

Figure 1. Photograph of the Ogle Cave stalagmite, made from an acetate surface peel. The ^{230}Th/^{234}U dated horizons are indicated. Note the equal spacing of growth layers and the more rapid convergence of the topmost growth layer.

TABLE 1. Uranium concentrations, isotope activity ratios, and calculated ages for the Ogle Cave stalagmite.

Sample Number	Description	U conc. (ppm)	$\frac{^{230}\text{Th}}{^{234}\text{U}}$	$\frac{^{234}\text{U}}{^{238}\text{U}}$	$\frac{^{230}\text{Th}}{^{232}\text{Th}}$	Calculated Age (x10^3 years B.P.)
76508-1	top layers	0.25	.713 ± .08	1.28 ± .07	g.t. 1000	126 ± 26
76508-2	basal layers	0.27	.849 ± .07	.985 ± .06	g.t. 1000	207^{+64}_{-40}

The average rate of water supply can be estimated. The stalagmite grew at an average rate of 6.4×10^{-12} cm/s which, for an equilibrium stalagmite 33 cm in diameter, implies a volume accretion rate of 5.4×10^{-9} cm³/s (Curl, 1973). With water bearing from 4 to 20×10^{-5} cm³ precipitable solid calcite per cm³ solution (the range for saturated solutions from 10° to 25°C and P_{CO_2} from 0.001 to 0.1 atm) the flow rate would have been between 2.7×10^{-5} and 1.4×10^{-4} cm³/s. For drop volumes of about 0.075 cm³, the period between drops would have been from 500 to 3000 seconds. Considerable temporal variation was likely, which may have contributed to the banding shown in Figure 1.

DISCUSSION

There is much evidence to suggest that lakes in many presently arid regions were expanded or created during the Pleistocene glacial epochs (see summary in Flint, 1971), due to an increase in the ratio of precipitation to evaporation. An example of this is the classic study of Gilbert (1890), which related the maximum lake levels of ancient Lake Bonneville to periods of glaciation in the adjacent area. In New Mexico, Leopold (1951) developed a model for glacial Lake Estancia based upon a lowering of the snowline, a reduction in temperature, and an increase in precipitation during the last glacial period. Under such conditions, it is likely that there would be a concurrent increase in regional plant cover and ground water recharge. The result of this climate change should be an increase in both drip rates and dissolved carbonate in subjacent cave seepage waters and ultimately an increase in the rate of speleothem deposition.

Our study indicates that the Ogle Cave stalagmite grew continuously from about 205,000 to 125,000 years B.P. This 80,000 year period is synchronous with the penultimate glaciation, as recorded in the marine and terrestrial paleoclimate records (see, *e.g.:* Mesolella, *et al.*, 1969; Bloom, *et al.*, 1974; Shackleton and Opdyke, 1973; Pierce, *et al.*, 1976). We feel that it is likely that the Ogle Cave stalagmite began growing shortly after the initiation of North American glaciation some 200,000 years B.P., at which time climate in New Mexico changed from arid to pluvial. Deposition was continuous over the next 80,000 years, slowing somewhat during retreat of the continental glaciers at about 125,000 years ago as the change back from pluvial to arid climate conditions was realized. The "coraline" surface overgrowth probably is indicative of the deposition that occurred during the arid interglacial conditions was realized. The "coraline" surface overgrowth probably is indicative of the deposition that occurred during the arid interglacial was broken by some natural cause or that the feeder channels became inactive during the last interglacial period.

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Biology of Ogle Cave

WITH A LIST OF THE

Cave Fauna of Slaughter Canyon

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ABSTRACT

Ogle Cave and 15 other caves in Slaughter Canyon, Carlsbad Caverns National Park, New Mexico were examined for cave fauna. Seventy-one invertebrates, representing 21 orders, and 4 vertebrates were found. Thirty-six species were new records for the Guadalupe Mountains. One previously unreported troglobite, an isopod (Brackenridgia sp.), *and a possibly troglobitic spider* (Leptoneta sp.) *are also reported.*

Data concerning the distribution and habitats of the fauna and the results of 28 pitfall traps placed in Ogle Cave are discussed.

INTRODUCTION

THE GUADALUPE MOUNTAIN region of southeastern New Mexico is famed for its spectacular caves. At least 20 occur within Slaughter Canyon and its major branch, West Slaughter Canyon, one of three major drainage lines which cross the Guadalupe Escarpment within Carlsbad Caverns National Park. Ogle Cave lies near the mouth of Slaughter Canyon, approximately 14 km southwest of the Carlsbad Caverns Visitor Center. One other cave, New Cave, is also a major cave. The geology of Ogle Cave and a general description of its passages are presented by Jagnow and by DuChene elsewhere in this issue.

The Guadalupe region lies within the semi-arid Chihuahuan Desert. The fauna of its caves are poorly known. Nicholas (1960) listed only three troglobites. Barr and Reddell (1967) indicated that the cave fauna is sparse, listing two troglobites (*Speodesmus tuganbius* [Chamberlin] and *Plusiocampa* sp.) and two other possible troglobites (*Thalkethops grallatrix* Crabill and *Ceuthophilus longipes* Caudell). The poorly developed Guadalupe fauna contrasts especially with that of the Edwards Plateau in Texas, where Mitchell (1969) reported 90 troglobitic species to exist. Biological studies in the Guadalupes have been primarily concerned with describing and cataloging the arthropod cave fauna (Barr, 1960; Bailey, 1928; Barr and Reddell, 1967; Benedict, 1928; Caudell, 1924; Chamberlin, 1952; Crabill, 1959 and 1960; Crosby, 1926; Elliott, in press; Kohls and Clifford, 1966; Muchmore, 1976; Roth 1968; and Shear, 1974.

Fifteen of the caves were examined during the course of this study. Helen's Cave (see map), a small, generally dry cave with a few moist areas, and Corkscrew Cave, another small, dry cave are located near the Ogle Entrance to Ogle Cave. The Ogle Mine Tunnel (see map) is a short adit intended by guano miners to be a lower entrance to Ogle Cave. A third small, dry cave, Longlegs Cave, is near the Rainbow Entrance to Ogle Cave. Across Slaughter Canyon, about 1 km distant, are New Cave and Wen Cave. Christmas Tree, Decorated, Goat, Ladder, and Lake caves are located one and one-half to 3 km up the canyon from Ogle Cave. In the West Slaughter branch of Slaughter Canyon, 3 to 5 km west of Ogle Cave, are Arch, Dome, Porcupine, Swallow and Window caves. Floors, walls, ceilings, and organic debris were searched. Only one trip was made to most of these caves, due to their remoteness.

Ogle Cave was closely examined in May, 1974. Twenty-five pitfall traps baited with rotten liver were placed within the Ogle section (see map) and three others (nos. 26 to 28) were placed outside the Ogle entrance. Five traps (nos. 1 to 5) were placed in the back portions of the cave, where the guano mining activities had been concentrated. Three traps (nos. 6 to 8) were placed in the slope below the mining area. Numbers 9 to 11 were placed in the Boulder Room, and nos. 12 to 15 were placed in the Sequoia Room. Numbers 16 to 19 were placed in the bottom of the talus, at the edge of the twilight zone. Numbers 20 to 25 were placed in the area immediately below the entrance, with one (No. 25) being set in a ledge about 9m below the surface. All traps were set out 24 hours before collection. The results of the trapping are shown in Table 1.

Soil samples were taken from both the Ogle (May, 1974) and

Trap Number	Diplura	Collembola	Orthoptera	Psocoptera	Coleoptera	Diptera	Acari	Relative Humidity, with Dry Bulb Temperature (°F)	
1	—	—	16(3) 17(2)	—	—	—	—	88%	D57
2	9(1)	—	16(6)	—	—	—	—	—	—
3	—	—	16(2)	—	—	—	—	—	—
4	9(9)	—	16(28) 17(4)	—	25(1)	—	—	—	—
5	9(18)	11(1)	16(24) 17(2)	—	25(4)	—	—	91%	D56
6	9(3)	—	16(13) 17(1)	—	—	*	—	—	—
7	—	—	16(4)	20(1)	—	—	—	82%	D57
8	—	—	16(14) 17(1)	20(1)	—	—	—	—	—
9	9(2)	—	16(2)	—	—	—	—	—	—
10	9(2)	—	16(2)	20(2)	—	—	—	88%	D56
11	—	—	16(1)	—	—	—	65(1)	88%	D56
12	—	—	16(12)	—	—	—	—	88%	D56
13	9(1)	—	16(4) 17(4)	—	—	—	—	88%	D56
14	—	10(2)	16(9) 17(2)	—	—	35(3) 35(1)	—	85%	D56
15	—	—	16(9) 17(1)	—	—	— 35(1)	—	—	—
16	—	—	16(16)	—	—	—	—	—	—
17	—	10(1)	16(3) 17(1)	—	25(1)	—	—	82%	D56
18	—	11,12	16(4)	—	—	—	—	—	—
19	—	*	16(6)	—	—	—	—	—	—
20	—	*	16(10)	20(2)	—	—	—	—	—
21	—	10,11	16(2)	20(1)	24(3)	35(1)	—	—	—
22	—	14(10)	—	20(1)	25(1) 24(7)	— —	—	—	—
23	—	—	20(3)	—	—	—	—	—	—
24	—	—	16(4) 17(2)	—	—	35(10)	—	75%	D60
25	—	—	16(1)	—	24(1)	—	—	—	—

TABLE 1. Summary of trap results in the Ogle Section. The first arabic number refers to the species listed in the cave fauna of Ogle Cave and Slaughter Canyon. The second arabic number (in parentheses) is the number of specimens collected. An asterisk means that the specimens were not identified.

Rainbow (September, 1974) sections of the cave. About 200 cm^3 of each were extracted for 48 hours in a Berlese funnel apparatus. Relative humidity 4 ft above the ground was measured with a Taylor sling psychrometer (September, 1974) at 10 sites in Ogle Cave.

The classification of cave fauna follows that of Barr (1963), with the additional category of "parasite." "Parasite" is used for those organisms which are restricted to a parasitic existence and whose presence in the cave is due to the host organism.

In the following list of all taxa collected in the Slaughter Canyon area, "Ogle Cave" refers to specimens from both the Ogle and the Rainbow sections of the cave, whereas "Ogle Cave (Rainbow Section)" refers to specimens taken only in the Rainbow Section and "Ogle Cave (Ogle Section)" refers to specimens taken only in the Ogle Section. Unless otherwise noted, specimens were identified by the Author.

CAVE FAUNA OF OGLE CAVE AND SLAUGHTER CANYON

PHYLUM ASCHELMINTHES

CLASS NEMATODA

1. Undetermined genus and species.
   Ogle Cave.
   Troglophile. Two specimens, one each from the Rainbow and Ogle sections, from organic material.
   Closer examination will probably reveal many more specimens in caves.

PHYLUM MOLLUSCA

CLASS GASTROPODA

2. Undetermined genus and species.
   Christmas Tree Cave, Helen's Cave.
   Accidental. Only the shells of these molluscs were found. They probably fell or were washed into the caves.

PHYLUM ARTHROPODA

CLASS CRUSTACEA

ORDER CYCLOPOIDA

Family Cyclopidae

3. *Eucyclops agilis montanus* (Brady)
   det. H. Yeatman
   Lake Cave (Vandalized Cave)
   Troglophile. This subspecies has been found in caves in Indiana and North Carolina and lakes in Ontario, Canada. The Slaughter Canyon specimen was collected from Ogle Cave by Ken Baker in 1960 and reported as *E. agilis* by Barr and Reddell (1967).

ORDER CLADOCERA

Family Holopedidae

4. *Holopedium amazonicum* Stigelin
   det. H. Yeatman
   Lake Cave
   Troglophile. This is a common species in the southeastern United States.

ORDER ISOPODA

Family Trichoniscidae

5. *Brackenridgia* sp. det. G. Schultz.
   Decorated Cave, Helen's Cave, Ladder Cave, Lake Cave, New Cave.
   Troglobite. This undescribed terrestrial isopod was thought to be rare until recently, but is now known from more than 20 caves in the Guadalupe region. It is usually found on decaying wood. Reddell (1965) reported an unidentified isopod from Culberson Co., Texas which also may have been this species.

CLASS DIPLOPODA

6. Undetermined genus and species.
   Christmas Tree Cave, Ogle Cave (Ogle Section)
   Accidental. This surface milliped was found below the entrance drop.

ORDER POLYDESMIDA

Family Trichopolydesmidae

7. *Speodesmus tuganbius* (Chamberlin)
   Ladder Cave, Ogle Cave, New Cave.
   Troglobite. This species is a common species in the caves of New Mexico and parts of Culberson Co., Texas (Reddell, 1965, 1970a). Shear (1974) reported *S. tuganbius* from caves in Lincoln, DeBaca, and Socorro counties, New Mexico. It usually occurs on organic material, especially decaying wood.

CLASS CHILOPODA

ORDER LITHOBIOMORPHA

8. Undetermined genus and species.
   Lake Cave, New Cave
   Troglophile? The Lake Cave specimen was found under a rock in the dark zone. The New Cave specimen, collected by W. R. Elliott, was small and pale, with longer appendages than other centipeds observed. Since there are two other described cavernicolous centipeds in Carlsbad Caverns National Park, the status of this specimen is uncertain.

CLASS INSECTA

ORDER DIPLURA

Family Campodeidae

9. *Plusiocampa* det. L. Ferguson
   Christmas Tree Cave, Decorated Cave, Lake Cave, New Cave, Ogle Cave.
   Troglobite. This insect is a common member of the cave fauna in New Mexico. Usually found on or near organic material, occasionally found on moist flowstone. Its distribution in Ogle is discussed later.

ORDER COLLEMBOLA

Family Entomobryidae

10. *Pseudosinella violenta* Folsom
    det. K. Christiansen
    Corkscrew Cave, Goat Cave, Lake Cave, New Cave, Ogle Cave.
    Troglophile. This species is widespread in Texas Caves (Reddell, 1970b) and is also common in many New Mexico caves. Can be found under rocks and around decomposing plant material.
11. *Entomobrya* (*Drepanura*) *california* (Schött)
    det. K. Christiansen
    Ogle Cave
    Troglophile? This species has been found in Texas Caves (Christiansen, pers. comm.). Specimens were also taken in traps on the surface.
12. *E.* (*Entomobrya*) *unostrigata* Stach
    det. K. Christiansen
    Ogle Cave (Ogle Section).
    Troglophile? Taken in Pitfall trap near edge of twilight zone.
13. *E.* (*E.*) *washingtonia* Mills
    det. K. Christiansen
    Ogle Cave (Rainbow Section)
    Troglophile? A single specimen was taken under rocks on the entrance slope
14. *Tomocerus* sp.
    det. K. Christiansen
    Ogle Cave (Ogle Section)
    Troglophile. Specimens were found in organic material below the entrance.

Family Sminthuridae

15. *Arrhopalites pygmaeus* (Wankel)
    det. K. Christiansen
    New Cave
    Troglophile. Specimens were taken on bits of wood left by guano miners.

ORDER ORTHOPTERA

Family Gryllacrididae

16. *Ceuthophilus longipes* Caudell
    det. T. Hubbell
    Christmas Tree Cave, Corkscrew Cave, Lake Cave, Longlegs Cave, Ogle Cave, New Cave.

Troglophile. Originally described from Carlsbad Caverns (Caudell, 1924); it was thought to be troglobitic by several workers (Barr and Reddell, 1967). The distribution of this species in Ogle Cave is discussed later. This species was taken by Mr. Glen Campbell in pitfall traps outside Spider Cave, Carlsbad Caverns National Park (pers. comm.).

17. *C. carlsbadensis* Caudell
det. T. Hubbell
Helen's Cave, Lake Cave, Ogle Cave, Ogle Mine Tunnel, Swallow Cave
Trogloxene. This species was described from Carlsbad Caverns (Caudell, 1924) and has been found in west Texas (Reddell, 1966). The distribution of this species in Ogle is discussed later. Found on walls and ceilings throughout the caves, they are most common near the entrance.

18. *C. conicaudus* Hubbell
det. T. Hubbell
Ladder Cave, Lake Cave, New Cave, Ogle Cave (Rainbow Section) and outside the entrance to Ogle Section.
Trogloxene. This species is widespread in Texas (Reddell, 1966) and will probably be found throughout the Guadalupe Mountains. This species is usually found on walls and ceilings near the entrance of the cave.

Family Gryllidae

19. *Gryllitta arizonae* Hebard
det. T. Hubbell
Ogle Cave (Ogle Section)
Accidental. Single specimen found in the entrance pit.

ORDER PSOCOPTERA

Family Psyllipsocidae

20. *Psyllipsocus ramburii* Selys-Longchamps
det. E. Mockford
Goat Cave, Lake Cave, Ogle Cave, Ogle Mine Tunnel.
Troglophile. These insects are found in a variety of organic material. Specimens from the Rainbow Section were found on feces and specimens in the Ogle Section were found in the pitfall traps. This species ranges from Wisconsin to Puerto Rico.

ORDER HEMIPTERA

Family Cimicidae

21. Undetermined genus and species
Ogle Cave (Ogle Section)
Parasite. These insects are parasitic on vertebrates. Their hosts were probably cave swallows, as they were taken under the nesting area.

Family Cydnidae

22. Undetermined genus and species
Ogle Cave (Ogle Section)
Accidental. Two specimens were found on the rubble slope below the entrance drop.

ORDER HYMENOPTERA

Family Formicidae

23. Undetermined genus and species
Wen Cave, entrance to Ogle Section
Accidental. The specimens in Wen were collected by S. Szerlip. Numerous specimens were taken in pitfall traps at the entrance to Ogle Section, whereas none were taken or observed in the cave.

ORDER COLEOPTERA

24. Undetermined genus and species
Ogle Cave (Ogle Section)
Several unidentified beetles were found in the pitfall traps in Ogle.

Family Carabidae

25. *Rhadine longicollis* Benedict
det. T. Barr, Jr. and author
Corkscrew Cave, Dome Cave, Lake Cave, New Cave, Ogle Cave.
Troglophile. This is widespread in the Carlsbad area. Individuals can be found in many areas of the caves, but they are most common in areas of soft soil (sand, silt, etc.). In Ogle, they were trapped in the greatest numbers in the area where large numbers of cave crickets (*Ceuthophilus*) were also collected.

Family Leiodidae

26. *Dissochaetus* sp. det. S. Peck
Ogle Cave (Rainbow Section)
Troglophile? Four specimens of a new species.

Family Tenebrionidae

27. *Eleodes easterlai* Triplehorn
det. T. Spilman
Ogle Cave (Rainbow Section)
Troglophile. This is the first record of this beetle outside of Mt. Emory Cave, Big Bend National Park, where it was found on and near the guano of *Leptonycteris nivalis* (Triplehorn, 1975). In the Rainbow Section, the beetles were taken in pitfall traps in guano near the back of the cave.

28. *Eleodes fusiformis* LeConte
det. T. Spilman.
Corkscrew Cave
Accidental. A single specimen was taken below the entrance drop.

29. *Embaphion contractum blaisdelli* Benedict
det. T. Spilman
Longlegs Cave, Ogle Cave (Ogle Section)
Troglophile. This species was described from Bat Cave in Carlsbad Caverns (Benedict, 1928), where it was found on guano. In Ogle, the specimen was found near the base of the entrance slope.

Family Staphylinidae

30. Undetermined genus and species
Ogle Cave (Ogle Section)
Accidental? Three species were reported by Barr and Reddell (1967) as troglophiles in the Carlsbad area. The specimens from Ogle were found below the entrance.

ORDER DIPTERA

Family Tipulidae

31. Undetermined genus and species.
Goat Cave
Trogloxene. Numerous specimens were observed mating on the walls.

Family Mycetophilidae

32. *Allodia* sp. det. B. Foot; R. Gagné
Ladder Cave, Ogle Cave (Rainbow Section)
Trogloxene? Specimens were collected on the wall.

Family Cecidomyiidae

33. Undetermined genus and species
Ogle Mine Tunnel
Accidental? A single specimen was found in a crack.

Family Lonchopteridae

34. *Lonchoptera* sp?
Lake Cave
Troglophile? A single specimen was found on organic material near a permanent pool in the cave.

Family Phoridae

35. *Megaselia cavernicola* Brues
det. W. Robinson
New Cave, Ogle Cave
Troglophile. This fly is common on the walls and ceilings of many caves in New Mexico and was also common in pitfall traps in the Ogle Section.

Family Helomysidae

36. *Amoebaleria* sp. det. G. Steyskal
Ogle Cave (Rainbow Section)
Troglophile.

Family Drosophilidae

37. Undetermined genus and species
Wen Cave
Trogloxene. Specimen taken in the twilight zone.

Family Muscidae

38. Undetermined genus and species
Wen Cave
Accidental. Found in the twilight zone.

Family Tachinidae

39. *Meigenielloides cinereus* Townsend
det. C. Sabrosky
Ogle Cave (Rainbow Section)
Troglophile. An uncommon species which ranges from Washington to Mexico. Habits are unknown.

Family Sarcophagidae

40. Undetermined genus and species
Ogle Cave (Rainbow Section)
Accidental

ORDER SIPHONAPTERA

41. Undetermined genus and species
Ogle Cave
Parasite. Four specimens were found below cave swallow nests, 3 in the Ogle Section and 1 in the Rainbow Section.

ORDER LEPIDOPTERA

Family Citheroniidae

42. *Anisota oslari* Rothschild det. S. Szerlip
Wen Cave
Accidental. Pupal exuviae were found in spider webs.

Family Noctuidae

43. *Yrias volcris*
det. D. Davis
New Cave
Trogloxene? Taken in the twilight zone.

Family Tineidae

44. *Amydria arizonella* Dietz
det. D. Davis
Longlegs Cave
Troglophile. Found on the wall.

Subphylum Chelicerata

CLASS ARACHNIDA

ORDER SCORPIONIDA

Family Vaejovidae

45. *Vaejovis* sp.
det. W. Gertsch
Helen's Cave
Accidental. Several specimens were found in leaf litter at the bottom of the entrance drop.

ORDER PSEUDOSCORPIONIDA (CHELONETHIDA)

Family Chthoniidae

46. *Apochthonius maganimus* Hoff
det. W. Muchmore
Ogle Cave. (Ogle Section)
Troglophile. Several specimens were taken in leaf litter below the entrance drop. They may be epigean forms which are now living in the cave.

Family Syarinidae

47. *Chitrella* sp. det. W. Muchmore
Ogle Cave.
Troglophile. In the Ogle Section, several specimens were taken by Berlese funnel from leaf litter below the entrance drop. In the Rainbow Section, a single specimen was taken by W. R. Elliot on moist flowstone.

Family Chernetidae

48. *Hesperochernes* sp. det. W. Muchmore
Helen's Cave
Troglophile. Specimens were taken by Berlese funnel from leaf litter below the entrance drop.

ORDER PHALANGIDA

Family Phalangiidae

49. *Leiobunum townsendii* Weed
det. C. Goodnight
Decorated Cave, Goat Cave, New Cave, Ladder Cave, Longlegs Cave, Lake Cave, Ogle Cave, Wen Cave.
Trogloxene. These harvestmen are common in the entrances of many Texas and New Mexico caves. They are occasionally found in large numbers, as in Decorated Cave, although most of the specimens in Slaughter Canyon caves were found singly or in small (5 to 20 individuals) groups.

50. *Eurybunum brunneus* Banks
det. C. Goodnight
New Cave
Trogloxene. A single specimen was found in a side passage that may open to the surface.

ORDER ARANEAE

Family Agelenidae

51. *Tegenaria chiricahuae* Roth
det. W. Gertsch
Christmas Tree Cave, Corkscrew Cave, Dome Cave, Lake Cave, Helen's Cave, Longlegs Cave, New Cave, Porcupine Cave, Ogle Cave.
Troglophile. This spider is a common funnel web spider in many of the Guadalupe caves. Although it shows no special cave adaptation, it has been reported only from caves, usually in the twilight zone or at the edge of the dark zone. Roth (1968) reported *T. chiricahuae* to be the only endemic species of *Tegenaria* in the United States.

52. *Cicurina* sp.
det. W. Gertsch
Dome Cave
Troglophile. This genus is widespread in Texas, although uncommon in New Mexico caves.

53. *Cicurina deserticola* Chamberlin and Ivie
det. W. Gertsch
New Cave
Troglophile. Specimens were found in the twilight and dark zones.

Family Gnaphosidae

54. *Herpyllus* sp. det. W. Gertsch
Ogle Cave (Ogle section)
Trogloxene? Found in the entrance.

Family Leptonetidae

55. *Leptoneta* sp.
det. W. Gertsch
Dome Cave, Ladder Cave, New Cave
Troglobite? This undescribed spider is a possibly troglobitic species; if so, it would be the first troglobitic spider in the Guadalupe region. There are several troglobitic species of this genus in Texas caves, however. The specimen from New Cave was taken several hundred feet from the entrance, in a crack.

Family Linyphiidae

56. *Eularia* sp. det. W. Gertsch
Ogle Cave (Rainbow Section)
Trogloxene?

57. *Eperigone antraea* (Crosby)
det. W. Gertsch
Ogle Cave
Troglophile. This species was described from Carlsbad Caverns and is known only from caves.

Family Lycosidae

58. *Pardosa* sp. det. W. Gertsch
Ogle Cave
Trogloxene. Found in the entrance.

Family Nesticidae

59. *Eidmannella pallida* (Emerton)
det. W. Gertsch
Lake Cave, New Cave
Troglophile. Usually found in the dark zone under rocks and other debris. Roth (1968) reported this species often to be found in cavities in the soil.

Family Pholcidae

60. *Psilochorus* sp. det. W. Gertsch
Ogle Cave, Longlegs Cave, Porcupine Cave
Trogloxene. Specimens found in the twilight zone.

61. *Physocyclus enaulus* Crosby
det. W. Gertsch
Helen's Cave
Trogloxene. Described from Bat Cave in Carlsbad Caverns, it is also common in the caves of the Edwards Plateau and the Glass Mountains, Texas. Reddell (1965 and 1970a) considered this species a trogloxene, although it probably does not leave the caves. (Roth [1968] reported this species outside caves in "protected cavities".) Specimen found in the twilight zone.

Family Salticidae

62. *Habrocestum* sp. det. W. Gertsch
Ogle Cave (Ogle Section)
Accidental. Found in the entrance.

Subclass Acari

ORDER PARASITIFORMES

Family Ixodidae

63. *Ixodes conepati* Cooley and Kohls
det. C. Clifford
Ogle Cave (Rainbow Section)
Parasite. A tick was found on the wall near the back of the Rainbow Section. Although there were cave swallow nests near the collection site, this species has been reported only from mammals. Kohls and Clifford (1966) reported this species from caves in Brewster and Culberson counties, Texas and from Eddy County, New Mexico.

Family Argasidae

64. *Ornithodoros* sp.
det. C. Clifford
Lake Cave
Parasite. Live specimens of this tick together with dead bats were taken from a lake. Probably parasitic on the bats.

ORDER ACARIFORMES

65. Undetermined genera and species.
Dome Cave, Goat Cave, Helen's Cave, Ogle Cave, outside entrance to Ogle Section.
Troglophiles? Mites found in these caves were under rocks or in leaf litter. A number of mites not represented in the cave were taken in traps 26, 27, and 28.

Family Ascidae

66. *Proctolaelaps* sp.
Ogle Cave (Rainbow Section)
Troglophile. Several specimens were extracted with a Berlese funnel from guano from the back of the Rainbow Section.

Family Anystidae

67. Undetermined genus and species.
Arch Cave
Trogloxene. A single specimen of this predacious mite was found just inside the entrance of the cave. Mites of this family have been found in earth cracks and caves in Northern Arizona by the author.

Family Ereynetidae

68. Undetermined genus and species.
Ogle Cave (Rainbow Section)
Troglophile. Specimens were recovered from guano in the back of the Rainbow Section.

Family Trombidiidae

69. *Ceuthothrombium* sp.
Lake Cave
Parasite. Troglophile? These mites were parasitizing *Ceuthophilus*. Specimens have been found on a number of *Ceuthophilus* from the Guadalupe Mountains region. They probably complete their life cycle in the cave. Nymphs and adults are probably free living predators.

70. Undetermined genus and species.
Decorated Cave
Parasite. Troglophile. These mites were parasitizing *Leiobunum townsendii* Weed in Decorated Cave.

Family Rhagidiidae

71. *Rhagidia* sp.
Corkscrew Cave, Ogle Cave (Rainbow Section)
Troglophile. A single specimen was collected on a guano-covered rock in the Rainbow Section. Elliot and Strandtmann (1971) reported *Rhagidia weyerensis* from Carlsbad Caverns. In Corkscrew Cave, these mites were found in leaf litter below the entrance drop.

PHYLUM CHORDATA

Sybphylum Vertebrata

CLASS REPTILIA

ORDER SQUAMATA

Family Colubridae

72. *Tantilla* sp.
Ogle Cave (Ogle Section)
Accidental. A report of a "black headed snake" by Paul Spangle in 1958 was found in NPS files at Carlsbad Caverns. No specimen was examined. It could be either *T. atriceps* or *T. nigriceps*, both of which are found in the area.

CLASS AVES

ORDER PASSERIFORMES

Family Hirundinidae

73. *Petrochelidon fulva pallida* Nelson
Dome Cave, Goat Cave, Ladder Cave, Lake Cave, Ogle Cave, Window Cave, and Swallow Cave.
Trogloxene. Cave Swallows were first reported in New Mexico from Goat Cave in 1952; they were reported from Ogle and Lake caves in 1959 (Ligon, 1961). They are found in the entrance to Carlsbad Caverns. In some of the caves, they contribute significant amounts of guano to the cave ecosystem.

CLASS MAMMALIA

ORDER ARTIODACTYLA

Family Cervidae

74. *Odocoileus hemionus* (Rafinesque)
Dome Cave, Ogle Cave (Rainbow Section)
Trogloxene? Deer appear to frequent the Rainbow Section of Ogle Cave, which they use as a bedding spot and, probably, as a source of water. Both Ogle and Dome have large, flat areas inside the entrance where deer can take shelter.

ORDER CHIROPTERA

75. Undetermined genus and species.
Ogle Cave (Rainbow Section), Lake Cave.
Trogloxene. Bats have been observed in two caves, roosting in cracks in the ceiling. In both cases, they were too far away to identify.

DISCUSSION OF OGLE SECTION

The arthropod cave fauna of the Ogle Section is dominated by troglophiles (48%) and trogloxenes (19%). There are only 2 confirmed troglobites. Within the Ogle Section, the organic material on which the cave life depends is varied. Below the pit entrance and on the slope, to approximately survey station OM4, there is leaf litter which has fallen into the entrance. The debris is concentrated along the sides of the passage. Cave swallows nest in the center of the passage during spring and summer. Below the nests, guano, grass, and egg shells accumulate. Fleas and a bed bug were found in this guano. The cave as far as station OM4 is considered to be in the twilight zone. The remainder is in total darkness.

Air temperature in the dark zone was measured at nine sites and averaged 56.3°F (range: 56 to 57°). Substrate temperature was measured at 3 sites and averaged 57°F. Relative humidity in the dark zone averaged 86.6% (range: 82 to 91%). Air temperature and relative humidity below the entrance drop were significantly different from those in the dark zone (see trap 24, Table 1). The low relative humidity in Ogle Cave is probably due to the constant loss of moist air through the Rainbow (upper) entrance. The highest relative humidity was measured at traps 4 and 5, where the guano was wet. This also was the area where the dark zone fauna was most highly concentrated.

The Sequoia and Boulder rooms (OM4 to OM15) were lacking in organic material, except for occasional bat guano pellets and guano spilled during the former mining operation. Bat guano was mined from OM15 to the back of the Ogle Section.

The dominant cave forms, as revealed by pitfall traps, were *Ceuthophilus* (cave crickets), diplurans, collembolans (four species), a psocopteran, and *Rhadine longicollis* (carabid beetle). The most common arthropod was the cave cricket (Table 1), which was represented by 3 species. Of these, only two, *C. carlsbadensis* and *C. longipes* were present throughout the cave. *C. conicaudus* was taken only in pitfall traps on the lip of the Ogle entrance. *C. longipes*, although widespread in the cave, was most common in and near the guano mining area (traps 4 and 5). Thirty percent of all *C. longipes* were found there, nearly all of them juveniles. The main corridor of the cave contained most of the cave crickets. The Boulder room (traps 9 to 11) had the fewest individuals. The trapping of individuals outside the entrance indicates that some climb the entrance drop to feed outside the cave. The exact movement patterns are not known, because most of the walls and ceilings are too high to examine closely. Due to the distances involved, it seems unlikely that the *Ceuthophilus* in the guano mining area migrate out the Ogle entrance. There could be other openings that allow passage of these cave crickets to the surface.

Most diplurans were taken in traps 4 and 5 (Table 1), but specimens were also taken in the Boulder Room, indicating that they are widely distributed through the Ogle section. One specimen was taken in trap 16, at the bottom of the talus slope, but no specimens were observed or taken in the twilight zone near the entrance.

The collembola in the cave represented 4 species, but only one (*Entomobrya californica*) enters the dark zone. (*E. californica* was also taken in a trap outside the entrance.) Most of the specimens were taken in areas near the entrance, where organic debris from the surface (traps 18 to 24) and on the surface (traps 26 to 28) is plentiful. Two species were found only on the surface. The cave individuals probably came from surface populations.

Psocopterans were represented by only one species. Most were found in organic material near the entrance, although one specimen was taken at trap 8, near the guano mining area.

A single dipteran species (*Megaselia cavernicola*) was taken in traps near the entrance (Table 1). Flies are usually found near decaying vegetation. In the Ogle section, there is an abundance of decaying leaves, twigs, and other litter near the entrance. A variety of diptera was found in the caves of Slaughter Canyon, but the data are too few to support conclusions on the distribution of these flies.

Coleopterans were represented by species from the families Tenebrionidae, Staphylinidae, Carabidae, and several smaller forms. A single tenebrionid (*Embalphion contractum blaisdelli*) and a staphylinid were taken on the talus slope below the entrance pit. Only one beetle was widespread in the cave, that being the carabid *Rhadine longicollis*, which is a common troglophile in the Guadalupe Mountains. Most of the specimens observed and collected were in the dark zone, around traps 4 and 5. This was also the area where most of the cave crickets were trapped. *Rhadine subterranea* is known to feed on *Ceuthophilus* eggs (Mitchell, 1968).

Several arthropods (orthopterans, Hymenoptera, Phalangida, Acari) were found outside the Ogle entrance, although in close proximity to the pit (traps 26 to 28), but were absent from the cave. The two most common surface arthropods were ants and mites. No ants were seen in the cave, and trapping indicated that they do not enter the cave even as far as the first ledge (cross section L-L' on the map). Mites in the cave were found in isolated areas further back, but were not common. On the other hand, surface traps contained 30 individuals of several groups. Several specimens of Blattidae and Gryllidae turned up in the surface traps, but there was only one record of Gryllidae from the entrance to Ogle Cave.

Four samples of the substrate were collected in Ogle Cave, at trap sites 2, 3, 4, and 23. Berlese extraction of samples 2 to 4 revealed no arthropods. The sample from trap site 23 contained mites, Collembola, pseudoscorpions, psocopterans, unidentified insect larvae, and other unidentified material.

Trap 23 was below the entrance, where there was an accumulation of organic material from the surface. The guano at the back of the cave is old, and no new guano is being added. There are no records of bats using the cave in recent times. The area disturbed by the mining operation probably had little effect on the cave fauna. Since the guano in the back of the Ogle Section is not supporting micro-arthropods, the large numbers of diplurans and *R. longicollis* are probably supported by the cave crickets.

DISCUSSION OF RAINBOW SECTION

The entrance to Rainbow Cave is a large, horizontal opening, approximately 15m wide and 6m high, facing south. The size and direction admit enough light to create a twilight zone for most of the length of the cave. Only a few areas behind large speleothems and rocks are totally dark. The front part of the cave is a steep talus slope with plant material between the rocks. The slope leads to a mostly guano-covered floor. There is no standing water and only a little dripping water. The cave appeared to be drier than the Ogle Section. In September, 1974, about 100m from the entrance, the relative humidity was 83% and the soil temperature was 60°F. The warmer temperature and lower humidity here, relative to those of the Ogle Section, could in part be due to the more open entrance.

The number of arthropod species within the Rainbow Section is nearly equal to that in the Ogle Section. A pseudoscorpion, several spiders, and collembolans present in the rich, moist leaf litter at the entrance to the Ogle Section are absent from the Rainbow Section. Diptera and mites were better represented in the Rainbow Section, however. No successful trapping was conducted in Rainbow, as the traps and bait were disturbed by animals (possibly skunk, raccoon, etc.) which entered the cave.

The same two troglobitic species found in the Ogle Section are also found in the Rainbow Section. The three species of cave cricket were also common in the Rainbow Section, with the more common species being *Ceuthophilus longipes* and *C. carlsbadensis*. The crickets spend most of the day on the walls and ceiling, descending at night to move out of the cave and feed. Vertebrates also were more common in this section of the cave. Cave swallow (*Petrochelidon fulva*), bats, deer, and probably other small mammals including *Peromyscus*, *Neotoma*, and *Procyon* use of the cave. Deer use the cave for shelter and, possibly, as a source of water (from some of the drips). A small colony of bats occupies a crack in the ceiling at the back of the cave, and cave swallows use the front part for nesting.

A sample of guano was taken from beneath an active swallow nest and placed in a Berlese funnel. More than 200 dipteran larvae, 300 mites of at least 2 species, a nematode, and a flea were recovered. The guano appeared to be from both swallows and bats.

OTHER CAVES IN SLAUGHTER CANYON

No trapping was done in the other caves examined in Slaughter Canyon and, therefore, no definite statements can be made on their fauna. The data from these caves indicate the fauna to be variable from cave to cave and to be particularly restricted in the drier caves (i.e.: Goat, Swallow, Porcupine, and Window). There were three troglobites (*Brackenridgia* sp., *Speodesmus tuganbius*, and *Plusiocampa* sp.) and possibly a fourth—a new species of *Leptoneta* which needs more study.

SUMMARY

The overall cave fauna in Slaughter Canyon, including Ogle Cave, is dominated by troglophiles (45%) and trogloxenes (23%). Only 6% are troglobites. The remainder are accidentals and parasites. The primary limiting factor for the cave fauna in Slaughter Canyon (and in the Guadalupe Mountains, generally) is the lack of moisture.

The Slaughter Canyon cave fauna includes 54 species, representing 48 genera and 50 families. Barr and Reddell (1967) identified 62 species of arthropods from Eddy County, of which 13 species were found in Slaughter Canyon. This brings the total from the caves of the Guadalupe Mountains and vicinity to 103 species.

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EDITORIAL

The new (1978) Copyright Act vests copyright in an author as he sets words to paper. It is no longer necessary to publish a work and then submit a formal application in order to receive copyright protection. Some members of the NSS Board of Governors wish to require authors to assign their copyrights to the NSS as a condition of publication, so that the NSS will continue to control reprinting of material first published by itself. The question was discussed, but not resolved, at the most recent Board meeting.

The NSS BULLETIN will not accept any papers for publication until the Board establishes its policy in this regard—we will receive contributions and place them on file, but none will be refereed or processed in any way. If the Board should decide to require assignment of copyright, authors should be informed of this as soon as they submit their work and should be given an opportunity to sign or to refuse to sign a transfer document. Further, should the Board eventually insist on transfer and an author refuse, any editorial work performed in the interim would have been in vain.

Papers accepted before the end of 1977 fell under the "implicit transfer" assumption of the old copyright law—the right to copyright passed to the NSS when a paper was submitted for publication. We have enough material "accepted in principle" to complete four issues in 1978.

Readers' comments on the copyright issue are invited and will be forwarded to the NSS Board of Governors. *JH*

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