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EXTRAORDINARY FEATURES OF LECHUGUILLA CAVE, GUADALUPE MOUNTAINS, NEW MEXICO

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Many unusual features are displayed in Lechuguilla Cave, Guadalupe Mountains, New Mexico, U.S.A. Early speleogenic features related to a sulfuric acid origin of the cave include acid lake basins and subterranean karren fields. Speleogenetic deposits, also products of sulfuric acid origin, include gypsum "glaciers" and sulfur masses. Features related to convective atmospheric phenomena in the cave include corrosion residues, rimmed vents, and horizontal corrosion/deposition lines. Speleothems of nonstandard origin include rusticles, pool fingers, subaqueous helictites, common-ion-effect stalactites, chandeliers, long gypsum hair, hydromagnesite fronds, folia, and raft cones. Other unusual features discussed are silticles and splash rings.

This paper was originally developed as a poster presentation for the Lechuguilla Cave geology session at the 1996 National Speleological Society Convention in Salida, Colorado. It is intended to convey an overview and basic understanding of the cave's remarkable suite of geologic features, some of which are virtually unique to this cave. Others were previously known but much better-developed and/or more abundant in Lechuguilla than elsewhere. Categories described here represent the peculiar things that make explorers experience Lechuguilla Cave as different from other caves. Following are the ones that seem particularly significant.

Lechuguilla Cave is a huge, bewilderingly complex, three-

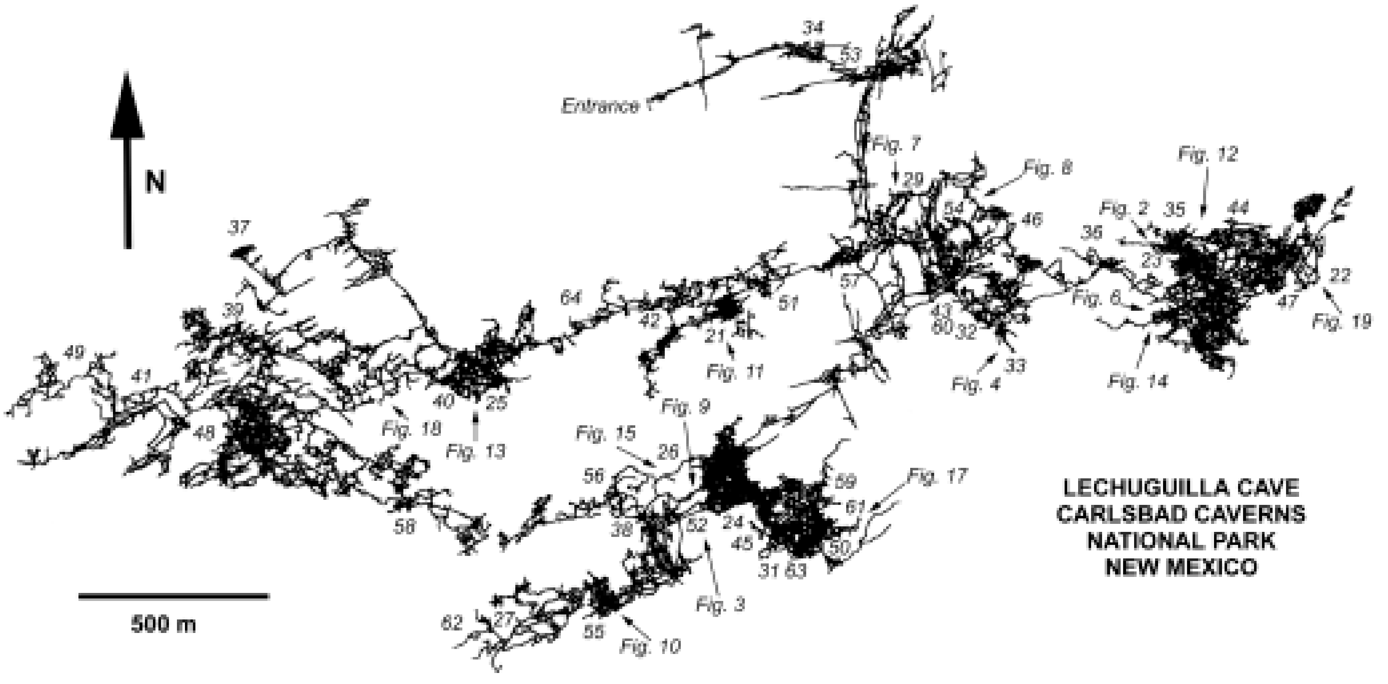

Figure 1. Line plot of Lechuguilla Cave. Guide to map locations: Nos. 2-18 are locations of figures in this paper; higher numbers below are named localities mentioned in the text. Blanca Navidad-19 Boundary Waters-20, Bryce Canyon-21, Chandelier Ballroom-22, Chandelier Graveyard-23, Darktown-24, Death Valley-25, East Rift-26, Emperors Throne Room-27, FLI Room-28, FUNC Survey-29, Ghost Town-30, Ghostriders Balcony-31 Glacier Bay-32, Glacier Way-33, Grand Illusion-34, Here be Dragons-35, Hoodoo Hall-36, Jackpot-37, Jewel Box-38, Keel Haul-39, Lake Louise-40, Lake of the Blue Giants-41, Lake of the White Roses-42, Land of the Lost-43, Land of Fire and Ice-44, MBF Survey-45, Mental Breakdown-46, Northern Exposure-47, Pearlsian Gulf-48, Pellucidar-49, Prickly Ice Cube Room-50, Rim City-51, Rusticles-52, Shangri-La-53, Shelobs Lair-54, Snow Whites Passage-55, Southern Climes-Stratosphere Room-57, Stud Lake-58, Sulfur Shores-59, Vesuvius-60, The Void-61, Western Borehole-62.

dimensional maze, 475 m deep, with more than 170 km of surveyed passage (Fig. 1). It fits the pattern defined by Palmer (1991) as a "ramiform maze," which is characteristic of caves of hypogenic (rising-fluid) origin. The cave consists largely of the following three morphologic elements: (1) large rooms and galleries; (2) intricate "boneyard" intergrading with breakdown or underlying larger voids; and (3) deep, rift-like, usually slanting slots, which also may underlie larger spaces. The rifts and some boneyard pits were probably feeder vents for ascending hydrogen-sulfide-rich fluids, which, upon mixing with oxygenated groundwater and/or reaching the water-table interface with air, developed sulfuric acid and dissolved the larger chambers. The input points probably moved eastward and downward over time as the Guadalupe Mountains were tilted during the late Tertiary and Quaternary periods (Hill 2000; Palmer & Palmer 2000).

Lechuguilla Cave, because it is deep and protected by its small entrance cross-section and tight siltstone caprock from rapid influx of surface water and air, has a geothermally-driven temperature gradient in which the present average temperature of the highest (entrance) part is about 2°C lower than its lowest parts. In the more vertical sections of the cave, this gradient drives convectional unidirectional airflow loops that cause evaporation in warmer areas and condensation in cooler. This process, which was probably more intense in the past, has contributed to unusual suites of interrelated, corrosive and depositional features in the cave.

EARLY SPELEOGENS

ACID LAKE BASINS

An acid lake basin may be thought of as a "negative rimstone pool," where a pond of aggressive water once stood, eating away its floor and undercutting parts of the limestone walls (Fig. 2). A distinct line marking the ancient water surface was thereby created. At least five examples have been recognized in Lechuguilla Cave, the most impressive being in the East Rift in the Eastern Branch, and near the Pearlsian Gulf in the Southwestern Branch. I am not aware of identical cases, confined to limited basins, reported from any other cave, but aggressive water, at the top of a phreatic zone or floodwater zone, is known to form solution-beveled flat ceilings and wall notches in other caves (Ford & Williams 1989). Such wall notches, on a larger scale than the restricted basins mentioned here, were recently recognized in the Keel Haul to Northern Exposure area of Lechuguilla's Western Branch.

The East Rift acid lake basin has conical orifices in the pool floor, which seem to have been source vents for corrosive fluids and/or gases. Above the water line, upward-facing surfaces are grooved by fields of rillenkarren, suggesting rapid condensation of highly aggressive films of trickling moisture. This topic is considered further in the next section. At some of these basins, the rillenkarren are overlain by several centimeters of granular gypsum, implying that the sulfuric acid cave development process was still active when the cave had drained at least to the level of the acid lake in each area.

SUBTERRANEAN RILLENKARREN

Subterranean rillenkarren are spectacular deeply-grooved fields of limestone bedrock (Fig. 2), and are cave analogs of the rillenkarren that more commonly develop from rain and snow on surface karst exposures (Sweeting 1973). Such features have been noted in thermal caves such as Lower Kane Cave, Wyoming, but those in Lechuguilla Cave and Carlsbad Cavern are the best-developed examples known to the author.

The cave rillenkarren were not formed by infiltrating surface water. The ceilings overhead are usually smoothly rounded and show no signs of water influx. The karren usually cluster around floor joints, or small openings connecting to lower-level chambers (which commonly are floored with calcite-raft deposits). They are not active today, but seem to date from a time when the regional water table was lowering, and when the temperature gradient was relatively high. This drove a "distillation-retort" effect. High evaporation at the water level caused the calcite rafts to accumulate, and condensation of the rising vapor at cooler levels attacked the bedrock and breakdown, etching the karren fields and resupplying dissolved calcite to the water below as the condensate trickled back down (Davis 1982, 1995).

Subterranean rillenkarren have thus far been noted in the Guadalupe caves only in Lechuguilla, Carlsbad Cavern, and Mudgetts Cave (a small cave near Lechuguilla) - not in any of the otherwise similar caves elsewhere in these mountains. Lechuguilla and Carlsbad are also by far the largest Guadalupe caves known. This suggests that the presence of rillenkarren is related to a particularly high intensity of the sulfuric acid cave-development process, which might have generated temperatures high enough to drive sufficient evaporation/condensation to produce rillenkarren. The present temperature in these areas is about 20°C. The paleotemperature has not been determined, but was probably not above 35°C (Palmer & Palmer 2000). The elevated temperatures may have been caused by exothermic reactions involved in generation of hydrogen sulfide and its oxidation to sulfuric acid.

SPELEOGENETIC DEPOSITS

GYPSUM "GLACIERS"

Lechuguilla Cave contains thousands of tons of massive or laminated gypsum, which accumulated where groundwater flow was not strong enough to carry away all of the sulfate produced by the sulfuric acid reaction with the limestone when the cave was enlarging (Hill 1987). These gypsum deposits are up to 10 m thick.

Gypsum beds in Lechuguilla have been dissolved away from large areas of the cave by later seeping and dripping surface water, or by fresh-water reflooding below -290 m. The best-preserved remnants, in dry rooms and alcoves, are at least 30 m long in some places, and strongly resemble miniature ice glaciers. The similarities include "bergschrund" gaps at the upper edge of the mass; pits and "crevasses" in the body (Fig. 3), and "bergs" calving from the lower edge. These effects are produced by dissolution pitting and by undermining at the contact with moist underlying rock, rather than by mass flow and melting as in true glaciers. At least one good example can be seen in every branch of the cave, the best being in the following chambers: Glacier Bay, Land of Fire and Ice, Prickly Ice Cube Room, Blanca Navidad, and Stratosphere Room.

SULFUR MASSES

In most areas of the cave, hydrogen sulfide from oil and gas deposits oxidized completely to sulfuric acid (Hill 2000), which in turn attacked the limestone, enlarging the cave and forming gypsum deposits. Locally, however, the oxidation process stopped at elemental sulfur, which occurs as lemon-yellow pods and stringers up to 1 m thick embedded in larger masses of gypsum (Fig. 4). The sulfur, which may be massive, granular, or platy, has been exposed locally by dissolution of the surrounding gypsum. The deposits seem to be spontaneously oxidizing very slowly: one can smell sulfurous gases in the air up to about 60 m from some sulfur localities.

DuChene (1997) has noted that these sulfur deposits occur in places where fine-grained sandstone layers form the ceiling and/or walls: perhaps the sandstone had inhibited oxygenation or had stalled completion of the reaction chain by preventing all sulfur from oxidizing as quickly as it would in contact with carbonates. Massive and crystalline sulfur is also found in Cottonwood Cave (Davis 1973), and small deposits occur in Carlsbad Cavern, but Lechuguilla Cave may contain more sulfur than all other known caves in the world combined. There are deposits in all three branches of the cave. The best are in passages off Ghost Town, Ghostbusters balcony, the Void, and near the Blanca Navidad chamber.

In other parts of Lechuguilla Cave and Carlsbad Cavern are much smaller, yellow-crystalline encrustations, which for many years were also assumed by observers to be sulfur. These crystals have been determined to be tyuyamunite and metatyuyamunite, uranium-vanadium minerals that were mobilized in groundwater and redeposited in the caves (DuChene 1997; Hill & Forti 1997).

ATMOSPHERIC SPELEOFACTS

I use here the umbrella term "speleofacts," which encompasses both speleothems and speleogens (Lange 1959), because some of the entities described unite both speleogenic and speleothemic elements sharing a common geometry.

CORROSION RESIDUE

In many places in Lechuguilla Cave, where currents of warm, moist air rise from deeper levels and impinge on walls and ceilings, the bedrock is attacked by condensation, leaving a lacy mat of insoluble residue up to 2.5 cm or more thick (Fig. 5). When heavy enough, this residue can fall in patches to the floor, leaving sticky dark-colored splotches. Corrosion residue is composed largely of iron, manganese, and aluminum compounds, or silica where on siltstone matrix (Cunningham *et al*. 1995). The color ranges from dark brown (most common) to reddish, orange, yellow and black, depending on the substrate which may be limestone, siltstone, or vein calcite.

Similar residues occur in other caves having sufficient relief and temperature gradients to drive convective airflow cells (e.g., Wind Cave and Jewel Cave, South Dakota). But, as with other features considered in this paper, corrosion residues seem more profoundly developed in Lechuguilla Cave than elsewhere. The Lechuguilla corrosion residues have been found to host a dense population of microorganisms. The extent to which the microbes may be actually responsible for creating the residue, or may simply be using the residue network as a convenient habitation substrate, is not yet clear. Nor is their food source. The microbes are believed to be chemolithoautotrophic (using inorganic energy sources), because no substantial amount of organic matter comes from outside, because the nearest relatives of organisms isolated from the residues are chemolithoautotrophic, and because organisms cultured from residue samples produced iron and manganese oxides (Northup *et al*. 2000). However, the hypothesis that the microorganisms are oxidizing iron or manganese in the bedrock raises questions, as these walls have been in the zone of oxidation for millions of years and should be already fully oxidized. Cunningham *et al*. (1995) suggested that the bacteria may be utilizing traces of sulfur-compound gases dissolving into the condensate from the impinging air stream. This could explain why corrosion residues are not so well developed in caves less rich in sulfur.

RIMMED VENTS

Rimmed vents are a composite speleogen/speleothem, having one side corroded and the other encrusted. In Lechuguilla Cave, the encrustation may be composed of calcite, aragonite, or gypsum, and rarely hydromagnesite. The corroded side may be coated with corrosion residue. The rims may form ear-like projections from the walls of passages, as in Rim City in the entrance passage series, and above the Grand Illusion in the Far East (symposium back cover), but are more often seen at constrictions or intersections between passages, or around impenetrably small holes in floors. They were originally recognized as distinct entities in the Caverns of Sonora, Texas (Burch 1967), and then in Jewel Cave (Conn & Conn 1977) and elsewhere, but as with many other unusual speleofacts, they are probably more abundant and larger in Lechuguilla than at any other site reported. Some gypsum rims in Lechuguilla's Far East are up to 1 m high and extend for up to 5 m along the edge from which they grow.

The mechanism of rim formation is not well understood, but they are believed to develop via simultaneous condensation and evaporation in response to humidity gradients across a wall projection. The encrusted sides normally face the surface or the entrance (i.e., a source of cooler, drier air), while the corroded sides face the warmer, moister cave interior. The moisture condensing on the corroded side is assumed to dissolve the substrate there, then move by wicking action to the other side, where evaporation redeposits the material as a rim. In some places, aragonite rims form along walls and ceiling while gypsum rims grow on the floor at the same site, suggesting that slightly drier and therefore denser air tends to follow the floor.

The "Stingray Eyes" are tiny vents, rimmed with hydromagnesite, in the floor of the "Rusticles" area of the Near East. Hydromagnesite rims also occur in the FUNC Survey in the Southwestern Branch. As far as I know, hydromagnesite rims have been recognized only in Lechuguilla Cave.

HORIZONTAL CORROSION/DEPOSITION LINES

These strikingly horizontal boundaries have evaporative deposits such as gypsum crust and aragonite frostwork below, and bare corroded wall above (Fig. 6). If it were not that associated deposits are not subaqueous, they could easily be mistaken for water lines (in fact, a water line and an atmospheric line are juxtaposed within 2 m of each other in the Lake of the Blue Giants chamber). Corrosion lines are well developed in certain long passages and large chambers, such as Snow Whites Passage, the East Rift, Glacier Way, and Death Valley.

Corrosion/deposition lines mark long-term stratification of air in these chambers. A thermometer test above and below the line in Glacier Way did not reveal a measurable temperature difference. However, humidity stratification alone (more humid air being lighter, and therefore drifting to the top) would probably account for the air separation. As with rimmed vents, the result is condensation attack above the line, seepage of condensate downward, and evaporative redeposition below. Hill (1987) also measured higher CO_2 concentration along the ceiling of Left Hand Tunnel in Carlsbad Cavern, showing that air stratification can also enhance corrosion of the upper walls.

SPELEOTHEMS OF UNCONVENTIONAL ORIGIN

"BIOTHEMS"

Rusticles. These bizarre, eccentric stalactites and columns (Fig. 7) are largely confined to a limited area of the Near East of Lechuguilla Cave, although they also have been reported from an obscure passage off the route to the Lake of the White Roses deep point in the Far East. The cores are composed of iron oxide minerals which, as seen under the microscope, consist of fossil microbial casts. The outer shells are composed of calcite crust. The rusticles appear to have grown underwater where reduced iron-rich fluid was trickling from above into standing water, giving rise to subaqueous streamers of iron-mineral sheaths of iron-oxidizing bacteria (Davis *et al*. 1990). These streamers were originally very fragile; had they not been encrusted with calcite before the basin drained, they would probably have disintegrated and disappeared.

The name "rusticles" was borrowed from accounts of the discovery of the wreck of the ship *Titanic*, which was found to be draped with submarine iron-rust stalactites of similar appearance and, probably, origin. Stalactiform deposits in Fairy Cave, Colorado (another cave of hypogenic sulfide-related origin), are interpreted here as subaqueous rusticles, but they are far less spectacularly developed there. Rusticles should not be confused with subaerial iron dripstone which is common in other caves (Hill & Forti 1997).

The pool finger complex. In several old pool basins in Lechuguilla Cave are fields of stalactiform fingers, up to 50 cm long, that evidently grew underwater. They are commonly interconnected by parabolic u-loops. Unlike the rusticles, they are made of solid calcite, without more than traces of iron or other constituents. They resemble rusticles, however, in seeming to be based on encrustation of bacterial streamers, fossilized fragments of which in places may be seen underneath the fingers. They are best developed in basins that were at the lower end of a series of flowstone slopes and ponds; the feeder flowstone may itself contain fossilized bacterial strings as can be seen above the MBF survey locality (Davis 1990). With the possible exception of some nontypical fingers in Stud Lake, they are not active today, and the identity and food source of the bacteria involved are not known. Northup *et al*. (2000) discuss the connection of bacteria and pool fingers in this issue.

In one location off the FLI Room (Fig. 8), the fingers are accompanied by web-like sheets that have been called "webulites." Aside from being based on calcification of biaxial organic sheets rather than uniaxial strings, their origin is the same.

In some places, pool fingers are transitional to the longer-known subaqueous palisade-like speleothem called "chenille spar." Pool fingers and related forms are not unique to Lechuguilla Cave; they are also known from Nevada, northern New Mexico, Colorado, Arizona, Wyoming, and elsewhere. However, it was the particularly well-developed occurrence in Lechuguilla Cave that was first given the "pool finger" name (in Davis *et al*. 1990), and that led to their being classified as a distinct speleothem type by Hill & Forti (1997).

COMMON-ION EFFECT SPELEOTHEMS

Subaqueous helictites. When solutions of different chemicals mix, if they contain one ion that is the same, this may trigger crystallization of the less soluble species. Until the discovery of peculiar new speleothems in Lechuguilla Cave, this "common-ion effect" had been recognized as a factor in speleothem deposition only in a few cases, including growth of calcite flowstone in gypsum caves (Hill & Forti 1997: 142), and growth of the speleothems in subglacial Castleguard Cave in Canada (Atkinson 1983).

Then, subaqueous helictites - wormlike speleothems with tiny central canals (no previously recognized subaqueous speleothem had been known to have that structure), were found in Lechuguilla Cave. They were first seen in a large room called Pellucidar, then subsequently in about 30 other locations (Fig. 9). Within Lechuguilla Cave some are still submerged, whereas others are "dead" in dry basins. This discovery was unique; all helictites previously known had been assumed to have grown in air, from capillary seepage of moisture from the wall.

The subaqueous helictite sites share one property: the basins in which they grew were invariably fed by flowstone that ran under gypsum deposits in such a way as to dissolve gypsum into the water feeding the pool. This suggested that the common ion effect is responsible for subaqueous helictites: trickles of calcium-sulfate-enriched water flow into pools already saturated with calcium carbonate, introduce excess calcium ions, and cause rings of calcite to precipitate around the entry points. This confines the gypsum-bearing influx to tiny canals and extends the resulting growth into helictitic form. Analyses of the inflowing and ambient water (Davis *et al*. 1990) in the Pellucidar pool are consistent with this hypothesis.

Confirmed examples of subaqueous helictites of the Lechuguillan type remain almost confined to Lechuguilla Cave, probably because gypsum is excessively abundant there, and few other caves have gypsum in contact with active calcite flowstone. Other, less spectacular, subaqueous helictites have been reported from nearby Endless and Virgin Caves, New Mexico, in localities also well supplied with gypsum (Mosch 1996.)

"Helictite bushes" in Wind Cave, South Dakota, have also been recognized as being subaqueous in origin (Davis 1989a, 1991), but these are considerably different from the Lechuguillan helictites. They have large internal canals, and the water source was from below, not from gypsum-enriched flowstone seepage. Helictite bushes may be more closely related to submarine "smokers" than to the subaqueous helictites of Lechuguilla Cave.

Common-ion-effect stalactites. Subaqueous helictites are not the only Lechuguillan speleothems that involve the common-ion effect. As might be expected, it also seems to be significant in subaerial calcite deposition. The most prominent such case is that of certain aberrant stalactites. These stalactites tend to be isolated below sources of gypsum-enriched seepage. They are lumpy, wavy, and irregular, rather than smoothly contoured as is typical of normal stalactites. This may reflect uneven concentration of calcium ions, from incomplete mixing of the stringy source flows.

The most spectacular example of a presumed common-ion-effect stalactite is the Gripping Hand group (Fig. 10) near the Blanca Navidad room in the Western Branch (Davis & Petrie 1994). This group consists of a flattened, branching stalactitic mass about 4 m long, which resembles a giant moose antler. It feeds a pool containing subaqueous helictites.

Common-ion-effect stalactites smaller than the Gripping Hand occur in the Chandelier Graveyard, Here Be Dragons, and the Far East. In the Far East, some have their tips spread out into flattened pads. This may mean that they dipped into standing water, with the gypsum mixing causing a shelfstone ring to form before the rest of the water was sufficiently saturated to grow shelfstone around the entire passage (Fig. 11).

EVAPORATIVE SPELEOTHEMS

"Chandelier" stalactites and stalagmites. Evaporative conditions have long prevailed in much of Lechuguilla Cave, so it is not surprising that speleothems of evaporative origin are plentiful. These include relatively common forms such as aragonite frostwork, and more unusual types composed of gypsum.

The most imposing forms of gypsum may be classed as stalactites. Most of these are coarsely crystalline and eccentric, lacking central canals, and of much more complex outline than calcite stalactites. This is probably because gypsum tends to precipitate in crystals that are large with respect to the size of the speleothem. The cave's most famous feature is elaborately branching selenite "chandeliers," which have grown up to about 6 m long in the Chandelier Ballroom. Smaller ones are found in other parts of the cave (front cover). Chandelier stalactites are not unique to Lechuguilla. Others about as large exist in Cupp-Coutunn Cave, Turkmenistan (Maltsev 1997), and smaller examples have been noted elsewhere in New Mexico and in Wyoming, Colorado, and Utah (Hill & Forti 1997).

As with several other characteristic Lechuguillan features, the Chandelier Ballroom's extraordinary chandeliers seem to owe their development to airflow convection driven by temperature gradient, the convection in turn driving an evaporation/condensation cycle. In a maze level about 25 m above the Ballroom, condensation slowly dissolves massive floor gypsum. The resulting seepage evaporates after seeping into the Ballroom, depositing chandelier crystals.

Gypsum stalagmites and columns, usually hollow, are also common in Lechuguilla Cave. Some of these stalagmites also radiate chandelier-style selenite crystal arms downward and outward, like fossilized Christmas trees (Fig. 12). The best examples are up to 4.5 m high, in the Chandelier Graveyard. These "chandemites" are rarer, and some think more bizarre in appearance, than chandelier stalactites.

Long gypsum hairs. The chandeliers are amazingly massive gypsum growths, but Lechuguilla is also notable for incredibly delicate ones. The apogee of this is its superlong gypsum hairs. These can be almost invisibly thin, in places gently spiraling, and up to at least 6 m long. They were first seen near Lake Louise, and later found in larger sizes and numbers in Darktown (Fig. 13). The areas where they are well developed are lined with mammillary calcite crust. This substrate presumably has exactly the right pore size and structure to extrude the hairs.

In some places, including Land of the Lost and Shelobs Lair, aggregates of hairs form cottony, cloudlike puffs that move in the slightest breeze. Other relatively common gypsum forms, including flowers and needles, reach exceptional size - more than 1 m in drier parts of Lechuguilla Cave.

Hydromagnesite fronds. Hydromagnesite is often associated with aragonite and gypsum in evaporative parts of Lechuguilla Cave. It is commonly seen as moonmilk, "sand," and "krinkle blisters," and less often as balloons and intermediate forms. An uncommon form (previously undescribed to the author's knowledge) is curving, featherlike fronds, first noted in the Boundary Waters section of the Far East, and subsequently in the Southern Climes (Fig. 14) and Mental Breakdown areas of the Western Branch. When occurring singly, these are up to 10 cm long. In one case, many radiate from a single stem and curve upward, forming a 10 cm "tree", resembling an aragonite bush except for a chalky appearance and curving branches. Whether this is a pure hydromagnesite form, or is based on an aragonite core, is unknown.

FOLIA

Folia are sloping, contoured, interleaved shelves, normally composed of calcite (but rarely of mud, halite, or sulfur; Hill & Forti 1997), that cover overhanging walls and ceilings. In Lechuguilla Cave, folia are found almost exclusively within about 37 vertical meters of the present water table surface at the Lake of the White Roses and Sulfur Shores (Fig. 15), the deepest points of the cave. The details of folia development are not well understood, but appear to represent a water-table equivalent of shelfstone. Shelfstone maintains a distinct horizontal level because it is controlled by a fixed, perched overflow point. Folia shelves are sloping and overlapping because the calcite accretion attempts to follow the irregular fluctuations of a calcite-saturated water table. (A subaqueous interpretation has also been proposed - see Green 1996.) Unlike shelfstone, calcite folia are invariably associated with deposits of calcite rafts. They are usually found in caves of hypogenic (rising-water) origin, and are known from Nevada, Utah, Arizona, and Colorado, as well as New Mexico and Europe (Hill & Forti 1997). In Lechuguilla Cave, the level at which folia growth begins probably marks the time at which the final withdrawal of aggressive groundwater occurred.

RAFT ACCUMULATIONS AND CONES

Calcite rafts develop as thin sheets on the surface of quiet, supersaturated water. They are fairly widely distributed in caves around the world, but are exceptionally abundant in parts of Lechuguilla Cave, where they form deep floor accumulations. Such deposits probably gathered as the groundwater surface drained past the lower levels of the cave, and seepage from above collected in increasingly isolated and restricted basins from which it evaporated. They may be, in part, the evaporative result of evaporation/condensation cycles in which condensation was causing corrosion effects such as rillenkarren at higher levels - in other words, another "distillation-retort" effect. There are at least two generations of old calcite rafts in Lechuguilla Cave: an older one represented by partly redissolved truncated raft cones in the Jackpot and Shangri-La rooms, and a younger one best developed in the Western Borehole. Only at the water table, and a few other pools, are rafts now actively growing in the cave.

When drops of water fall from fixed ceiling points above raft-covered water surfaces, the impacts may cause rafts to sink. Others drift into the resulting gaps and are sunk in turn, creating symmetrical stalagmite-like raft piles (called cave cones) beneath the water, 3 m or more high in places. When exposed by a declining water level, they may become encrusted or overgrown with aragonite frostwork. Encrusted raft piles can usually be distinguished from true stalagmites by their conical (rather than parabolic or cylindric) shape, reflecting the angle of repose of the heaped rafts. In some cases, however, the rafts are cemented together as they accumulate, forming towers much steeper than the angle of repose (Fig. 16).

OTHER FEATURES

"SILTICLES"

Where flowstone-depositing seepage has access to fine sediment, and where it flows over ledges, the sediment may become cemented into comb-like fringes of stalactiform growths up to 25 cm long. The sediment is usually silt, but it may also be hydromagnesite moonmilk, as seems to be the case in the example shown in figure 17. Unlike true stalactites, silticles lack central canals and commonly taper to sharp points. They are prevalent in caves of the Guadalupe Mountains but have received little attention in the literature. Few, if any, of those in Lechuguilla Cave seem to be active today; they date from wetter times when water influx washed preceding deposits of loose silt or moonmilk over ledges.

SPLASH RINGS

When water drops fall on cave floors, the splash rebound may spray out as a symmetrical corona around the impact point, falling in a partial or complete circle or ellipse up to 2 m in diameter. Depending on the water composition and the substrate, this may create either negative (speleogenic) or positive (speleothemic) rings on the floor. In Lechuguilla Cave, negative rings incised into gypsum (Fig. 18) and residual sediment are relatively common, the best display being in the Blanca Navidad room (one such incised ring has been seen in a calcite raft deposit). In the Vesuvius area of the cave, two positive splash rings have developed as raised welts on otherwise smoothly contoured flowstone (Davis 1989b).

CONCLUSIONS

On first impression, the features discussed in this paper seem heterogeneous and unrelated except that they all happen to be unusual characteristics of this one peculiar cave. On closer examination, however, many of them can be seen to be interrelated to each other by way of their dependence on the unusual origin of the cave from rising water charged with hydrogen sulfide and sulfuric acid (Palmer & Palmer 2000), or on convective airflow loops driven by the strong temperature gradient generated by the cave's large vertical relief.

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Back cover (*Journal* page 50**): "The Ear" - gypsum rim, Far East. Photo by David Harris, Harris Photographic.**

Front cover(*Journal* page 158**): Chandelier stalactite, Western Branch (Jewel Box). Photo by David Harris, Harris Photographic.**

Figure 2 (Top Left). Acid lake undercut and rillenkarren above, in Far East (Bryce Canyon). Rillenkarren are more than 1 m high. Photo by Kathy Sisson-DuChene.

Figure 3 (Top Right). "Crevasse" in gypsum "glacier," Prickly Ice Cube Room. Photo by David Harris, Harris Photographic.

Figure 4 (Bottom Left). Sulfur mass, Near East (Ghostriders balcony). Photo by Kathy Sisson-DuChene.

Figure 5 (Bottom Right). Corrosion residue coating wall, Land of the Lost vicinity. Area shown ~1 m high. Photo by David Harris, Harris Photographic.

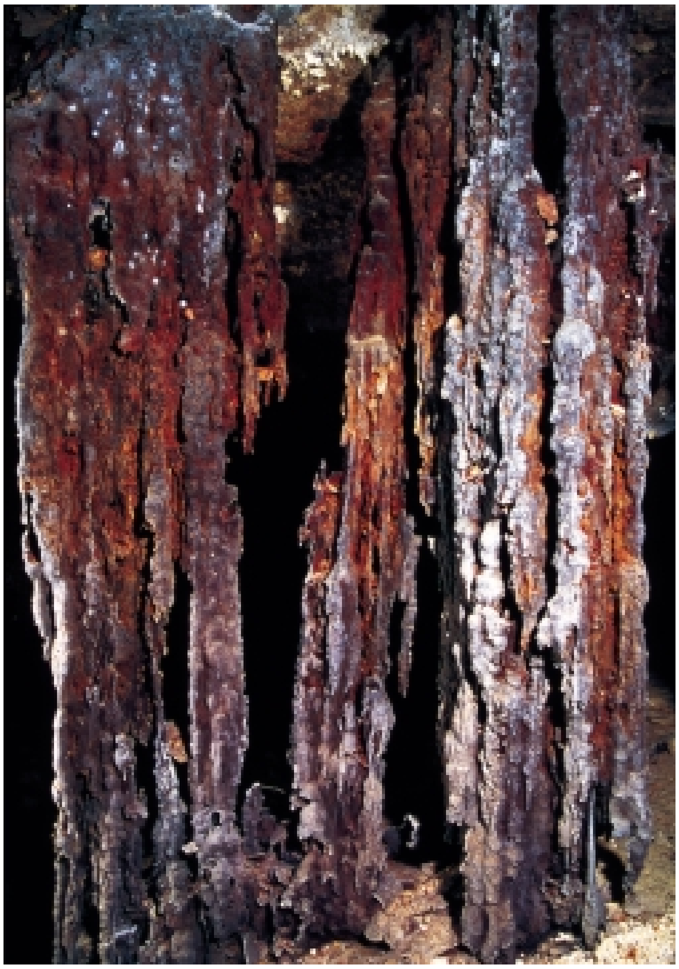

Figure 6 (Top Left). Stratified air line, Near East (Emperors Throne Room). Photo by Nick Nichols.

Figure 7 (Top Right). Rusticles, Near East. Area shown ~1 m high. Photo by David Harris, Harris Photographic.

Figure 8 (Bottom Right). Pool fingers, Southwestern Branch (FLI room). Fingers ~0.3 m long. Photo by David Harris, Harris Photographic.

Figure 9 (Bottom Left). Subaqueous helictites ~0.3 m long, in High Hopes. Photo by David Harris, Harris Photographic.

Figure 10 (Top Left - Next Page). The Gripping Hand (Blanca Navidad Room). Note caver for scale. Photo by David Harris, Harris Photographic.

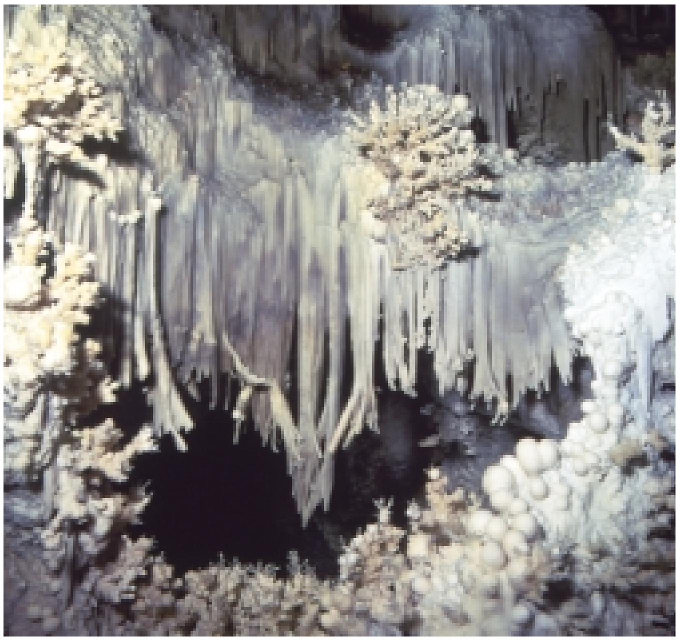

Figure 11 (Top Right - Previous Page). Common-ion-effect stalactite with rimstone pad (Far East). Photo by David Harris, Harris Photographic.

Figure 12 (Bottom Left - Previous Page). Chandelier stalagmite, Far East. Photo by Kathy Sisson-DuChene.

Figure 13 (Bottom Right - Previous Page). Long gypsum hair, Southwestern Branch (Darktown). Visible section ~0.3 m long. Photo by Larry McLaughlin.

Figure 14 (Top Left). Hydromagnesite fronds, Rock 'n Rillen Room (Western Branch). Longest ~7 cm long. Photo by Peter Bosted.

Figure 15 (Top Right). Folia, Sulfur Shores. Photo by Dick LaForge.

Figure 16 (Middle Left). High-angle raft cones, encrusted with aragonite (Hoodoo Hall). Height up to ~5 m above basal slope. Photo by David Modisette.

Figure 17 (Bottom Right). Silticles, Far East (Boundary Waters). Area shown ~0.7 m high. Photo by David Harris, Harris Photographic.

Figure 18 (Bottom Left). Small negative splash ring in gypsum, Chandelier Graveyard. Photo by Peter Bosted.