Arizona Geological Society

Field Trip to Colossal Cave and the Surrounding Area, Pima County, Arizona

Leader: William Peachey, Speleologist
Colossal Cave Mountain Park

February 19, 2000

Colossal Cave
Mountain Park

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Colossal Cave Mountain Park

Physical and Biological Resources

General Geology

Introduction:

Colossal Cave Mountain Park is the only interpretive site in the Pima County parks system where visitors can view, in close proximity to one another, rock units representing the entire span of geologic time in southern Arizona as well as evidence of the physical changes that accompanied geologic events. Faults and folds are represented at all scales. Evidence of the expansion and shrinkage of rock volumes is found throughout the study area. Evidence of metamorphic changes in rocks—i. e., quartzite from sandstone, marble from limestone, and gneiss from granite—is equally common. More subtle associations formed by faulting reveal relative movements of large volumes of rock on the order of tens of miles horizontally and thousands of feet vertically over tens of millions of years.

The cave and canyon terrain also allows direct observation of the effects of physical and chemical erosion and deposition, both as the result of past events and as dynamic forces still shaping the Sonoran desert.

What we see today is a mosaic of rock types and ages in very complex relationships with one another as they form a portion of the southwestern flank of the Rincon Mountains within the Basin and Range physiographic province. This province is characterized by isolated mountain rock masses whose intervening valley floors have settled below them. Typically, the valleys contain thousands of feet of sediments eroded from the mountains that border them.

The initial published geologic investigation in the area, of which we are aware, was conducted by Darton in 1925. In it, he notes the curious position of Paleozoic limestones that appeared to have been thrust over Precambrian granite. Over the intervening decades the true character of that relationship remained unknown.

Actually preceeding Darton, the first formal mapping effort at Colossal Cave took place in 1917–18. This was undertaken by Byron Cummings, the first head of the Anthropology Department at the University of Arizona. Cummings had assistants in the surveying, one of whom was Lynn Hodgson, then a local teenager, who was to become a prominent southern Arizona outdoorsman. Hodgson died at age 96 in 1996, evidently the last of the original geological investigators of the Colossal Cave area. Unfortunately, neither the map nor a report on the effort was published, and any copies of the map have since disappeared. Today the only existing record of the map consists of an incomplete set of data reduction tables of the surveys.

Since the early work by Cummings and Darton, many studies, both published and unpublished, have addressed questions about the Colossal Cave Mountain Park area. These are too numerous to detail here and so have been compiled as part of the bibliography to this report.

These references support current views of western regional North American geology: that is, three significant events, which occurred relatively late in geologic time, are largely responsible for the landscapes we see in the region today. They are the **Laramide orogeny**, a mountain-building episode that occurred **75–40 million years ago** (m. y. a.), the **Mid-Tertiary extension,30–20m. y. a.**, and the **Basin and Range extension, 15–5 m. y. a.**

These events overprinted the vast number of the older rock units in the area (that is, they masked older chemical and physical characteristics with younger ones), and even overprinted the rock units produced by one another, to yield the great complexity and diversity we see today in the geology of Colossal Cave Mountain Park and the study area.

COLOSSAL CAVE MOUNTAIN PARK

GEOLOGIC UNITS*

	QUAT		ALLUVIUM M		O	
	TERTIARY	PLIOCENE				
		MIOCENE	PANTANO FORMATION M	SIL. RED BRECCIA	O	
		OLIGOCENE		TURKEY TRK. ANDESITE	O	24 M.Y. RADIOMETRIC AGE-DATE
		EOCENE	WRONG MOUNTAIN			
		PALEOCENE	NIPPER FORMATION			
	CRETACEOUS	LATE	UPPER VOLCANIC SEQUENCE			
			FORT CRITTENDEN FORMATION			
		EARLY	BISBEE GROUP	CINTURA FORMATION		
				MURAL LIMESTONE		
				WILLOW CANYON FM.→M	O	
				GLANCE CONGLOMERATE	O	
PALEOZOIC ERA	PERMIAN	OCHOAN				
		GUADALUPIAN	RAINVALLEY FORMATION			
			CONCHA LIMESTONE		O	
		LEONARDIAN	SCHERRER FORMATION		O	
			EPITAPH FORMATION		O	
			COLINA LIMESTONE		O	
M		WOLFCAMPIAN	EARP FORMATION		O	
	PENN.	VIRGILIAN				
		MISSOURIAN	HORQUILLA LIMESTONE		O	
		DES MOINESIAN				
		ATOKAN				
		MORROWAN				
	MISS.	CHESTERIAN	PARADISE FORMATION			
		MERAMECIAN	ESCABROSA LIMESTONE	(COLOSSAL CAVE)	O	
		OSAGIAN				
		KINDERHOOKIAN				
	DEVON-IAN	LATE	MARTIN LIMESTONE		O	
	ORD.	EARLY	EL PASO LIMESTONE			
	CAMBRIAN	LATE	FRANCONIAN		O	
		MIDDLE	ABRIGO FORMATION			
			BOLSA QUARTZITE		O	
		EARLY				
	PRECAMBRIAN	LATE	PIONEER SHALE		O	
			RINCON VALLEY GRANODIORITE M		O	1.5 B.Y. RADIOMETRIC AGE-DATE
		MIDDLE				
		EARLY				

O - FOUND WITHIN COLOSSAL CAVE MOUNTAIN PARK

M - ILLUSTRATED ON STUDY AREA-GEOLOGY MAP

* - AFTER BRYANT 1968, DREWES 1977, KRANTZ 1983, DICKINSON 1991, RICHARD & HARRIS 1996.

AGS Field Trip 19 February 2000

Descriptions of Major Rock Units:

In order to understand the effects of these three events, it is first necessary to describe the rock units that are present in the area. The sole geologic map with the necessary detail to encompass the entire study area is that of Drewes:1977. It provides the basis for the descriptions of the major rock units below, the designations in the Colossal Cave Mountain Park Geologic Units Table (Figure 9), and the generalized geology portrayed in the Study Area Geology Map (Figure 10). Additional information comes from Bryant:1968, Krantz:1983, Dickinson:1991, and Richard and Harris:1996.

The Geologic Units Table lists all of the rock units found in the Park; and the Study Area Geology Map portrays only the six major age-groupings of rocks.

The descriptions presented below singles out those rock units in the study area that are visually dominant or of special importance:

Rincon Valley Granodiorite:

The Rincon Valley Granodiorite has been radiometrically age-dated from area samples at **1.45–1.56 ± .05 billion years.** It is the oldest rock type in the study area. Coming from the upper (youngest) Precambrian period, it is a massive, medium-grained biotite granodiorite which usually exhibits a chloritic (iron) light- to medium-greenish cast and a crystalline texture with a salt-and-pepper appearance. It is unmetamorphosed but has been highly fractured. It forms the surface rock west of Pistol Hill along the northwest boundary of the Park, and also is a prominent rock type along sections of the Agua Verde Creek bottom.

Pioneer Shale:

The second oldest rock type found in the Park also comes from the upper Precambrian sequence . The Park exposures have been further metamorphosed to a massive dense form called **argillite** that lacks the textural fabric of either a shale or a slate. This is undoubtedly due to its long geologic history. Although the Pioneer is only found in the Park at a few limited exposures along the Agua Verde Creek channel, it has characteristic and unique black spotting that makes it one of the most distinctive rocks of the Park.

Bolsa Quartzite: The early to middle Cambrian Bolsa Quartzite of the earliest Paleozoic Era is another very distinct rock type. It bears diagnostic purple and white striping—the relict slipfaces of metamorphosed sandstone deposits. The "mature" sands were composed largely of iron (purple) and silica (white) grains that now form weathering-resistant dense rocks. The exposures of Bolsa in the Park form an irregular east-west band of occurrences in the hills bordering the north bank of the Agua Verde. Here they are highly fractured due to the proximity of major faults. Because of its great resistance to weathering, it is also commonly found in the Park as an element of erosional **lag deposits** where it has been stranded as other, less resistant units have weathered away, or as **float** where it forms a long-term, well-rounded, and distinctive addition to canyon bottom rock debris.

Abrigo Formation: The middle to late Cambrian Abrigo Formation immediately succeeds the Bolsa Quartzite in the early Paleozoic Era. In the Abrigo, sequences of channel silts and sands are interbedded with limestones of shallow tidal deposits in thin beds that usually form covered slopes in the Park. However, one member of the formation stands out. Its upper beds weather to an unusual "corrugated" surface. Alternating layers of relatively durable silts and sands (creating ridges) and relatively soft limey sediments (creating troughs), make them stand out among Park geologic units and make identification straightforward.

The local Abrigo is also of special importance to the science of geology because it contains index fossils from the Cambrian Period. These link the Abrigo in the area to a specific time period during the history of life on earth and link it with other, similar deposits both in the southwest and elsewhere (for example, fossil **trilobites** and **hyoliths** from the Abrigo in the Park are similar to those found in the famous Burgess Shale fossil locality of western Canada).

The limited exposures of the Abrigo in the Park are arrayed similarly to those of the Bolsa and are usually in contact with it on its north. The Abrigo is generally seen in the hill terrain south of an east-west line running through Colossal Cave.

Paleozoic Limestones (undivided): An undivided series of generally grey Paleozoic Era limestones and a few other formations make up the remainder of the Paleozoic from the Devonian through the Permian Periods. From oldest to youngest, these are the **Martin, Escabrosa, Horquilla, Earp, Colina, Epitaph, Scherrer, and Concha.** With the exception of the Mississippian Escabrosa limestone, most of these units have been so compressed, dilated, fractured, faulted, folded, and overturned during the millions of years since they formed that they are no longer identifiable without detailed examination. Even their guide fossils (solitary & colonial corals, brachiopods, bryozoans, crinoids, fusilinids, and others) have usually been broken into pieces or distorted to a degree that they, too, are no longer specifically identifiable. And so, they are described here together.

The Escabrosa Limestone is the most easily identified and visually prominent limestone in the Park due to its great thickness; this also makes it the greatest cliff-forming limestone. Most of the other Park limestones are relatively thin-bedded in comparison. In contrast, the Escabrosa's thick beds give it the mechanical strength to maintain large cave passages once they have formed—which makes the development of Colossal Cave in the Escabrosa more than coincidental.

Taken together, these "later" Paleozoic rocks (especially the limestones) form most of the prominent features—the rugged hill, mountain, and canyon topography—in the study area. In addition to the cliff-forming attributes of the Escabrosa, any views across the Park towards the distant backdrop of the Rincon Mountains are framed by mountain and canyon slopes that display faulted and folded beds of the Paleozoic limestones. From their northernmost exposures at the northeast of the Park, the Paleozoic limestones form two broad swathes of grey bedded slopes, ledges, and cliffs that continue southwest along either side of Posta Quemada Canyon, cross the Agua Verde Creek drainage to encompass the Agua Verde Hills, and terminate along the north side of the Cienega Creek bottomland.

Wrong Mountain Granite:

The Wrong Mountain Granite is an early Tertiary Period intrusive body (pluton) of granite which was later metamorphosed into mylonitic (a type of penetrative texture or fabric) gneiss at its faulted contact (the low angle Catalina Fault), with cover rocks of the Paleozoic described above.

Though the nearest exposure of the Wrong Mountain Granite is beyond the Park boundary to the northeast, it represents a major element of the area's geologic history, in that it is "connected" to the Park by movement on the Catalina Fault. In addition, the Wrong Mountain Granite makes up most of the distant backdrop slopes below Rincon Peak at the skyline. From the summits of peaks in the northern and eastern reaches of the Park, the contrast of bedded upper carapace rocks above the fault plane with the light granitic rocks upslope but below the fault plane marks their contact at the Catalina Fault.

Erosional debris from Wrong Mountain Granite is a major constituent of the canyon bottom alluvial deposits in the Park, due to its dominance in the terrain upstream and its durability relative to other rock types.

Pantano Formation:

The highly noticeable and extensive Pantano Formation of the mid-Tertiary Period is comprised of the most diverse group of rock types in the Rincon Mountains. Included in it are units of sedimentary & metamorphic breccias, conglomerates, sandstones, lake bed limestone & clay deposits, intrusive andesite, and extrusive basalt & rhyolite tuff. Within the Park a red breccia and an andesite are of particular interest, for their visual impact and hydrological importance, respectively.

The Red Breccia:

Second only to the Paleozoic Limestones in visual impact in the Park is the informally named "siliceous red breccia." It is the metamorphic result of the melting of the Bolsa Quartzite under heat and pressure and its reconstitution as a "composite" rock consisting of a silica-rich and iron-stained groundmass (matrix) embedded with angular pieces of other rocks (clasts) that together form a breccia. The hot and flowing matrix could only escape upward from a fault zone through major vertical fissures in the various cover rocks. As it ascended, it tore off pieces of whatever rock types were at hand and incorporated them as its clasts. Therefore, the same matrix bears different clasts when seen at different localities within the Park and so the overall appearance of the Breccia varies from place to place. From pebbles to boulders, pieces of the "pure" silica quartz and iron matrix are seen as startlingly bright red rocks that sparkle from the reflecting faces of tiny quartz crystals.

Just east of Colossal Cave, one of the great vertical (tear fault) fractures has fostered erosion to form Posta Quemada Canyon. There the siliceous red breccia forms massive abutments at the canyon portal and is also seen as red masses at irregular intervals on the canyon slopes. Additional exposures of this breccia form portions of Pistol Hill, the low hills along Old Spanish Trail in Rincon Valley, and various hills along Agua Verde Creek.

The Andesite:

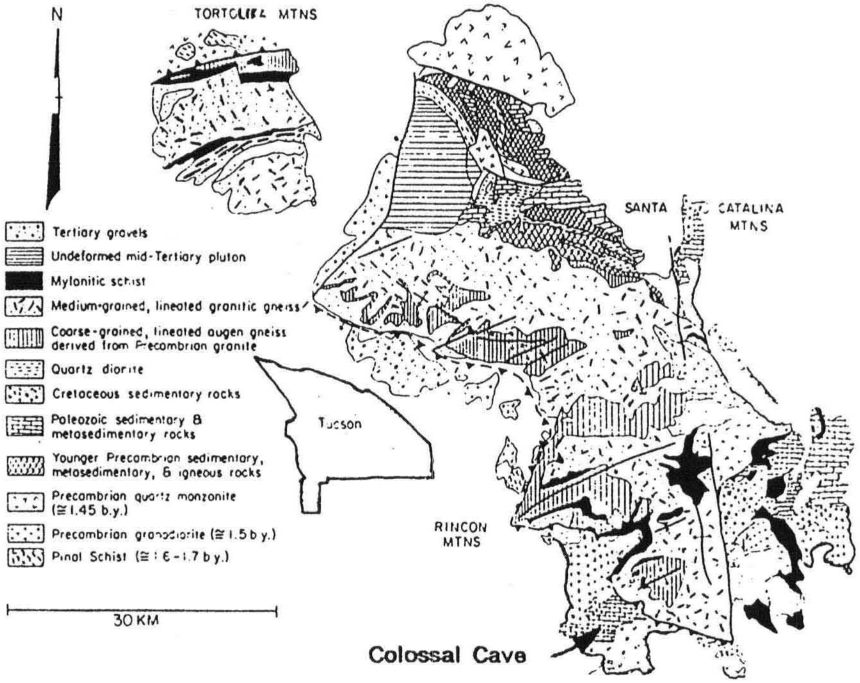
A different and unobtrusive element of the Pantano Formation, although quite limited in area, is quite important to the hydrology, vegetation, and wildlife of the Park. This is a radiometrically dated (24 m. y. a.) intrusive rock that is locally known as the "Turkey Track" andesite. The fortuitous intrusion of a volcanic dike of andesite straddles the path of the the Posta Quemada drainage just above its confluence with Agua Verde Creek and just below a major semi-permanent spring on La Posta Quemada Ranch, The top of the intrusion forms a dam that impounds the spring's flow to form the Posta Quemada cienega/riparian area. In addition to its importance for vegetation and wildlife, this surface water source attracted use first by the Hohokam Indians, followed by the Apaches and Spanish; 19th-century Americans used it as a stagecoach stop and watering point; and throughout the 20th century it has served as a ranch headquarters.

Quaternary Alluvium:

The Quaternary alluvium is a series of deposits from the latest geologic period, the Quaternary, which includes the present time. It is the youngest geologic deposit in the Park and study area. For the most part, its various silt- to boulder-sized sediments are unconsolidated as they form scattered lateral benches along drainages and form the channel bottoms themselves. However, some deposits display light-colored white caps, layers, and lenses of hardpan (caliche)—due to the arid desert climate, carbonate weathers from rocks (especially the limestones!) in solution and is redeposited near the surface.

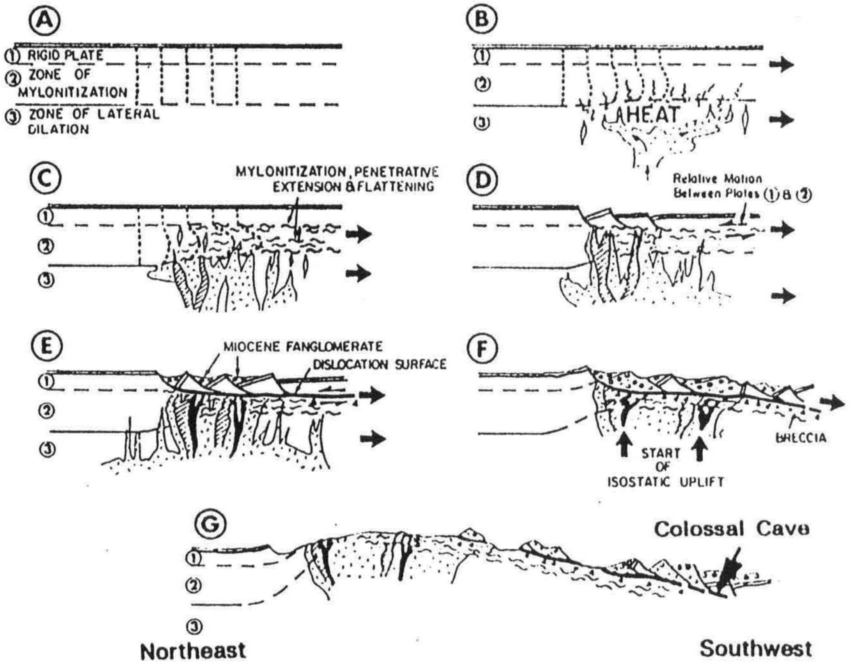
Even though these Quaternary deposits do not form the most impressive portions of the scenery, they are a large percentage of the total material underfoot in the area. This is especially the case for the borders of the study area to the west and south, the benches flanking the major drainages, and most of the channel bottoms of nearly every large drainage. It is in the canyon, wash, and arroyo bottoms where much of the travel from place to place is confined in such rough topography. And so it is at exactly those places and at the human scale where the Quaternary alluvium, composed of all the other area rocks, makes its presence known through myriad sizes, shapes, colors, patterns, textures, and degrees of weathering.

Development of the Tertiary Metamorphic Core Complex



Generalized structure map of the Rincon–Santa Catalina–Tortolita complex. Adapted and interpreted from the maps of Banks (1974), Creasey and Theodore (1975), Drewes (1975, 1978a), Davis and others (1975), and Banks and others (1977).

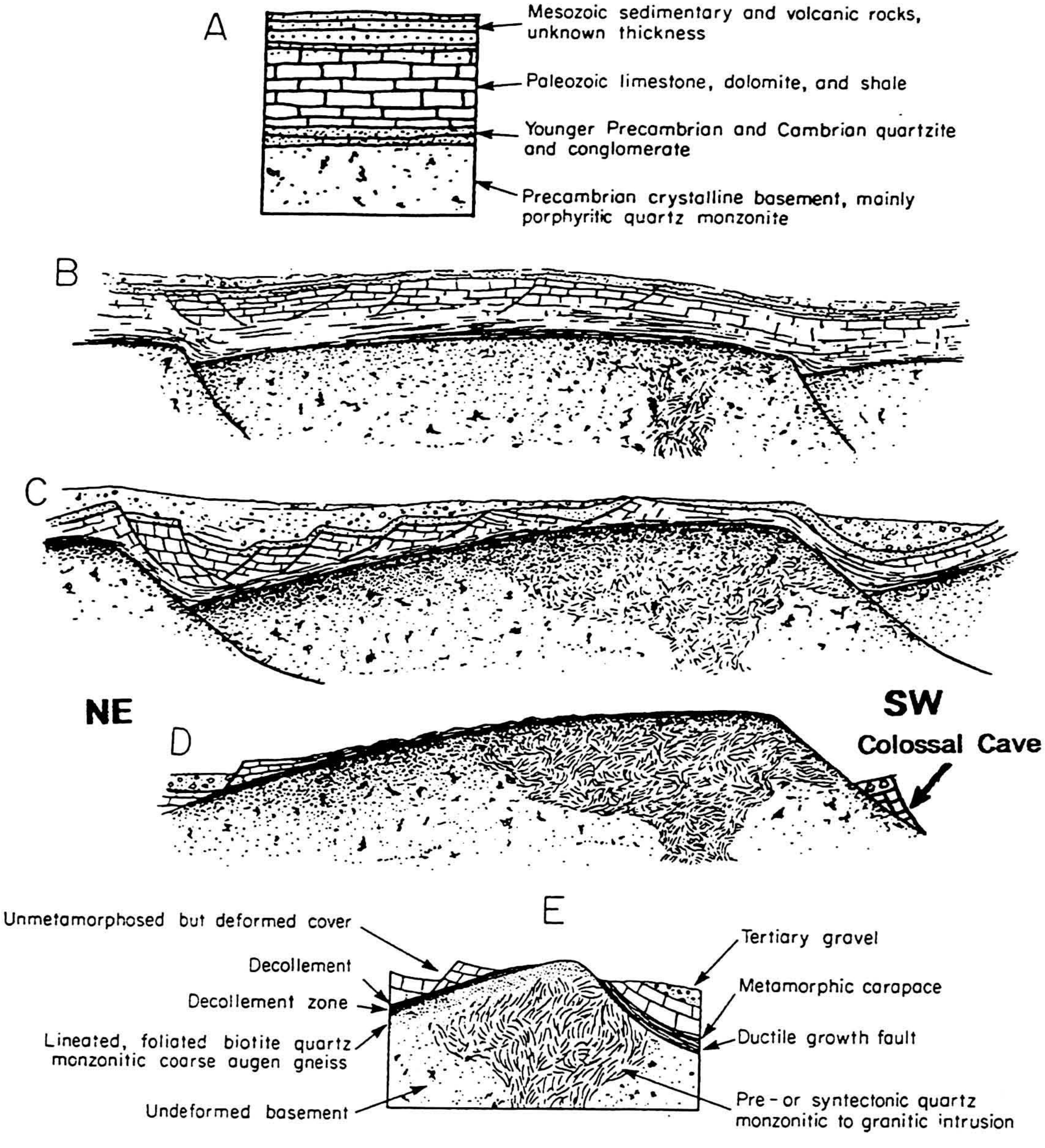
Davis, George H., 1980. GSA Mem.153



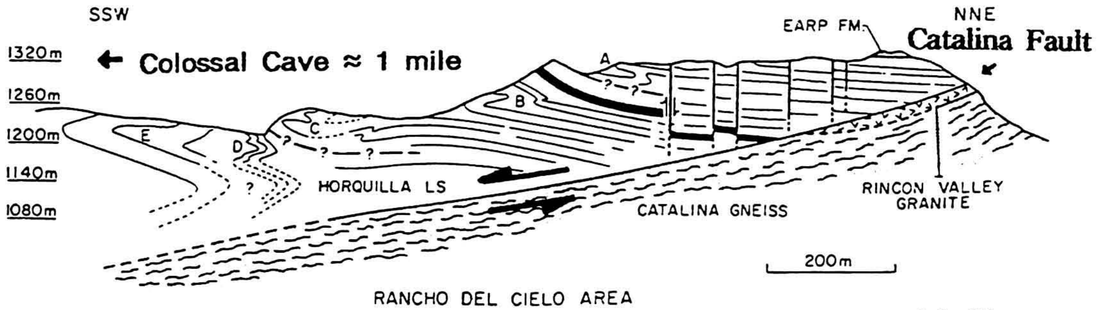
Model for Tertiary evolution of metamorphic core complexes. (A) Concept of three crustal layers, each responding distinctly to Tertiary heating and tensional stress. (B) Magma emplacement and east-northeast-directed extension initiate necking (stretching) in zone 2. (C) Continued extension in zone 3 leads to tensional separation and intrusive dilation; mylonitization develops in more ductile zone 2. (D) Differences in response to crustal extension between zones 1 and 2 create differential strain and fragmentation of rigid plate. (E) Continued differential strain between zones 1 and 2 and dissipation of heat creates the dislocation of surface and further rotational faulting of upper-plate blocks; rapid fanglomerate-breccia accumulation within fault-bounded troughs; clasts mainly from nonmylonitic plate 1, but exposure and erosion of mylonite zone may occur locally. (F) As tectonic denudation proceeds, area of maximum thinning responds to removal of zone 1 by isostatic uplift and deformational thinning in zone 2. (G) Present configuration of complex.

Rehrig, William A., and Reynolds, Stephen J., 1980. GSA Mem.153

Davis, George H., 1980. GSA Mem.153



Generalized tectonic reconstruction of the geologic evolution of metamorphic core complexes.



Cross section of decollement zone and upper plate rocks on the southern flank of the Rincon Mountains (from Davis and others, 1974).

General Features of the Study Area Limestone Terrain:

In addition to the attributes of Colossal Cave, there are other characteristics that are only found in the study area's limestone terrain. These features manifest themselves at different scales, from noticeable to quite subtle.

At the panoramic scale, the highly folded limestone beds not only display interesting colors and textures, they literally create the shapes of the mountainsides, cliffs, and canyons through weathering processes which only they undergo. The pervasive fracturing and faulting of the limestones allows chemical weathering to enlarge soluble zones into countless cracks and crevices, which promote infiltration of rainfall and reduce runoff. In turn, this minimizes slope wash and the kinds of mass movements that tend to widen valleys and reduce the steepness of their slopes.

Stream cutting, on the other hand, is enhanced in limestone terrains because their channel bottoms are more easily dissolved and abraded than those of most other rock types. The result can be steep-walled canyons with denuded slopes such as that which has developed in the Park along Posta Quemada Creek. The rapid drainage and high infiltration rates which promote the development of steep slopes also work to produce thin soils that are exposed to intense sunlight in desert climates.

La Posta Quemada Canyon
↓
Agua Verde Creek
↓
Cienega/Pantano Creeks
↓
Rillito Creek
↓
Santa Cruz River
?
Gila River
↓
Colorado River
↓
Gulf of California

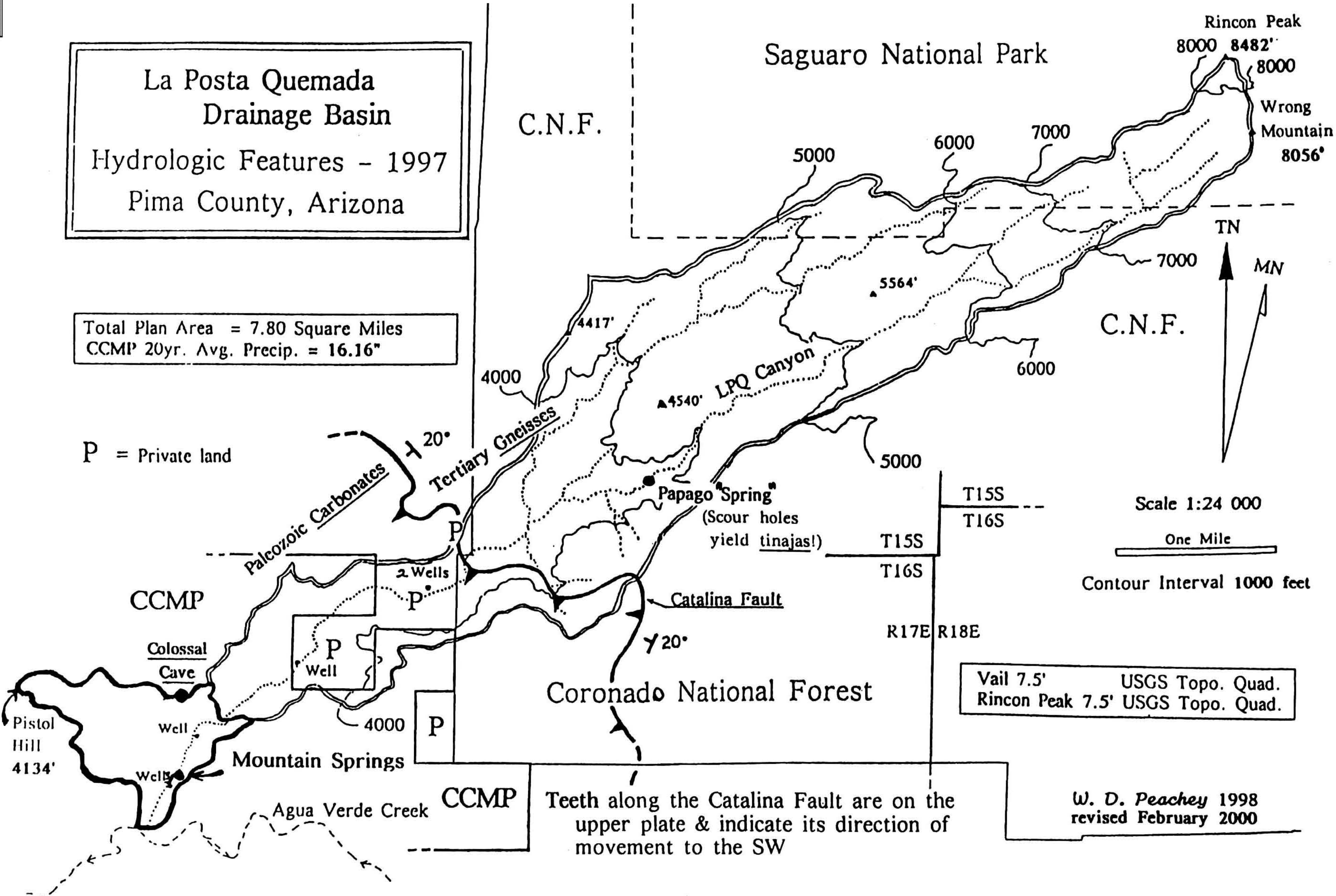
These factors interact to create poor conditions for many plants, so the canyon walls are usually sparsely vegetated in comparison to their bottoms. However, some characteristic desert plants, such as Saguaros, Ocotillos, Agaves, and Foothills Paloverdes, find the anchorages on these slopes and the lack of competition to be much in their favor.

At the landscape scale, these conditions in the Park offer the sole Tucson Basin example of a desert limestone terrain that typifies many regions worldwide. At the human scale, the Park limestones show other features which are also found in such terrains worldwide.

La Posta Quemada Drainage Basin

Hydrologic Features - 1997

Pima County, Arizona



Total Plan Area = 7.80 Square Miles
CCMP 20yr. Avg. Precip. = 16.16"

P = Private land

Scale 1:24 000

Contour Interval 1000 feet

Vail 7.5' USGS Topo. Quad.
Rincon Peak 7.5' USGS Topo. Quad.

Teeth along the Catalina Fault are on the upper plate & indicate its direction of movement to the SW

W. D. Peachey 1998
revised February 2000

Note:
- The unusual linearity of this drainage basin
- The change in the drainage pattern across the Catalina Fault
- The change in the basin width across the Catalina Fault

Karren and Arêtes:

Solutional weathering on the various limestone surfaces creates extensive areas of unusual visual and physical textures in the Park. Tiny channels form patterns on sloping limestone surfaces where the carbonic acid in running rainwater has sculpted the rock faces. Often, these are linked into chains of tiny scalloped troughs bordered by sharp edges. Where two, three, or more of these solutional pockets meet, sharp points often form, and the channels become lined with serrations.

On highly fractured surfaces, the trickling rainwater may follow the cracks, concentrating the power of the acid, and developing deep v-shaped grooves with wandering lines of knife-edged ridges separating them. In general, the many and varied forms of this patterned weathering are termed karren. The sharp points are called arêtes. Although visually interesting, the extreme sharpness makes karren-covered limestone second only to lava fields in its damage to footwear and its ability to injure those unlucky enough to take a fall upon it!

Kamenitzas:
(Dissolution Pans)

There may be found at a few scattered locations in the area an equally interesting but non-hostile form of weathering. Never common on horizontal surfaces of limestones, these features are wide, shallow circular-shaped pools that have been formed by rainwater dissolving the rock at a ponding point. These kamenitzas often widen in such a way that they develop overhanging rims except at their overflow points. While karren are to be found on most limestone surfaces that have been exposed to weathering, kamenitzas are very rare due to the special circumstances needed for their development and the great length of time (even in wet climates) that it takes to create them. Only a handful have been noted in the Park. Most of these strange pools are at best a few inches in depth and may reach a few feet in diameter; thus they provide a limited resource for wildlife for only a short period following rains. Research on their growth rates in an arid environment may one day yield information about the erosion rates in the Sonoran Desert landscape.

Solution tubes: Another common feature of the Park's limestone terrain is the **solution tube.** These holes range in size from tubules so small that they are barely visible to those nearly man-sized in diameter. They represent an advanced state of weathering of the rocks in which they are found, as they are the conduits formed by waters that have dissolved and enlarged pathways over time. Starting as tiny tubules that commonly follow partings or weaknesses in the limestones such as fractures, joints, faults, and bedding planes, they may enlarge or merge with one another to reach sizes that can border on admitting passage by humans. They are often found spaced along fractures or bedding planes and are seen to follow the inclinations of those structures. Solution tubes formed at different attitudes under water. Today, exposed and no longer filled with groundwater, they conduct rainwater from the surface down into the limestone, and thus can continue to enlarge.

Many open solution tubes become living spaces and foraging habitat for a large variety of invertebrate species. Small to medium-sized vertebrates—from amphibians through mammals—also take refuge in them, converting what appear to be bare rock surfaces into vast three-dimensional apartment blocks. Solution tubes choked with debris collect soils and provide shade. Those that retard the downward path of moisture may become "planters" for various cacti, shrubs, and other plant life. A percentage of the solution holes in the Park contribute rainwater to the larger, humanly enterable spaces that are known as caves. The water carried by these tubes may release the acidifying carbon dioxide gas which it picked up in route through the subsurface and thereby deposit the calcium carbonate of cave formations.

Stylolites and Veins: Two other kinds of features, **stylolites and veins**, the first uncommon and rarely recognized for what it represents and the other so common that its significance is not appreciated, are found in the area's limestones. They are features that affect the surface textures and visual appearances of the limestones and that also reveal processes which the rocks have undergone.

Stylolites are wavy graph-like lines, usually of low amplitude, which may be seen on bare limestone surfaces or that commonly form the boundary between limestone beds. They are the trace evidence for losses in volume that bodies of limestone rock have undergone due to great pressure. With enough pressure, **calcite**, the major mineral of limestone, can go relatively easily and directly into solution and by flowing away from the area of pressure cause limestone to lose volume. The stylolites are the lines that form where the interfaces of these limestone masses dissolve against one another. Because of the overall pressure upon the entire volume, the limestone itself is often metamorphosed into marble and so stylolites are often seen in marble.

The calcite of the limestone that has been pressured into solution must go somewhere. As the calcite flows to an area of reduced pressure where it can crystalize into a solid form again, it has reduced the volume of the rock mass at its original location. In a new location, it may force its path into fractures in other rocks that are under less pressure where it can solidify to form a calcite **vein**. The vein increases the volume of the rock at the new site. Veins of diferent colors may indicate the addition of other minerals and/or may indicate different episodes of veining.

Cave Definitions

Cave - A humanly enterable underground space which attains total darkness*

Shelter Cave - A feature whose mouth is greater in width than the distance to its back

*The definition currently accepted by the National Speleological Society

Rock Types & Forms of Arizona Caves

Ranked by
Relative Abundance

Limestone(COLOSSAL)
Sandstone
Lava(tubes)

These three
Form the vast majority of
Arizona's Caves!

Other **Igneous Rocks** - Granite, Rhyolite, etc...
Tectonic Fissures - Fractures in various rock types
Breccia Pipes - strange mineral emplacements
Soil Piping - caves & features in dirt!
Tafoni - Surface weathering of rocks
Gypsum - Only one known...

Speleology & the Formation of Caves

Introduction: Speleology is defined as the scientific study or systematic exploration of caves. The aspects of speleology that we will take up here are spelogenesis: the origin or creation of caves, and speloethems: cave formations or decorations.

Speleogenesis: One of the most notable weathering processes that can take place in a mass of limestone occurs hidden from view—the process of cave development or speleogenesis. Worldwide, **caves are defined as humanly enterable underground spaces which achieve the condition of total darkness.** The process of their creation generally refers, but is not limited, to various methods of enlargement of cavities and pathways within volumes of limestone rock by the solutional (chemical) weathering of **calcium carbonate** ($CaCO_3$). And, although other processes and rock types may develop caves, it has been by the solutional weathering of limestone that cave features have formed in the study area.

Epigenic Cave Formation: According to recent surveys (Palmer:1991), about 90% of the world's known limestone caves formed at relatively shallow depths (100s to 1000s of feet—rather than miles—deep) due to the dissolving action of cool acid-laden surface waters' downward penetration of carbonate rocks. In fact, for most of this century this **epigenic** process was the method most speleologists favored for nearly all cave development (Shaw:1992).

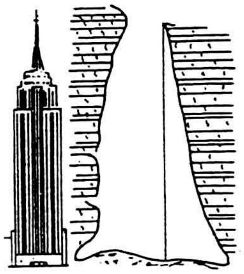
Hypogenic Cave Formation: However, in recent decades, detailed studies enabled by new and more precise techniques have revealed that many of the world's largest caves have formed at depths beyond the influence of rainwater descending from the surface. An estimated 10% of limestone caves formed at relatively greater depths due to hot acid solutions rising from below—this is known as **hypogenic** cave formation.

This is especially significant in the consideration of caves in the western U. S. where geologic events of the past 100 million years have fostered conditions that are particularily conducive to this type of cave development. Caves of world-class size and significance such as **Jewel and Wind Caves** in South Dakota, as well as **Carlsbad Caverns** and its newly-explored neighbor, the much larger and even more fantastically decorated, **Lechuguilla Cave** in New Mexico, owe their existence to the rising of acid solutions from below at deep sites of formation (Palmer:1991)

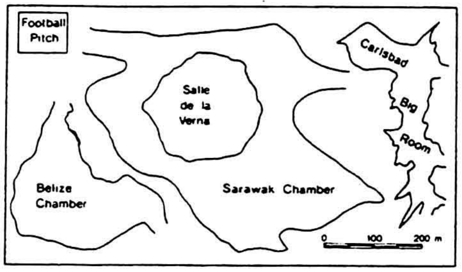
In southern Arizona, few studies by speleologists, beyond mapping of passageways, paleontology, or the study of bats, have contributed much information about this region's modes of cave development. However, historically, caves associated with mines (the Copper Queen Mine in Bisbee, the Glove Mine in Amado, etc.) have frequently been described by mining geologists as occurrences associated with the acidic conditions fostered by the invasion of ore-bearing solutions into adjacent limestones. Essentially, these are explanations of cave development that describe the deep acid-dissolving of the carbonate rocks—explanations that, for unknown reasons, have long escaped the attention of cave researchers.

About the Formation of Colossal Cave:

Similarily, for many decades, the cave features at **Colossal Cave** have been interpreted to have been the result of the relatively shallow percolation of acidized rainwaters whose pathways gradually dissolved progressively larger openings in the limestones of the area—epigenic cave development. The general path for these waters was thought to have been down off of the flank of the Rincon Mountains and through the study area's buried limestones towards lower points such as springs at the edge of the local basin (Brod:1987). The time frame in which this development was thought to have occurred spans an indeterminent period of time as early as the Pleistocene Epoch, which began 1.6 m. y. a.

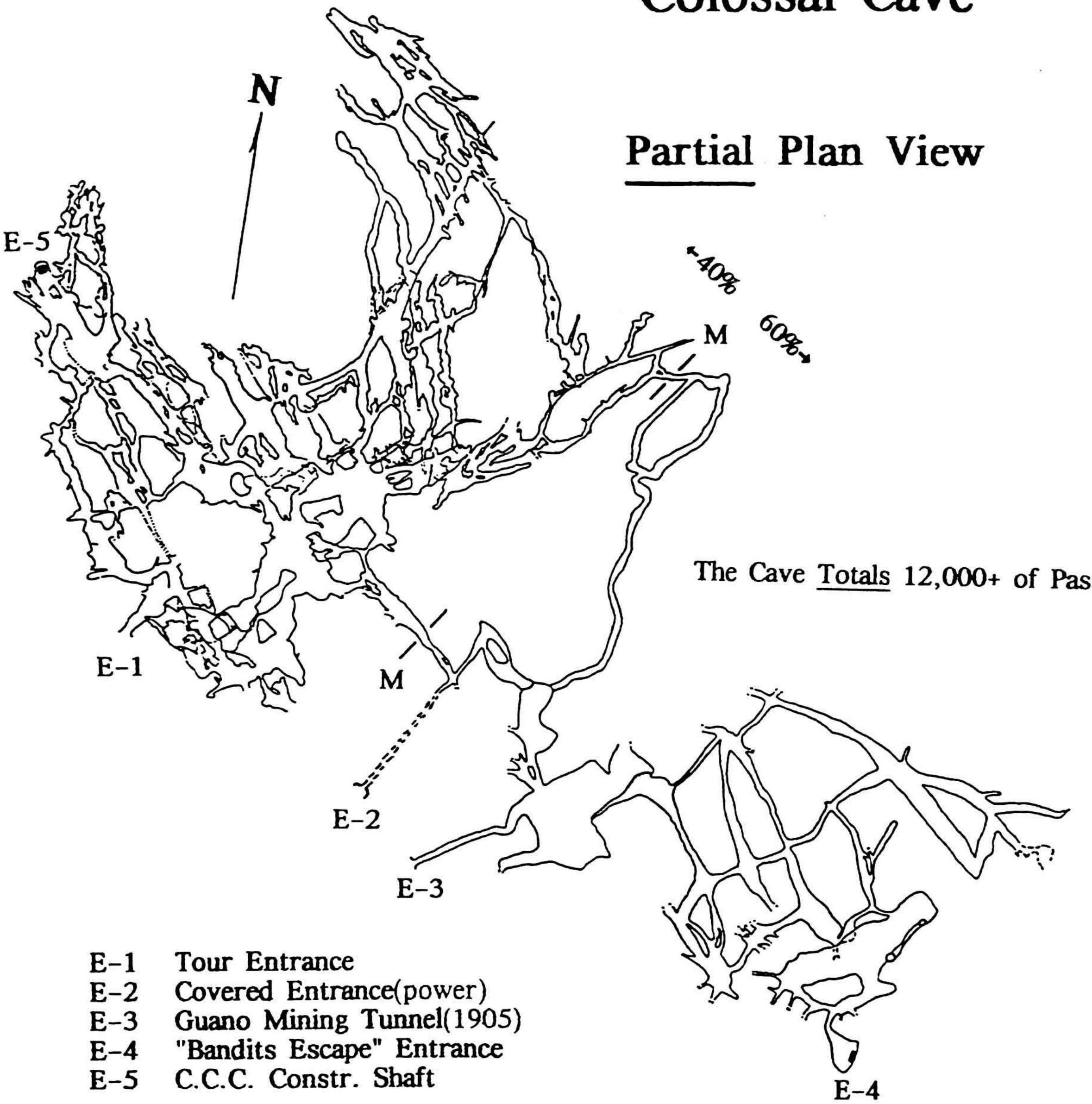


Examples of the largest cave chambers or rooms. Sarawak Chamber, Lubang Nasib Bagus (Good Luck Cave), Mulu National Park, Sarawak; Belize Chamber, Actun Tun Kul (Tun Kul Cave), Belize. Big Room, Carlsbad Caverns, USA and Salle de la Verna, Gouffre Pierre St Martin, France. The great shaft of El Sotano, Mexico, is compared to the 430 m Empire State Building, New York.



Colossal Cave

Partial Plan View



The Cave Totals 12,000+ of Passage

E-1	Tour Entrance
E-2	Covered Entrance(power)
E-3	Guano Mining Tunnel(1905)
E-4	"Bandits Escape" Entrance
E-5	C.C.C. Constr. Shaft

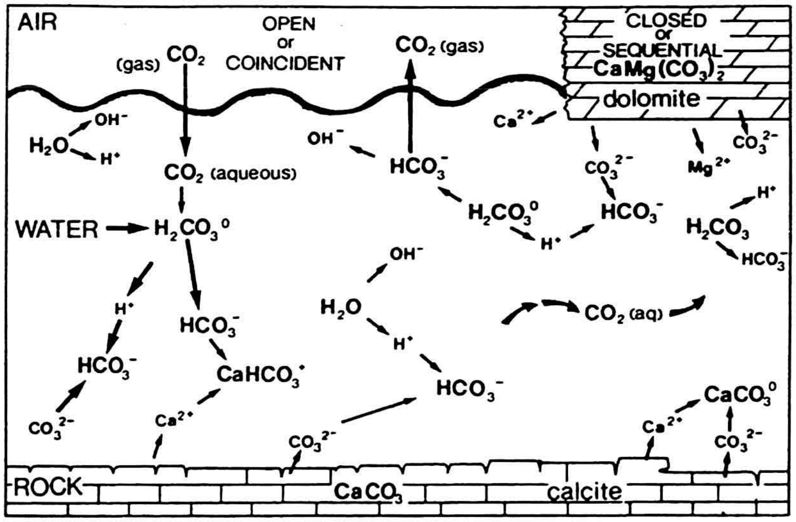
M Match line of Maps- Brod(1987)/UAAC Grotto(1965)

This map is the same as Plate 3, reduced to a scale of approximately 12 meters per cm., and is included to show the overall pattern of the cave

Brod, L.G. Geology and Speleogenesis of Colossal Cave, Pima County, Arizona. Unpub. M.S., Univ. Az., 1987.

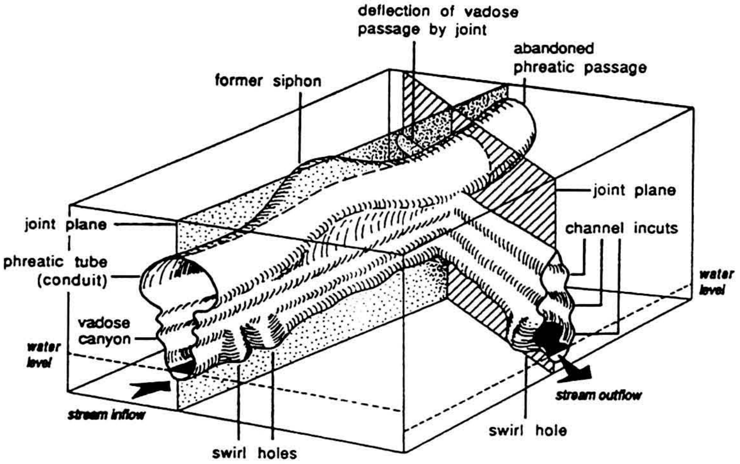
Vadose(Aereated zone) & **Phreatic**(saturated zone)
Karst Solutioning Processes

Epigenic Caves



Cartoon depicting the dissolved species and reactions involved in the dissolution of calcite and dolomite under coincident and sequential conditions.

....resulting passages



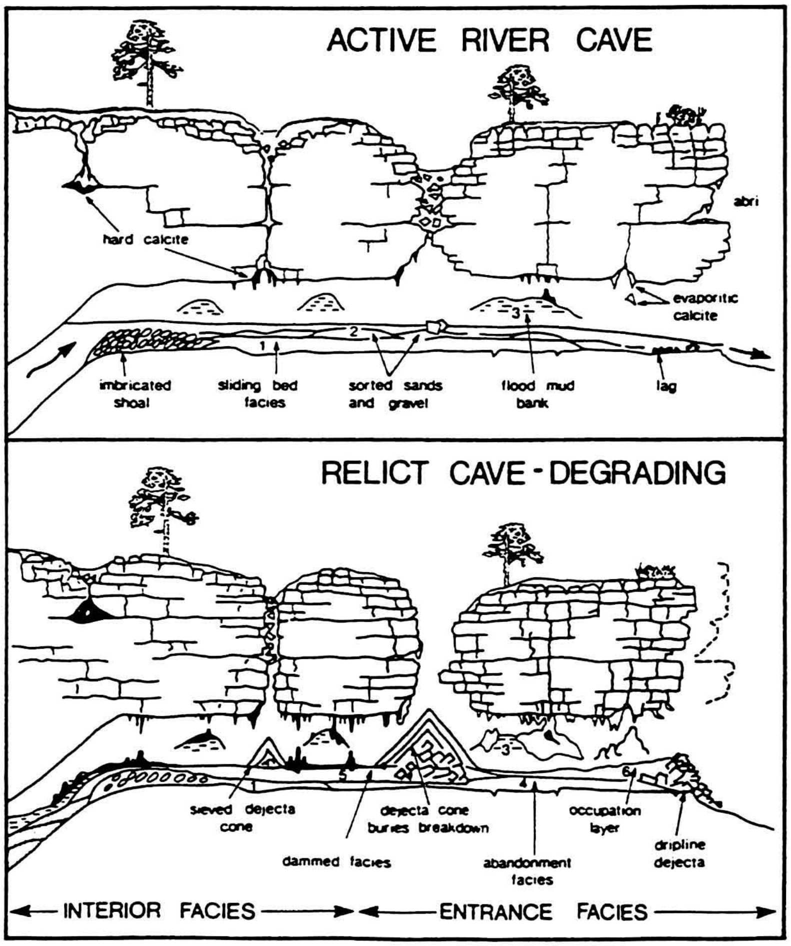
AGS Field Trip 19 February 2000

Cave interior deposits

"Late" Stage

Clastic, Chemical, & Organic Debris

Caves function as giant sediment traps, accumulating samples of the clastic, chemical and organic debris mobile in the natural environment during the life of the cave.



Model for the principal categories of clastic and precipitate deposits in hydrologically active or relict caves.

Later, subsequent erosion of the Rincon Mountain highlands northeast of the Park area shed materials into the Tucson basin and created canyons, which lowered the base level (water table). The lowering of the water table below the passages caused cave enlargement to cease and the process of infilling by formations (speleothems–see below) to begin. At some point (probably many tens of thousands of years ago) the erosion of the limestone containing the Cave exposed a series of entrances that allowed the great degree of air exchange with the surface we know today and caused Colossal Cave to become a "dry" cave.

New Findings About Colossal Cave Speleogenesis:

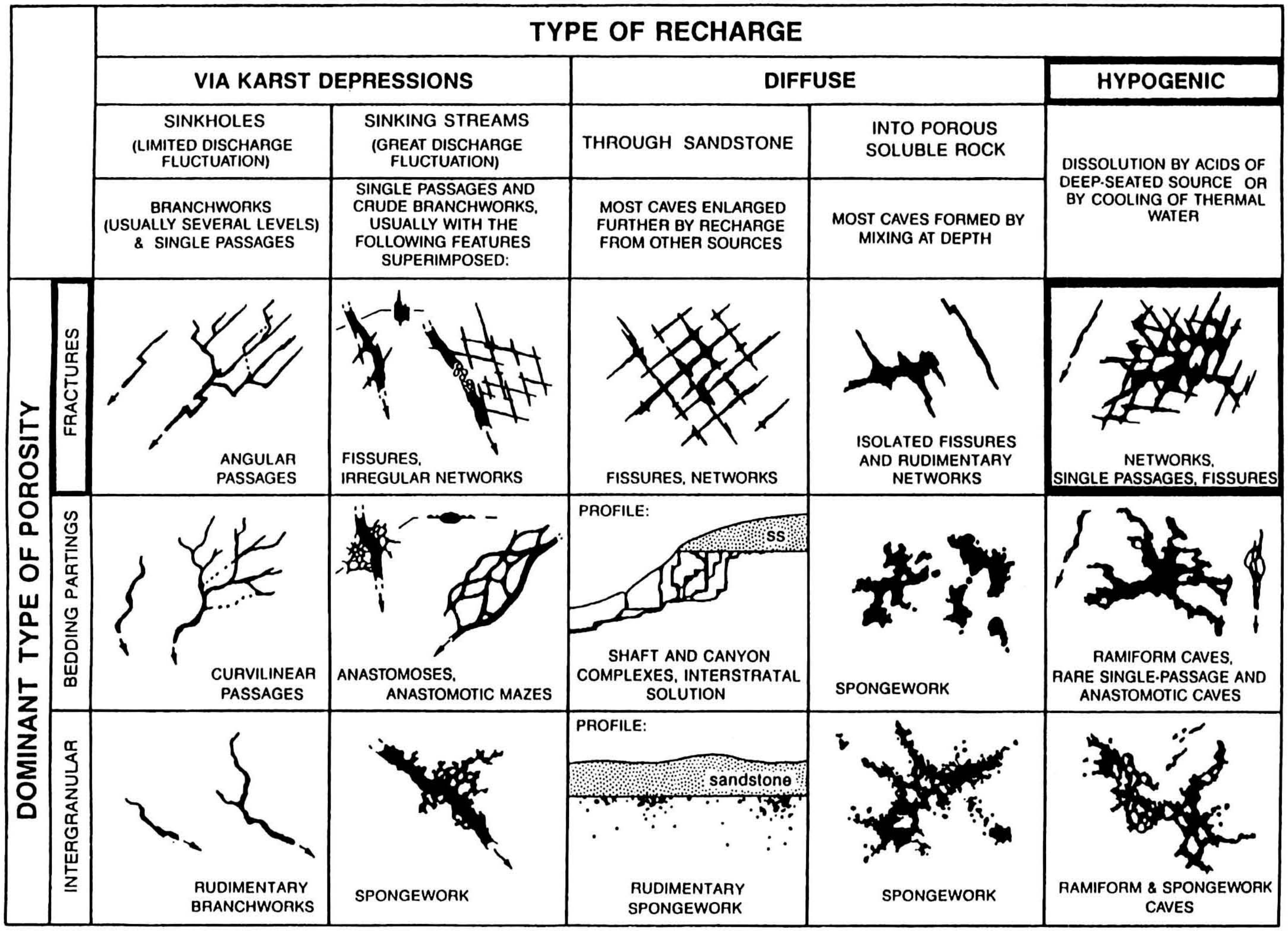
However, recent discoveries in Colossal Cave indicate that it was formed by the hypogenic process—deep formation by rising acid solutions—and place its time of development much further in the past.

A few large calcite dog-toothed spar crystals had been discovered in the course of earlier work in the Cave in the 1980s at one limited site in a tiny side passage. While calcite dog-toothed spar crystal has long been known to indicate hot solutional conditions (hydrothermal), their limited extent and numbers in the Cave were thought to be unimportant in the overall story of its development and the application of technical analysis was thought to be of little value.

Then, in late 1997, an extremely easy, yet accurate method of analysis of calcite crystals to determine the temperature at which they were formed was described in the second edition of *Cave Minerals of the World* (Hill and Forti:1997).

Normal cave calcite deposted by drip waters (cool) was long known to luminesce green after being excited by a common electronic photographic flash unit. A section in Hill and Forti described hydrothermal calcite—formed at or over a temperature of 60°C (140°F)—as giving off an afterglow of red when flashed. Not only did the few crystals in the one formerly known limited area of Colossal Cave glow red, but numerous heavily dissolved and barely recognizable crystal masses were found in extensive areas of the cave that glow red as well!

World Cave Passage Morphologies by <u>Porosity</u> & <u>Recharge</u> (N=4500)

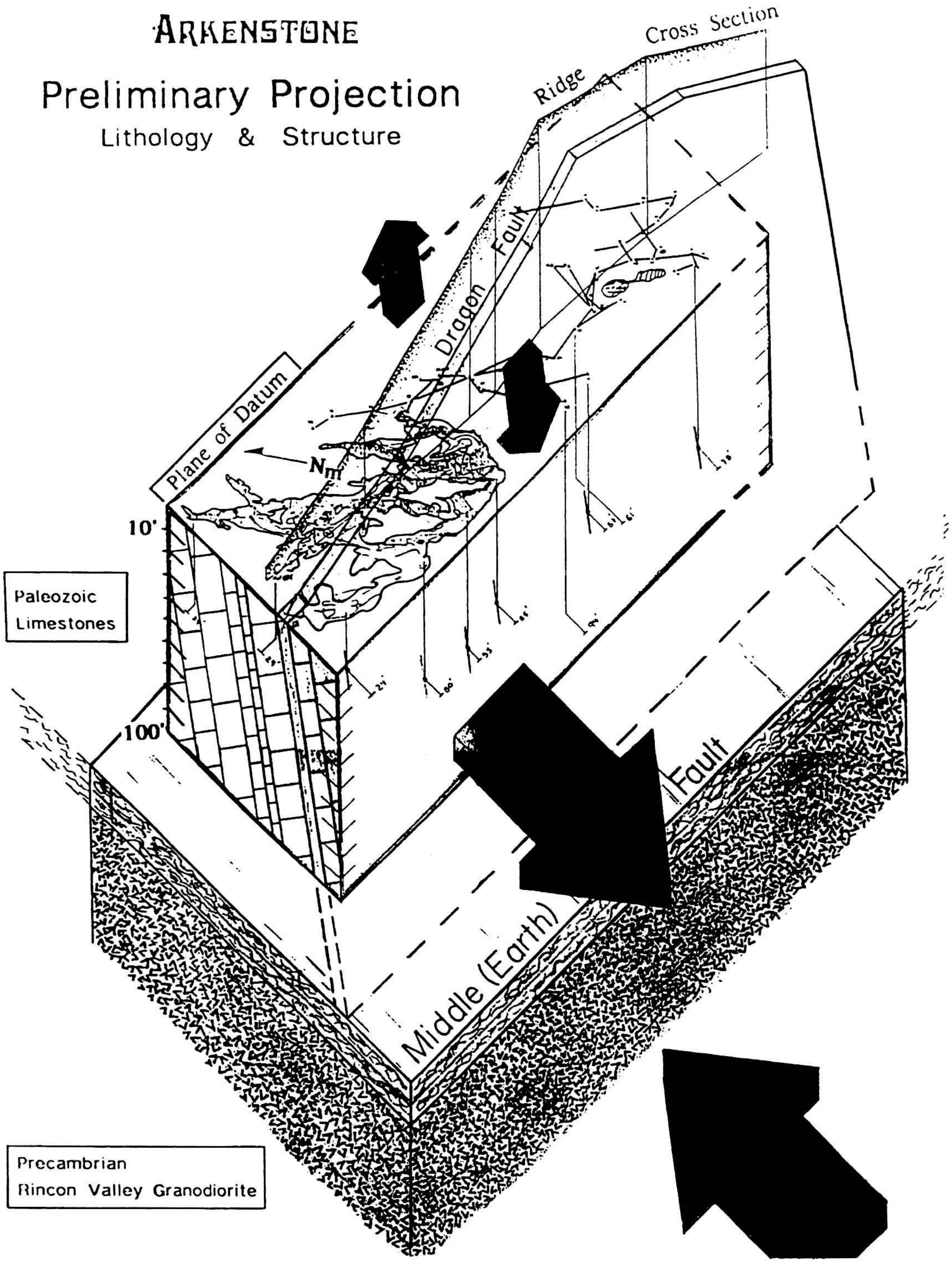


	TYPE OF RECHARGE				
	VIA KARST DEPRESSIONS		DIFFUSE		HYPOGENIC
	SINKHOLES (LIMITED DISCHARGE FLUCTUATION)	SINKING STREAMS (GREAT DISCHARGE FLUCTUATION)	THROUGH SANDSTONE	INTO POROUS SOLUBLE ROCK	DISSOLUTION BY ACIDS OF DEEP-SEATED SOURCE OR BY COOLING OF THERMAL WATER
	BRANCHWORKS (USUALLY SEVERAL LEVELS) & SINGLE PASSAGES	SINGLE PASSAGES AND CRUDE BRANCHWORKS, USUALLY WITH THE FOLLOWING FEATURES SUPERIMPOSED:	MOST CAVES ENLARGED FURTHER BY RECHARGE FROM OTHER SOURCES	MOST CAVES FORMED BY MIXING AT DEPTH	
DOMINANT TYPE OF POROSITY					
FRACTURES	ANGULAR PASSAGES	FISSURES, IRREGULAR NETWORKS	FISSURES, NETWORKS	ISOLATED FISSURES AND RUDIMENTARY NETWORKS	NETWORKS, SINGLE PASSAGES, FISSURES
BEDDING PARTINGS	CURVILINEAR PASSAGES	ANASTOMOSES, ANASTOMOTIC MAZES	PROFILE: SS SHAFT AND CANYON COMPLEXES, INTERSTRATAL SOLUTION	SPONGEWORK	RAMIFORM CAVES, RARE SINGLE-PASSAGE AND ANASTOMOTIC CAVES
INTERGRANULAR	RUDIMENTARY BRANCHWORKS	SPONGEWORK	PROFILE: sandstone RUDIMENTARY SPONGEWORK	SPONGEWORK	RAMIFORM & SPONGEWORK CAVES

Colossal
Arkenstone
} Rincons

Scroll — Catalinas

Palmer, A.N., 1991. Origin and morphology of limestone caves: Geol. Soc. Am. Bull., v.103, p.1–21.



Pseudo-isometric projection of the cave map into an idealized schematic block diagram of the lithological and structural domains of the cave ridge. The arrows represent the relative magnitudes and directions of movement of the various rock units as related by the Dragon and Middle(Earth) Faults.

This discovery provides a crucial piece of evidence that, with more studies, will probably one day provide an overall proof set to conclusively change the mode of cave development for Colossal Cave to one of probable deep origin due to upwelling hot acid solutions acting at great depth from the surface similar to those described above yet forming a "new" subgroup within the deep category.

In the short term, the finding pushes the age of development of Colossal back an order of magnitude—placing its probable time of formation sometime before 10 m.y.a. in the mid-Miocene Epoch!!! This is likely because the geological conditions for cave development by the hydrothermal mode seen in the Cave are known not to be present before or after that time window. From the present perspective all indications are that Colossal Cave is a "fossil" cave of great antiquity.

The much later history of infilling of the passages by speleothems after the ultimate drop in the local water table, exposure by erosion, and finally the development and effect of the Cave entrances remains the same.

Speleothems:

When the passages of a limestone cave grow, the speleothems (or cave decorations) are usually not present because of the corrosive nature of the solutions that are creating the expansion of the passages. Then when the source of solutions ceases, commonly through a local drop in the water table, air appears in the cave conduits. When air-filled passages appear in a cave, the first classic speleothems also begin to appear. While some cave mineral forms grow under water, most of the mass of speleothems found in limestone caves are made of calcite (calcium carbonate) and grow in the air.

Calcite-saturated mineral-bearing waters seep into the cave from sources that release carbon dioxide into the passages and thereby initiate the precipitation and growth of the calcite, in forms influenced by gravity as determined by where and how they appear in cavern spaces. For instance, water drops emanating from ceilings may initiate calcite growth at that point and proceed to grow a speleothem that hangs down and is commonly known as a **stalactite.** If the same drops fall to the floor, it may begin the growth of a typical **stalagmite.** Both speleothems have the potential to grow from the same source point on the ceiling but, due to different conditions prevailing in that particular spot and at that paricular time, one or the other or both may grow as a result. Calcite that grows upon a slope will often take the form of **flowstone**—the list of the various forms of calcite growth in caves is very extensive.

Gypsum:

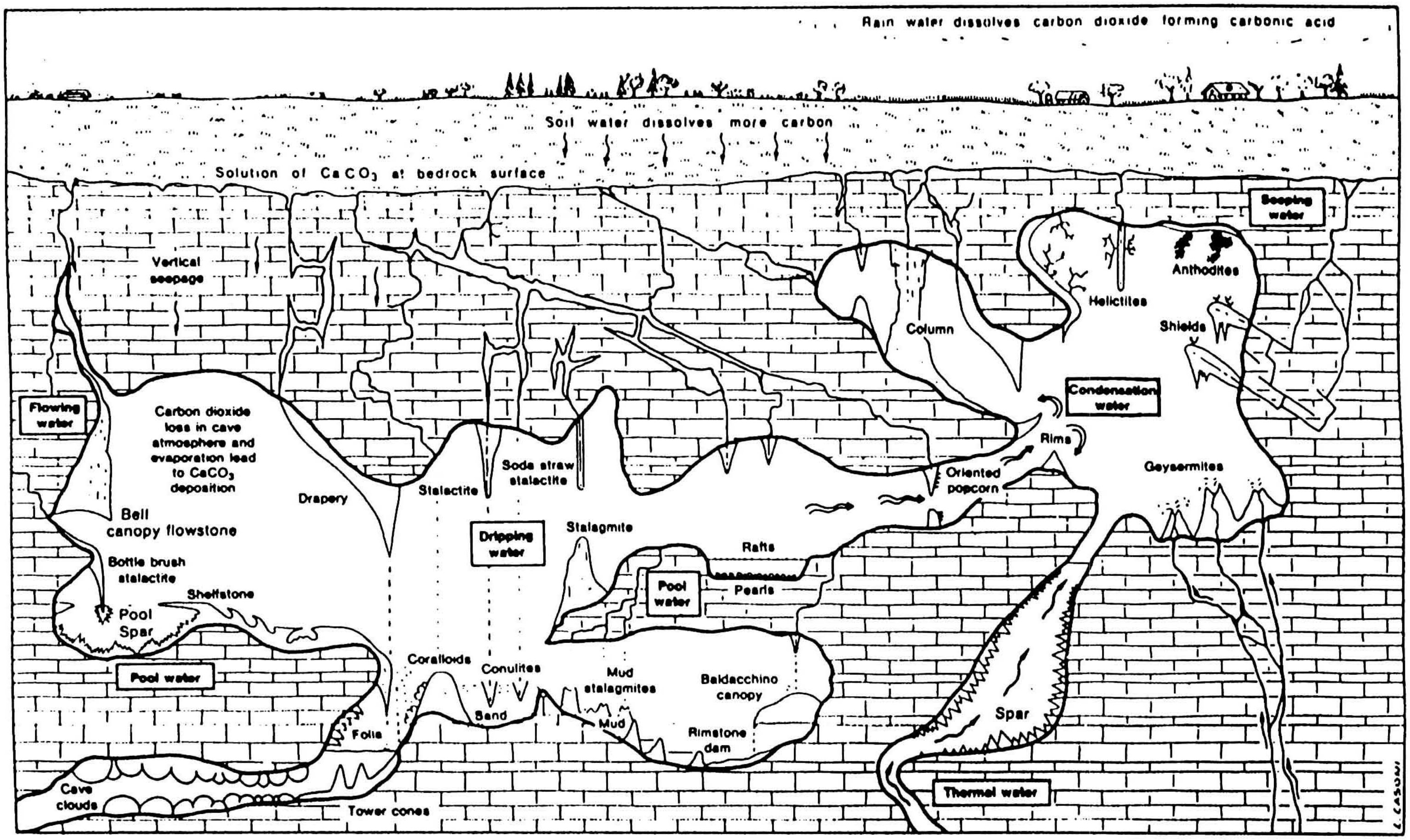
In addition to calcite, many other minerals may be found in caves. One of the most common minerals, possibly second in occurrence to calcite is gypsum (calcium sulphate). Very common in most U. S. and world caves, this mineral is relatively rare in southern Arizona caves. However, it is found in notable forms in the study area, and a tabular "rose" form has recently been identified in Colossal Cave.

Crystalline Urea and Biphosphammite:

Two mineral occurrences in Colossal Cave are of world note. They are **crystalline urea** and **biphosphammite.** These organic crystals have grown from bat guano in the extremely dry conditons of the Bat Roost area of the Cave.

Figure gives an overview of the speleothems and cave minerals that are known to occur or likely to occur in Colossal Cave Mountain Park sites, and ranks their rarity in southern Arizona, the U. S., and the world. No doubt, over time there will be a number of additions to this list.

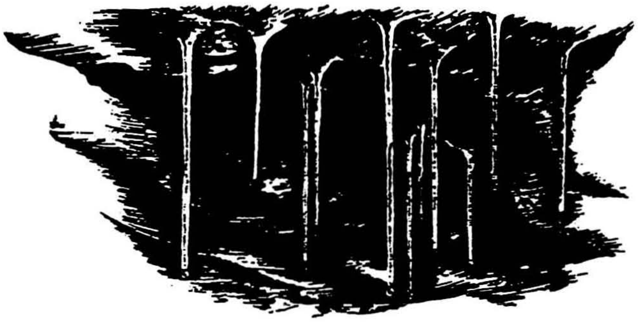
Common Types of **Calcite** and **Aragonite** Deposits (*Speleothems*) in Caves & Their typical Locations



Hill and Forti, 1986. Cave Minerals of the World, 1st ed.

Common Cave Formations

SODA STRAWS are thin-walled hollow tubes about a quarter of an inch in diameter. They grow as water runs through their centers and deposits rings of calcite around their tips. Occasionally they reach lengths of five or six feet.



STALACTITES form as mineral layers are deposited by water flowing over the outsides of soda straws. They usually form when the centers of the soda straws become plugged.

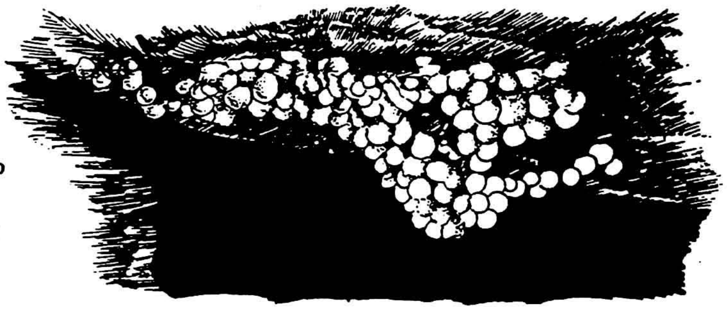
STALAGMITES grow up from the floor where mineral-laden water drips from above, generally beneath stalactites. In contrast to the pointed tips of carrot-shaped stalactites, the tops of stalagmites are blunt and rounded.

COLUMNS are formed when stalagmites meet overhanging stalactites, or when a stalactite grows all the way to the floor or a stalagmite all the way to the ceiling. Water flowing down the sides of the column gradually enlarges it by adding layers of flowstone to the surface.

Mohr, C.E. and Poulson, T.L., 1966. The Life of the Cave

[Coralloids]

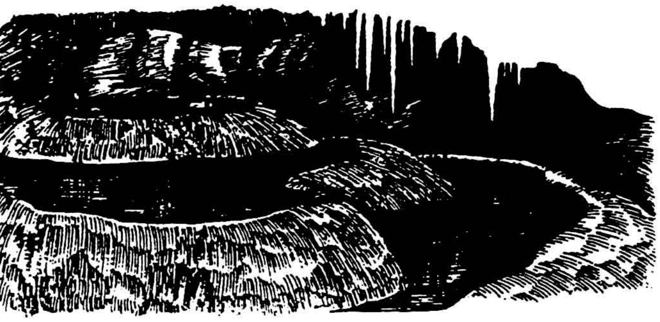
CAVE GRAPES are irregular clusters of rounded knobs of calcium carbonate. Also known as cauliflower, popcorn, and cave coral, they build up on walls and existing formations in flooded chambers.



DRAPERIES form where beads of water trickle down the undersides of inclined surfaces. As drop after drop flows along the same irregular course, a thin, often translucent sheet of calcium carbonate gradually extends downward, sometimes for several feet.

BACON FORMATION is drapery with alternating darker and lighter bands. These bands are the result of variations in the mineral content of the trickling water.

RIMSTONE DAMS often create steplike terraces along streams and on cave floors. Though generally only inches high, they occasionally build to heights of several feet and enclose sizable pools of water. Calcite is deposited when the water loses carbon dioxide as it flows over the lips of the dams.



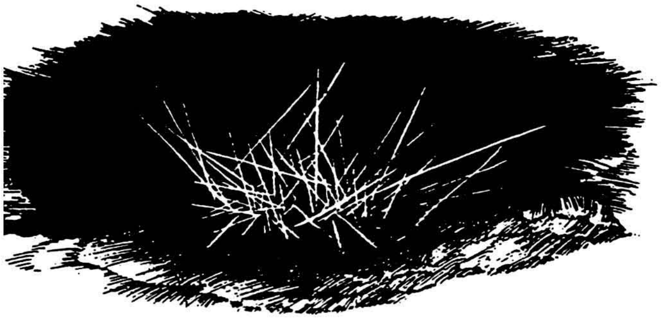
FLOWSTONE forms where films of water flow over walls, floors, and formations, depositing sheets of calcium carbonate like icing.

CAVE PEARLS, generally an inch or less in diameter, form around sand grains and other particles in pools where there is enough agitation from dripping to prevent the pearls from becoming cemented to the bottom. They slowly enlarge as layer upon layer of calcite is deposited.

[Agravitic]

HELICTITES are small twisted structures that grow from walls, floors, ceilings, and other formations. The contorted forms result from water seeping so slowly through minute central canals that calcite crystals form in irregular positions at the tips.

GYPSUM FLOWERS are found on the walls of many drier caves. They grow from their bases instead of their tips; each petal is pushed outward—sometimes a foot or more—as new crystals form at the bottom.



GYPSUM NEEDLES grow like fragile strands of glass from the sediment of cave floors. Eventually breaking as a result of their own weight, the delicate needles sometimes lie in jumbled heaps.

DOGTOOTH SPAR, large pyramid-shaped crystals of calcium carbonate, forms underwater in flooded chambers. In certain caves in the Black Hills of South Dakota, these crystals are as much as six inches long.

Working List - January 2000

COLOSSAL CAVE MOUNTAIN PARK

CAVE MINERALS, SPELEOTHEMS[†], AND SPELEOGENS[††]

CAVE MINERALS & SPELEOTHEMS:

CARBONATES

Calcite

- Flowstone
- Stalagmites
- Stalactites:
  - Soda straws
- Coralloids
- Draperies:
  - Bacon
- Columns
- Helictites/Heligmites
- Welts
- Shields
  - (in unusual numbers)
- Linings:
  - Cave velvet (r)
- Canopies
- Microcrystalline(≤ 1micron)

Aragonite

- Frostwork
- Anthodites
- Linings (P)

Huntite

- "Moonmilk"(R*)

Ankerite

- Coralloids(R*)

SULPHATES

Gypsum

- Flowers (r)
- Fibrous:
  - Hair (r)
  - Cotton (P)
  - Needles (r)
- Tabular (r)
- Crusts (r)
- Roses(r)
- Stars(R*)

OTHER

(Nitrates, Phosphates, etc.)

- Urea (R*)
- Biphosphammite (R*)
- Goethite (P)
- Hematite (P)

- Sulphur (R) crusts
- Copper carbonates (P)
- Barite (xtals) & crusts) (P)
- Quartz (xtals & crusts) (P)

Rafts (calcite) (r) Bubbles (calcite) (R*) Shelfstone (calcite)

WATER LEVEL∼∼WATER LEVEL

Rimstones/Microrimstones (calcite) Tower cone (calcite) (R*) Tower coral (calcite) (R*)

Cave Clouds
(calcite) (Mammalaria?) (R*)

Dogtooth Spar (calcite)

SPELEOGENS:

Petromorphic boxwork (calcite)
Compressive bridges (Unique)

r — rare in southern Arizona
R — rare in America
R* — rare in the World
P — *more* than moderately possible to probable occurrence in a Park site

[†] Speleothem: a cave deposit; a secondary mineral deposit in a cave.
[††] Speleogen: a cave feature created from the primary wallrock of the cave.

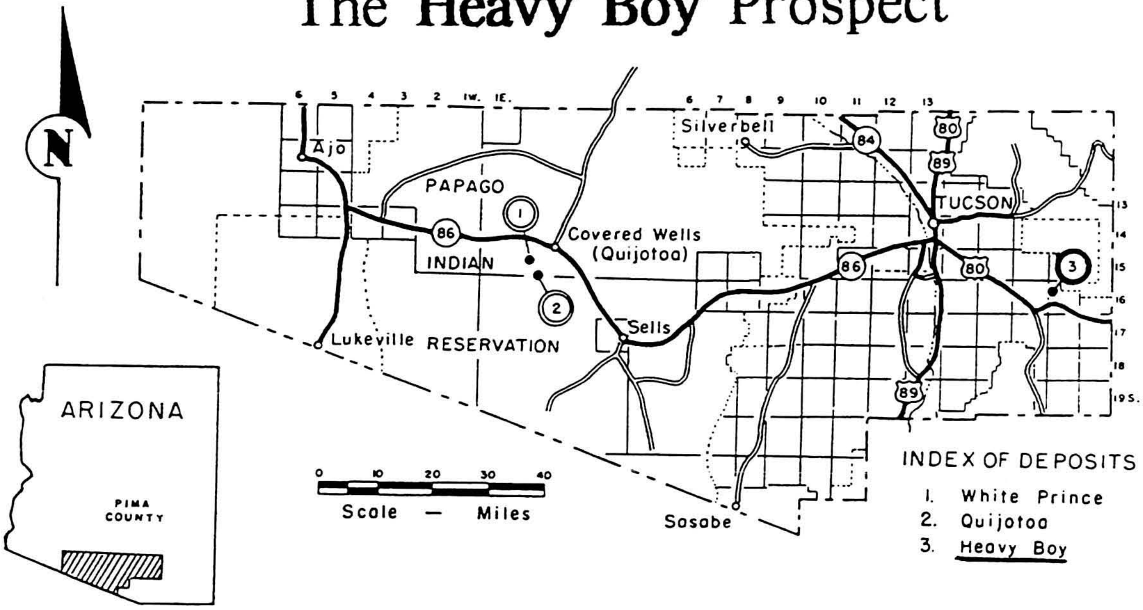
About the **Red Luminescence** of Colossal Cave Dog-tooth Spar Calcite

Excerpted from an article by **Yavor Shopov** in the Special Topics section of Cave Minerals of the World(Hill and Forti, 1997)

"Luminescence of high-temperature hydrothermal minerals is mainly due to cations, because molecular ions and molecules destruct at high temperatures. Therefore, the luminescence of cations can be used to indicate the hydrothermal conditions under which these cave minerals formed. Minerals deposited by low-temperature hydrothermal solutions have short-life flourescence due to cations and long phosphorescence due to molecular ions.

For example, the orange-red luminescence of $\mathbf{Mn}^{2+}$ in calcite sensitized by $\mathbf{Pb}^{2+}$ can be observed only in hydrothermal calcite, because $\mathbf{Mn}^{2+}$ has no strong bands of excitation and can luminesce only in the presence of $\mathbf{Pb}^{2+}$ in $\mathbf{Ca}^{2+}$ sites which absorb UV light and transmit excitation energy to $\mathbf{Mn}^{2+}$. But $\mathbf{Pb}^{2+}$ has a very big ionic radius and can substitute for $\mathbf{Ca}^{2+}$ only at high temperatures. Therefore, if calcite has only orange-red, short-term phosphorescence, it is sure to have formed in high-temperature, hydrothermal solutions(>300°C). But if it has long-time afterglow in addition to a fast orange-red phosphorescence, then it is a low-temperature hydrothermal calcite(Shopov, 1989a, b; Fig. 244). Minimal temperatures for the appearance of this orange-red luminescence have been estimated by Y. Dublyansky(Pers. comm.) by fluid inclusion analyses of hydrothermal cave calcites to be about 40°C. However, our direct measurements of luminescent calcite in hot springs shows that even at 46°C such luminescence does not appear, and it probably does not appear at < 60°C. Luminescence of hydrothermal calcite formed at lower temperatures looks like the typical "normal" cave temperature speleothem luminescence, ...green."

The Heavy Boy Prospect



Barite Deposits of Pima County.

Heavy Boy Group

The Heavy Boy group, consisting of four contiguous unpatented claims, is leased from the State of Arizona by Charles W. Hopkins and James I. Stevens. The property is in the NE 1/4 sec. 8, T. 16 S., R. 17 E., on the east side of Mountain Spring Canyon, about one-half mile east of Colossal Cave, at an approximate altitude of 3,500 feet. The claims are accessible from Tucson by traveling approximately 30 miles southeast to Colossal Cave, either by U.S. Highway No. 80 or the Sahuaro National Monument Road. One-half mile south of the Cave entrance take the picnic-area road to the west, keep to the signed La Selvilla Barbeque Road for 0.8 mile. The property is on the hillside across the wash.

The claims originally were owned by the late W. E. Johnson during the latter 1940's. The property was relocated by the present owners in May 1955.

Major exploration work has been confined to claim 3 on a brecciated, barite-bearing fault zone with indefinite walls, cutting massive, somewhat cherty, Paleozoic limestone. The zone strikes N. 30° E. and is essentially vertical. From a bench cut about 80 feet long, a crosscutting 35-foot adit has been driven S. 65° E. The interior is caved but appears to have been opened to a width of about 25 feet. Occasional nodules or disseminations up to 1 foot or more in diameter are present in the walls and can be inspected.

A pit excavated in the floor of the cut just north of the adit exposes a 10-foot face, which appears to be a fault plane. The upper part consists of weathered and fragmental material containing nodules and broken masses of barite; the lower, more solid portion of the face exposes several irregular disseminations of barite. Clusters of replacement barite crystals occur in the adjacent massive limestone. Two lots of handsorted ore of milling grade, estimated to contain about 50 tons, are piled on the dump.

Local concentrations of barite ranging from a few inches to 2 feet in width, occur above the workings to the east and along the hillside to the northeast for hundreds of feet. These concentrations occur in fractures of various attitudes or as unrelated replacement masses. A shallow cut approximately 500 feet N. 80° E. of and about 150 feet higher than the adit exposes a zone of mineralization dipping with the hillside slope. A thickness of at least 4 feet of barite containing occasional large inclusions of rock fragments is disclosed, but the extent of the body has not been determined.

Stewart, L.A. and Pfister, A.J., 1960. Barite Deposits of Arizona. U.S.D.I. Bureau of Mines Rep. of Invests. 5651.