GEOLOGY OF KARTCHNER CAVERNS STATE PARK, ARIZONA

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Kartchner Caverns is developed entirely within the Mississippian Escabrosa Limestone in an isolated fault block along the east flank of the Whetstone Mountains in southeastern Arizona. The geology of the cave, along with the detailed surface geology, was studied and mapped in preparation for commercial development of the cave. Seven black to dark-gray marker beds throughout the lower Escabrosa section provided the key for unlocking the geology of Kartchner Caverns and the surface area. A 130 m measured stratigraphic section shows the distribution of these key organic-rich marker beds. More than 60 mapped faults cut Kartchner Caverns and probably date to the Miocene emplacement of the Kartchner block. Three geologic cross-sections illustrate how Kartchner Caverns developed near the 1408 m msl base level, and then stoped upwards along faults to resistant ceiling beds. Kartchner Caverns has been stable in its development for >50Ka.

This study of Kartchner Caverns during 1990 and 1991 provides a detailed understanding of the geology in preparation for the commercialization of this spectacular cave resource. Initially, the subsurface geology was mapped within the cave. Later, the author also mapped the Park's surface geology. Key dark marker beds within the lower Escabrosa Limestone were used to tie the geology within the cave to the surface geology. Marker beds were also used to calculate displacements on more than 60 faults cutting Kartchner Caverns.

Geologic cross-sections provided a better understanding of where to locate the entrances of Kartchner Caverns for commercial development. Mapping of potentially hazardous ceiling blocks also helped determine the eventual layout of the commercial trails. Structural analysis of the cave helped with the understanding of how present-day water infiltrates the cave along faults and fractures, and forms perched aquifers on top of impermeable marker beds. Detailed mapping of the faults and fractured zones also helped determine where the tunnel excavations would experience difficulties and additional expense. Understanding the geology of Kartchner Caverns should ultimately allow for better management of the cave.

Upon discovery in 1974, Kartchner Caverns had only one small entrance. Early explorers had to crawl 100 m and negotiate one tight squeeze before they discovered the Big Room (Tufts & Tennen 1999). To get to the Rotunda and Throne Rooms, explorers had to wade through waist-deep mud. In order to develop the cave for visitors, more-accessible entrances and routes needed to be constructed. The preferred access points should lead conveniently to the cave's key features, dovetail into a planned traffic pattern, and accommodate the number of people that the cave can carry. Access points should also be amenable to microclimate controls, structurally stable, easily excavated, and accessible to security supervision. A total of ten different locations were originally considered for potential entrances.

Based on a weighted point system, three potential entrances were finally selected for detailed geologic studies. Each potential entrance was also considered for handicapped-accessible ramps, stairs, or elevators. Ultimately, the two current entrances were selected and successfully excavated. The geology of Kartchner Caverns, as presented in this paper, played a critical role in the selection of those entrances.

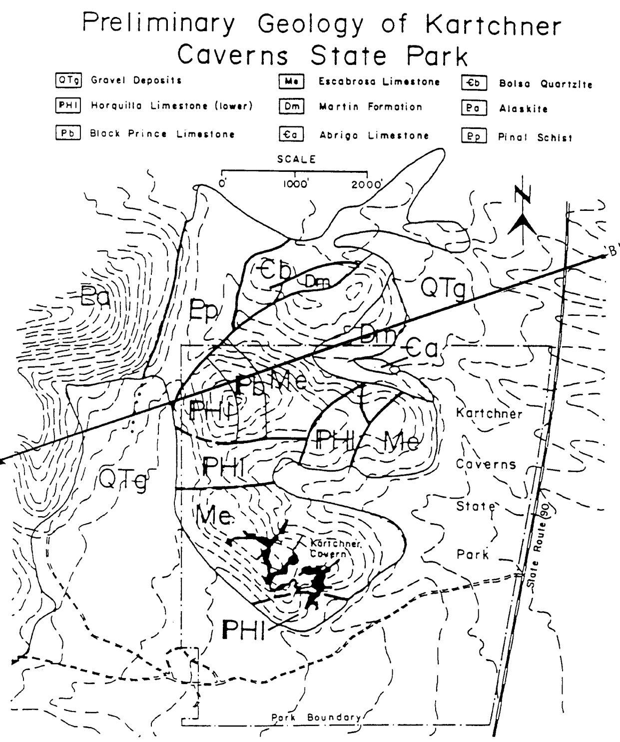


Figure 1. Surface geology of Kartchner Caverns State Park as depicted by Creasey (1967). A portion of cross-section B-B' is shown in Figure 2 (from Wruckel *et al.* 1983, with geology modified slightly from Creasey 1967.)

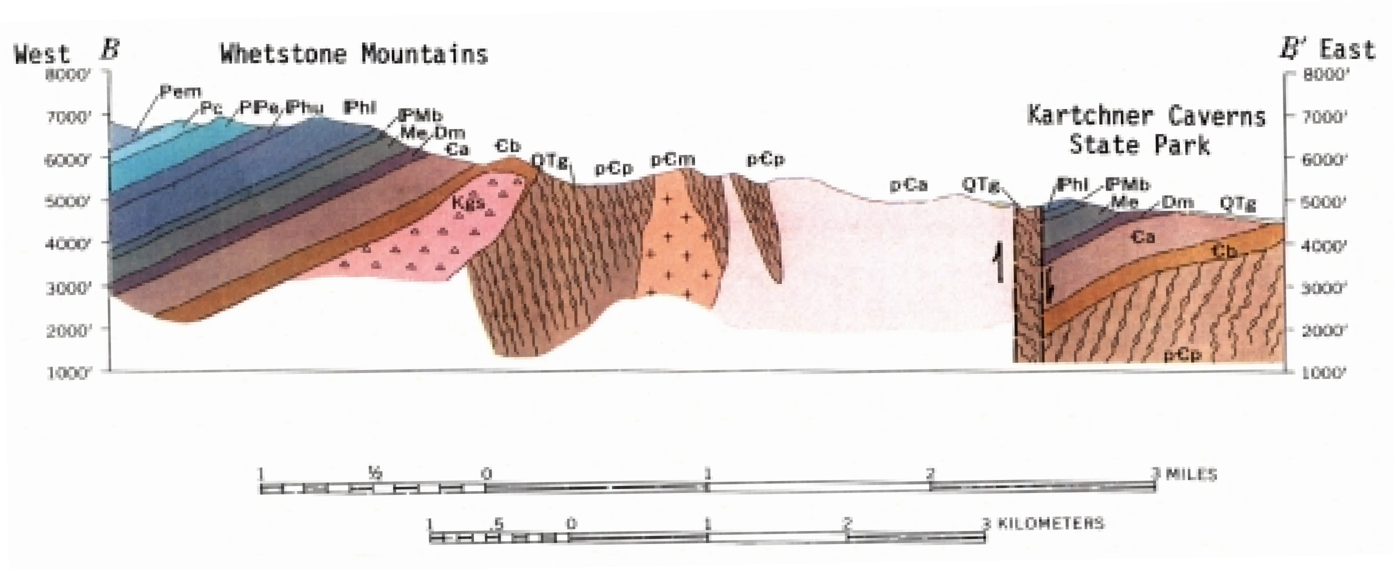


Figure 2. Structural geology cross-section B-B' from Creasey (1967) showing relationship of Kartchner Caverns State Park to the Whetstone Mountains to the west. Kartchner Caverns is in the Escabrosa Limestone (Me).

Figure 2 Legend:

Age:	**Geologic formations:**	
Tertiary & Quaternary	QTg	= Gila Conglomerate. Locally includes capping of pediment gravels.
Cretaceous	Kgs	= fine-grained granodiorite sill
Lower Permian	Pem	= Epitaph Formation, middle limestone and marl member.
	Pel	= Epitaph Formation, lower dolomite member.
	Pc	= Colina Limestone.
U. Pennsylvanian	PPe	= Earp Formation.
Middle &	Phu	= Horquilla Limestone, upper member.
U. Pennsylvanian	Phl	= Horquilla Limestone, lower member.
U. Mississippian or L. Pennsylvanian	PMb	= Black Prince Limestone.
Mississippian	Me	= Escabrosa Limestone (contains Kartchner Caverns)
Devonian	Dm	= Martin Formation
Cambrian	Ca	= Abrigo Limestone
	Cb	= Bolsa Quartzite
Precambrian	pCa	= Alaskite, includes aplite dikes.
	pCm	= Quartz monzonite.
	pCp	= Pinal Schist

REGIONAL GEOLOGIC SETTING

The regional geologic setting for Kartchner Caverns is best illustrated by the Geologic Map compiled by Creasey (1967). The Whetstone Mountains, immediately west of Kartchner Caverns, are a simple monoclinal uplift of westward- to southwestward-dipping rocks. This north-trending uplift is broken by relatively few faults, and exposes a more complete Paleozoic section than any other range in southeastern Arizona. The Whetstone Mountains are part of the highly faulted Basin and Range Province, which covers the southwestern half of Arizona, and continues to the north and west into Nevada and western Utah. Most of the ranges within this province are bounded by north-trending horst and graben faults, and the intervening valleys are filled with thick Tertiary and Quaternary sediments. Kartchner Caverns State Park encompasses the majority of a down-dropped block of Paleozoic rocks on the east flank of the Whetstone Mountains.

Figure 1 shows the geology of this fault block as mapped by Creasey (1967). The mineral resource potential of this area was further studied by Wrucke *et al.* (1983). Creasey's cross-section B-B' (Fig. 2) illustrates the structural nature of this fault block. It is bounded to the west by a high-angle normal fault that has down dropped the Paleozoic section nearly 3.2 km. Rocks in the low carbonate hills overlying Kartchner Caverns generally dip 15-35°SW (Fig. 2).

The area is actually much more faulted than indicated by Creasey, and has also been mapped by Thomson (1990). Kartchner Caverns lies entirely within the Mississippian Escabrosa Limestone, contrary to Creasey's map that shows the entrance within the Horquilla Limestone.

GEOLOGIC MAPPING

The author's original report to Arizona State Parks included a subsurface geology map of Kartchner Caverns at a scale of 1" = 50', a subsurface stratigraphic section at 1" = 20', and three cross-sections, A-A', B-B', and C-C', at 1" = 20' (Jagnow 1990). Original full-scale copies of these maps and cross-sections are available through Arizona Conservation Projects, Inc. In 1991, the author constructed a detailed surface geology map of Kartchner Caverns at a scale of 1" = 50'. The portion of that map directly over Kartchner Caverns is reproduced in this report at a smaller scale (Fig. 3). Upon completion of the detailed surface geology mapping, cross-sections A-A', B-B', and C-C' were revised slightly to more accurately tie together the surface and subsurface features (Fig. 4).

MAPPING METHODS AND PROCEDURES

Mapping the geology inside a cave is often easier than mapping the same geology on the vegetated surface because, except where obscured by secondary deposits, caves provide the geologist with an excellent three-dimensional, internal view of stratigraphy and structure and nearly "fresh" bedrock surfaces. For these reasons, the subsurface geology of Kartchner was mapped first, and then expanded to the surface. While Thomson (1990) mapped the Escabrosa Limestone as a single unit over all of Kartchner Caverns State Park, Jagnow (1991) mapped the detailed geology directly above Kartchner Caverns, subdividing the Escabrosa Limestone into multiple units.

Strikes, dips, fault traces, and major fracture traces were sketched on the 1" = 50' base maps during in-cave and surface inspections. The maps proved very accurate. Powerful battery-operated spotlights and numerous photographs allowed geologic mapping from existing trails within the cave.

STRATIGRAPHY

The Kartchner Caverns geologic section is so broken by faults that there is no single location within the cave or on the surface displaying an uninterrupted stratigraphic section. The measured stratigraphic section (Fig. 5) was pieced together throughout the cave and on the surface. Some surface locations have complete sections, but are partially covered by talus.

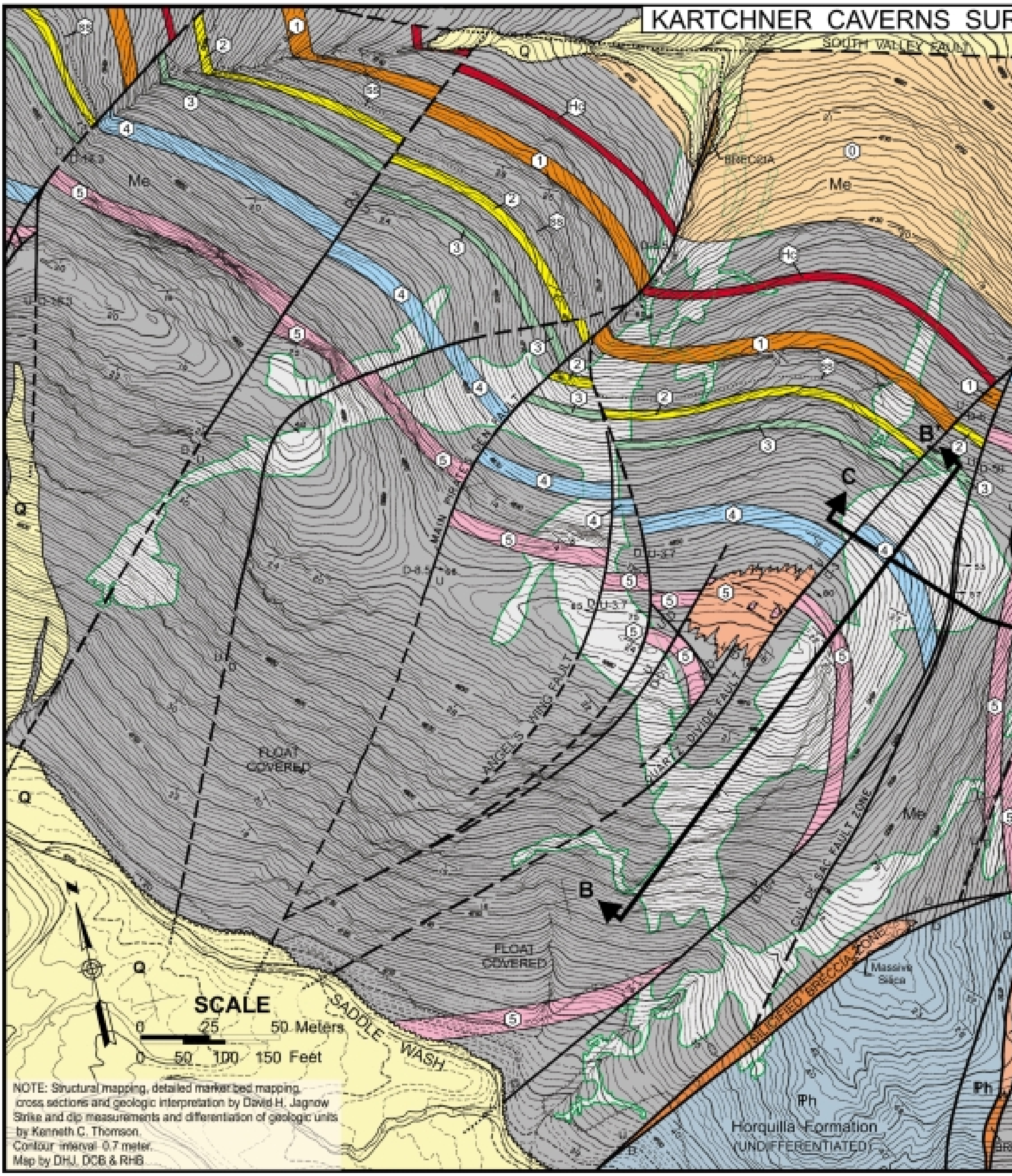
Initial observations throughout the cave revealed a series of "black beds" (actually dark gray) that can be traced throughout the entire cave. These prominent dark beds have been mapped as key stratigraphic marker beds, designated by the numbers zero (0) through five (5) in ascending order on Figure 5. Although similar in outward appearance, each bed has its own characteristic lithology and fossil assemblage, with distinctive intervening sequences. These six beds, plus a horn coral bed between units zero and one (also colored), provided the keys for mapping the entire cave and the detailed surface geology.

The measured stratigraphic section was established as follows: 1) Powerful spotlights were used to examine the geologic section along the northeast wall of the Big Room (within a single fault block) and northeast wall of the Throne Room (Fig. 6). Bed thicknesses were estimated and coloration was accurately described. 2) The identical section was then located and measured on the surface, immediately east and north of the cave. This allowed for accurate lithologic description and for an additional measured section above the Big Room section. 3) Additional section was described throughout the River Passage and out to Granite Dells. The abundance of faults in this area made it difficult to accurately determine thicknesses of this upper portion of the section. 4) Photographs were taken showing the bedding and faults in the Big Room and Throne Room. 5) Laser cross-sections were made through the Big Room and Throne Room, pinpointing the location of all prominent beds. This provided accurate thickness measurements, as well as the dip of the bedding plane ceilings. 6) Laser cross-sections were combined with the photographs and surface descriptions to produce the detailed stratigraphic section shown in Figure 5.

Kartchner Caverns is developed in 69 m of the Mississippian Escabrosa Limestone. The thickness of specific beds varies throughout the cave, and a range of thicknesses is given for some of the more studied units. The lowest portion of the geologic column (marker bed 0) is exposed in Echo Passage and Pirate's Den, along the northeast side of the cave. The highest portion of the stratigraphic section (marker bed 5) is located in Granite Dells, the southwestern extremity of the cave.

Figure 5 shows the minimum thickness of beds, and as such, best represents the measured section in the Big Room or front section of the cave. The bedding thicknesses in the back section of Kartchner Caverns (Throne Room, Rotunda Room, and beyond) are consistently thicker than in the front section of the cave. The entire section thickens to ~82 m as indicated on cross-sections B and C. These differences will be described in more detail in the discussion of the cross-sections, but may indicate a substantial amount of strike-slip movement along the fault zone between the Throne Room and Cul-de-sac Passage.

The key stratigraphic marker beds, 0 through 5, each have


KARTCHNER CAVERNS SUR
SOUTH VALLEY FAULT
BRECCIA
Me
Q
B'
C
B
FLOAT COVERED
FLOAT COVERED
SADDLE WASH
SCALE
0 25 50 Meters
0 50 100 150 Feet
NOTE: Structural mapping, detailed marker bed mapping, cross sections and geologic interpretation by David H. Jagnow
Strike and dip measurements and differentiation of geologic units by Kenneth C. Thomson.
Contour interval 0.7 meter.
Map by DHJ, DCB & RHB
Massive Silica
Horquilla Formation
(UNDIFFERENTIATED)

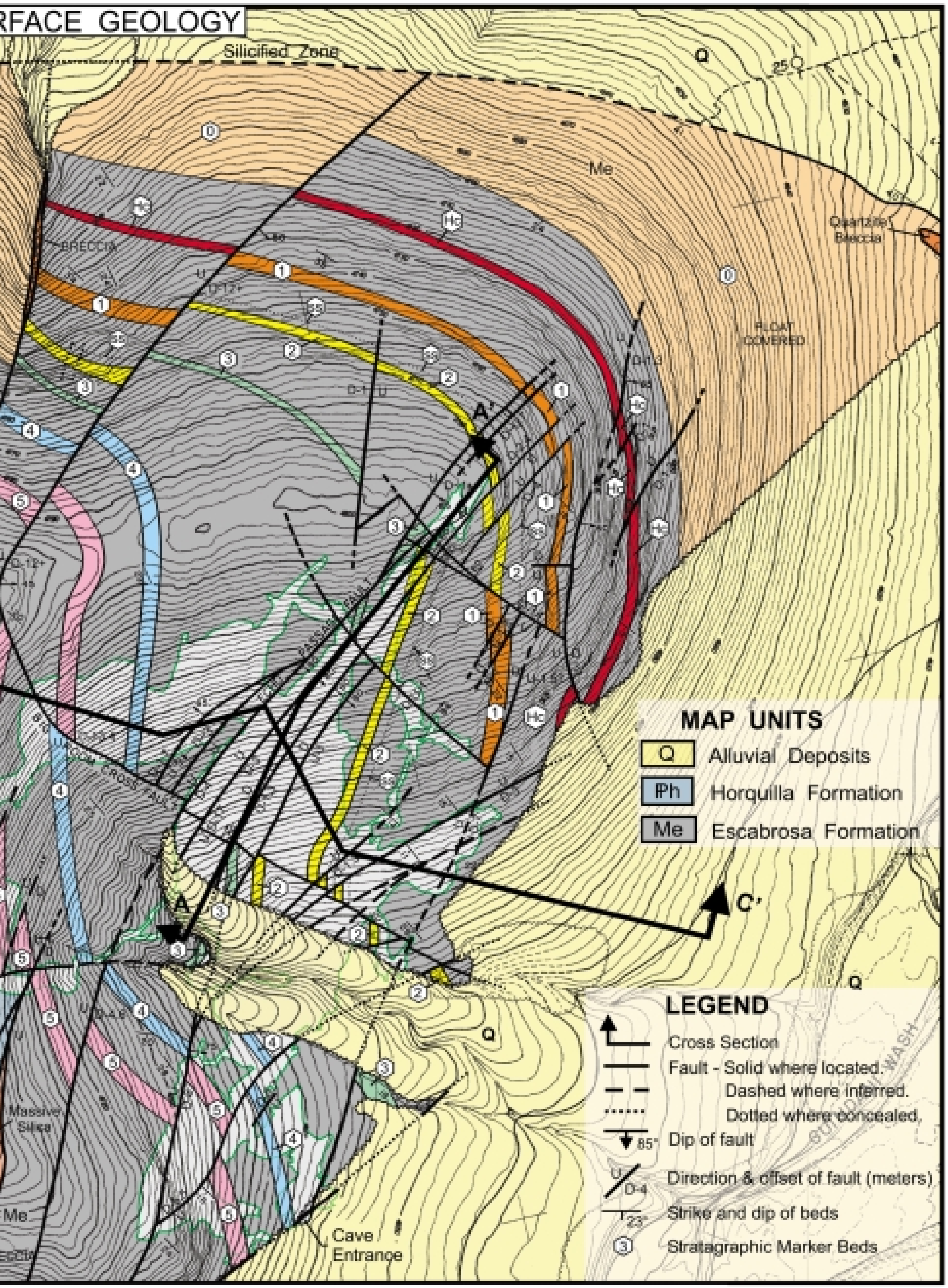


Figure 3.

Detailed surface geology of Kartchner Caverns.

distinctive lithologies (Fig. 5). All of the units appear black in the cave due to a high percent of organic matter. When broken, the rock yields a "fetid odor"; i.e., smelling faintly like oil. On the surface, these units are more easily eroded, forming slopes between the adjacent cliff-forming limestones and dolomites. Most of these dark beds are aquicludes, unable to absorb water because of the high organic content within the rock. They serve as perched aquifers, with water seeping into the cave along the top of each bed, commonly forming rows of stalactites from the bed. Within the cave it is often impossible to determine the character of a bed if it is well out of reach on the cave ceiling or wall. Therefore, the unique intervening sequences above and below each marker bed often determined stratigraphic position.

Figure 7 is a wide-angle photograph and overlay interpretation of the northeast wall of the Big Room. It shows marker beds 1, 2, and 3, as well as the fault interpretation, and the location of cross-section A-A'. The unique stratigraphic signature of the interval below bed 2 is perhaps the most easily recognized sequence in the entire cave (Fig. 5). Bed 2 is underlain by 0.6 to 1 m of very light tan limestone, which is underlain by 1 to 1.2 m of red-brown sandstone or sandy limestone. The sandstone is underlain by a lighter tan limestone, which is underlain by another distinctive series of three thin, wavy beds—reddish limestone, over tan limestone, over more reddish limestone. This unique signature very closely matches a sequence in the Throne Room and provides positive identification of the Throne Room section.

REGIONAL STRATIGRAPHIC COMPARISON

Creasey (1967) measured a 170 m section of Escabrosa Limestone along the north flank of the Whetstone Mountains, ~11.2 km west-northwest of Kartchner Caverns. Judging from the location of Kartchner Caverns relative to the surface outcrops, the Kartchner Caverns stratigraphic section should be equivalent to the bottom half of the Escabrosa section. Indeed, the bottom 146 m of Creasey's section correlates very well with the 130 m Kartchner Caverns section with equivalent units shown in Table 1. It appears that the lowest stratigraphic point within Kartchner Caverns, the northeast end of the Pirate's Den and Echo Passage, must come within a few meters of the top of the Martin Formation.

The Kartchner Caverns stratigraphic section (Fig. 5) includes the lower 130 m of Escabrosa Limestone. The underlying Martin Formation crops out at the eastern tip of the Kartchner block. The actual thickness of the basal dolomite (marker bed 0) is uncertain. This unit is truncated by faulting along the northern edge of the Kartchner block, and is truncated by the eastern end of the South Valley fault where it contacts the Martin Formation.

Aside from variations in thickness, the only major differences are that marker bed 4 is missing in Creasey's section, and interval 3-4 is a cherty limestone at Kartchner, but has been altered to a cherty dolomite in Creasey's section. These distinctive marker beds in the Escabrosa Limestone may, perhaps, correlate for great distances.

Table 1. Correlation of Kartchner Caverns stratigraphic section to that of Creasey (1967).

Kartchner Caverns Section:	Creasey's Section F:
Interval 5+: 9.1 m cherty limestone	5. 7.9 m massive cherty limestone
Marker Bed 5: 3.0 m dk. gray ls.	6. 6.0 m dk. to med. gray thin limestone
Interval 4.7: 6.7 m cherty dol. slope	7. 15.2 m cherty dolomite slope
Interval 4.2: 6.4 m cherty ls. cliff	8. 8.3 m massive ls. cliff
Marker Bed 4: 3.0 m crin. ls. slope	——missing——
Interval 3-4: 21.3 m cherty ls. pinkish	9. 15.2 m cherty dol. pinkish in part
Marker Bed 3: 1.5 m black dol. w/hematite	10. 9.7 m black dol. local pink
Interval 2-3: 8.5 m massive gray ls. cliff	11. 8.5 m massive gray ls. cliff
Marker Bed 2: 2.4 m dk. gray dol. slope	12: 7.6 m dk. gray dol. slope
Interval 1.4+: 6.4 m ls. w/ ss. cliff	13: 20.4 m massive ls. cliff
Interval 1.2: 3.0 m wavy-bedded thin ls.	14: 4.3 m thin-bedded dk. gray dol.
Marker Bed 1: 3.4 m dk. gray ls. w/corals	15: 3.7 m dk. gry. ls. w/ss streaks
Interval 0.9: 3.0 m thinly bedded ls/dol	16: 4.0 m thinly bedded impure ls.
Interval 0-0.9: 21.3 m massive ls. cliff	17: 17.7 m massive ls. cliff
Marker Bed 0: 30.5 m dk. gray sandy dol.	18: 17.0 m gray massive dol.
Martin Formation——————	Martin Formation—————-

STRUCTURAL GEOLOGY

Compared to most of the Basin and Range, the Whetstone Mountains are relatively simple and unfaulted. However, the down-dropped block that contains Kartchner Caverns has been broken by thousands of small displacement faults. More than 60 mapped faults cut Kartchner Caverns. All the major passages and rooms in the cave are controlled by base-level solution along these faults.

The majority of faults exposed in the Caverns are high-angle normal faults trending northeast from 20° to 60°. Most of these faults are vertical or dip steeply to the southeast. Fault displacement is usually <3 m. The faults are highly variable, curving along strike, changing dip, bifurcating and merging with one another. The southwest end of the Australia Room is a good example. The fault swarm from Sharon's Saddle merges with the more northerly fault from Grand Central Station. The amount of displacement along the faults also varies, occasionally dying out into a fracture with no displacement. The Red River fault/fracture is an example with no surface expression.

Most of the faults are marked by an abundance of reddish-brown limonite (iron-oxide) staining. About one-third of the fault zones are also filled with quartz (Hill 1999). The best example of a quartz-filled fault is at the Quartz Divide, where the main Throne Room-Rotunda Room fault zone is filled with 0.3 m of white quartz. The quartz-filled fault zone has been left standing while the cave dissolved out around it, leaving a quartz wall from floor to ceiling. The trail leads through a break in the quartz wall. On both sides of the Quartz Divide, quartz has also filled the fractured bedrock, allowing exquisite quartz boxwork to weather out in the ceilings.

The Cul-de-sac fault (Fig. 3), which terminates the west end of the Cul-de-sac Passage and controls the alignment of the River Passage, appears to structurally separate the east and

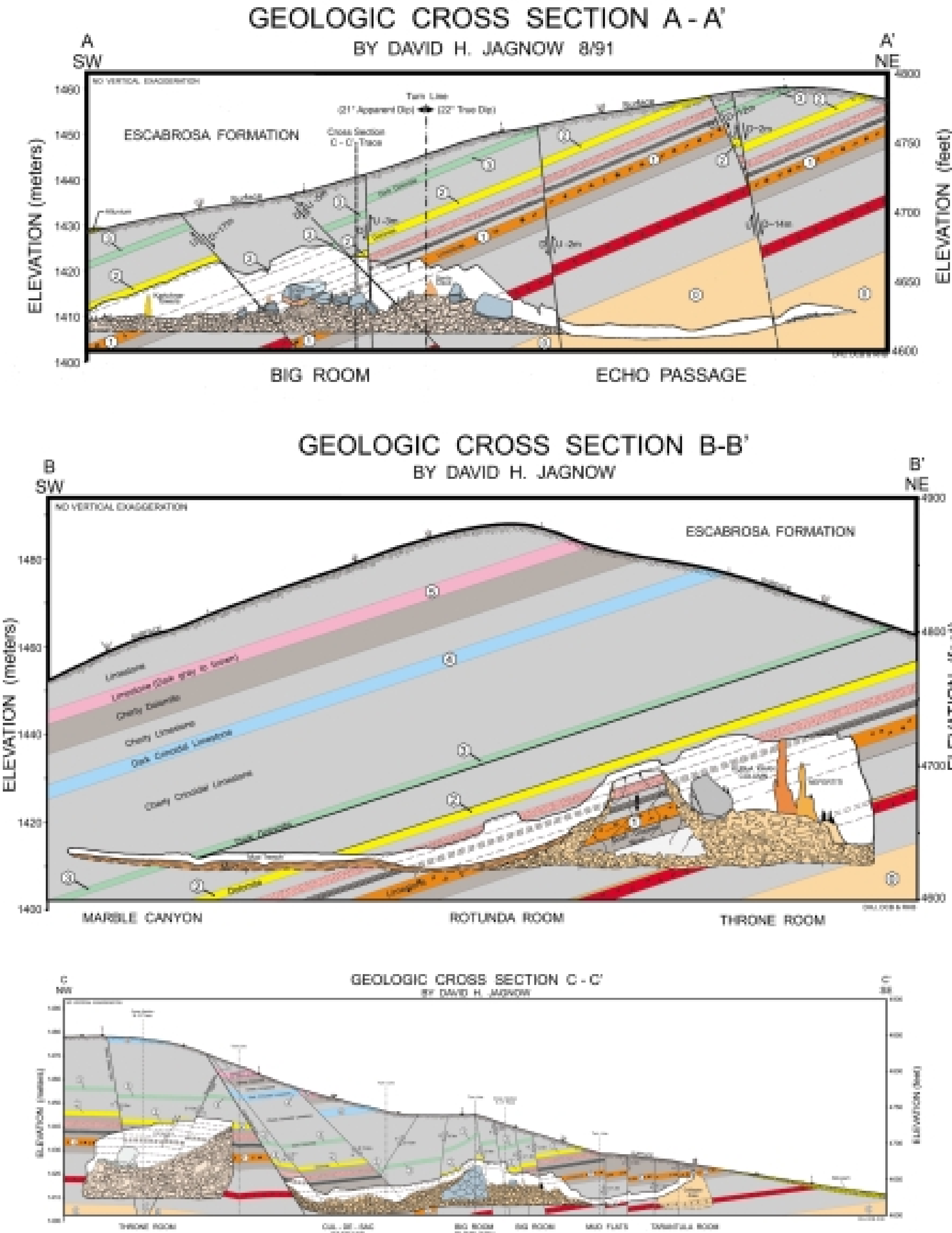


Figure 4.

Geologic cross-sections A-A', B-B', & C-C'.

west sections of Kartchner Caverns. This fault has at least 16 m of vertical displacement between the Throne Room and Cul-de-sac (Fig. 4, C-C'). The eastern section of the cave is cut by many more faults than the western section. Faults cut most of the Big Room every 6 to 15 m. Fewer faults cross the western section of Kartchner Caverns (from the Throne/Rotunda passage to the northwest), which has a thicker stratigraphic sequence. Individual units are 2-4 m thicker than the equivalent units immediately east of the Cul-de-sac fault, as if laterally offset some distance. Thus, it appears that the Cul-de-sac/River Passage fault may also have a substantial amount of strike-slip movement. Major movement on this fault is substantiated by the mineralized (primarily hematite) breccia zone at the end of the Cul-de-sac, and by the 1.8 m breccia zone between faults near the Shelf Passage.

Faulting in the western section of Kartchner Caverns is straight forward and easily mapped. Most of the faults are near vertical and of small displacement. Pirate's Den is, perhaps, the most structurally interesting area in the western section. It is developed entirely in the lowest black dolomite (marker bed 0), and the passages trace the outlines of the crossing faults.

Pirate's Den is terminated abruptly to the north by the intersection of a major east-west fault, the South Valley fault (Fig. 3). Within the cave, this fault is marked by abundant rust-colored limonite staining and fault gouge. However, on the surface the South Valley fault is the southernmost of a series of three major east-west faults composing a major fault zone 91 m across (K. Thomson 1990, pers. com.). Kartchner Caverns is terminated to the north by this major fault zone, which contains thick veins of quartz. There may be other caves north of this fault zone, but it is doubtful that Kartchner Caverns crosses this major insoluble zone.

DISCUSSION OF CROSS-SECTIONS

Cross-sections A, B, and C were all constructed at a scale of 1' = 20' (Fig. 4). Wherever possible, laser generated profiles were incorporated into the cross-sections to provide accurate passage profiles and precise locations of specific marker beds.

Cross-section A-A' starts near the entrance to the River Passage, crosses the entire Big Room, and continues to the northeast out Echo Passage. The dipping ceiling above Kartchner Towers, along the base of marker bed 4, was used to determine the dip along the line of section. This dip, 21°SW, corresponds well to the 20° dips measured farther out in the Big Room, and a 35° dip just west of the Overlook. Section A-A' crosses two normal faults and three reverse faults. The geology is beautifully displayed along the northeast wall of the Big Room. The most complete, unfaulted section in the entire cave extends from the top of the Big Room into Echo Passage. The cross-section can be matched with the wide-angle photograph in Figure 7. The north end of Echo Passage must be close to the base of the Escabrosa Limestone, above the Martin Formation.

Cross-section B-B' begins in the southwest in the Marble Canyon Passage, crosses the Mud Trench, and climbs up through the Rotunda Room into the Throne Room at the northeast end. The Throne Room profile is laser generated and tied to the geology. The remainder of this profile was generated from the original survey data (floor elevations and ceiling heights). Once again, the location of known marker beds indicated an apparent dip along the section of 18°, which correlates well with a true dip of 22° measured in the Throne Room.

The Rotunda Room and Throne Room are collapse rooms. These rooms originally dissolved out near the 1408 m msl elevation, and then the ceilings slowly collapsed, or stoped, upwards 12-21 m until they reached competent beds that supported this great expanse. Finally, the rooms stabilized at their current configuration, and travertine grew on top of the breakdown floors. Judging by the size of the massive speleothems, these rooms have been stable for tens of thousands, if not a hundred thousand years. Dates on bat guano piles on top of the breakdown indicated there has been no significant collapse for at least 50 Ka (Buecher & Sidner 1999). The only true solutional cave shown on cross-section B-B' is at the southwest end (Marble Canyon, Mud Trench, and SW end of Rotunda Room).

The large block between the Rotunda and Throne Rooms is interpreted to have dropped more or less intact, as the rock units in the block correspond to the ceiling about 1.5 m above. The geologic interval below marker bed 1 correlates very closely to the front of the cave. The bottom of the Throne Room comes very close to intersecting the black dolomite of marker bed 0, which is actually exposed just inside the North Passage.

Cross-section C-C' is, perhaps, the most revealing of all three cross-sections. With several of the faults in the cave, it was impossible to determine the amount of vertical displacement underground. However by matching the measured stratigraphic section with the known locations of marker beds on the cross-sections, a reasonable displacement could be determined for almost all of the faults.

The cave passages depicted in cross-section C-C' were mostly laser generated, except from the Cul-de-sac turn-line east to the Big Room Overlook turn-line. That portion of the cross-section, cutting up the back side of the Big Room Overlook, is based on estimated ceiling heights. Of primary importance on this cross-section is the relationship of the Cul-de-sac Passage to the Throne Room. These rooms are closer

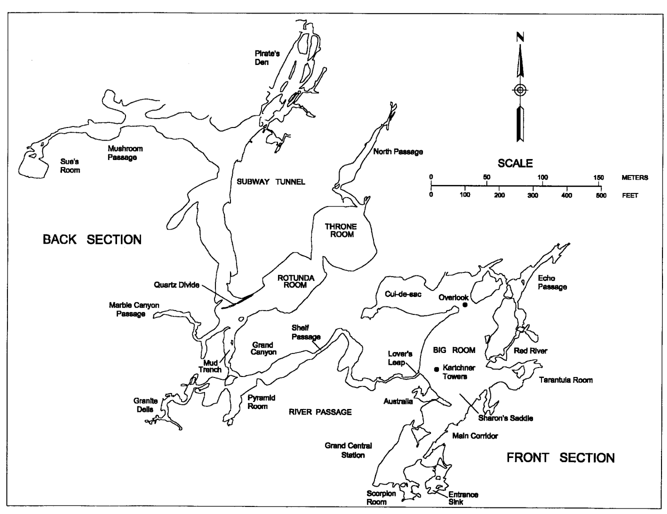


Figure 6. Kartchner Caverns place names index map.

than the original maps showed, and are separated by at least one major fault. The Cul-de-sac/River Passage fault appears to have at least 16 m of throw. There are actually two parallel faults, dipping 70°SE. Between these two faults, separated by about 9.1 m, is a highly mineralized (limonite) zone of fault breccia. The stability and lateral extent of this zone was of major concern in considering construction of a tunnel between the Cul-de-sac and Throne Rooms, and proved a major obstacle during the blasting of the Throne Room entrance tunnel.

A second concern was the profile of breakdown beneath the southeast end of the Throne Room. Section C-C' shows a nearly vertical breakdown/bedrock contact. An alternative interpretation would have the breakdown/bedrock contact dipping 53°, and intersecting the end of the Cul-de-sac. However, this does not appear to be the case. The limonite-stained wall at the end of the Cul-de-sac is interpreted as highly-fractured bedrock, rather than cave breccia.

Cross-section C-C' also illustrates that the Big Room Overlook is perched atop another large breakdown block similar to the block between the Throne and Rotunda Rooms. This block is visible along the northwest wall of the Big Room, just southwest of the Overlook.

The southeast end of C-C' illustrates how close the Tarantula Room comes to the surface. The Tarantula Room is a large collapse cone. The highest surveyed point is within 1.8 m of the surface. When considering a commercial entrance to the cave, this location was given high priority, and eventually became the exit for the tour. The area southeast of the Tarantula Room collapse was more highly fractured than depicted on the cross-section, and proved very difficult to excavate because of its instability.

CONCLUSIONS

Kartchner Caverns is developed entirely within the lower portion of the Mississippian Escabrosa Limestone in an isolated fault block along the east flank of the Whetstone Mountains in southeastern Arizona. Seven black to dark-gray marker beds throughout the lower Escabrosa section provided the key for unlocking the geology of Kartchner Caverns as well as the surface geology. A 130 m measured stratigraphic section shows the distribution of these organic-rich marker beds. Kartchner Caverns is cut by more than 60 mapped faults that probably date to the emplacement of the Kartchner block during Miocene time. Three geologic cross sections illustrate how Kartchner Caverns developed near the 1408 m elevation base level, and then stoped upwards along faults to resistant ceiling beds. The massive speleothems that rest atop the breakdown floors attest to the fact that Kartchner Caverns has been stable in its development for more than 50,000 years.

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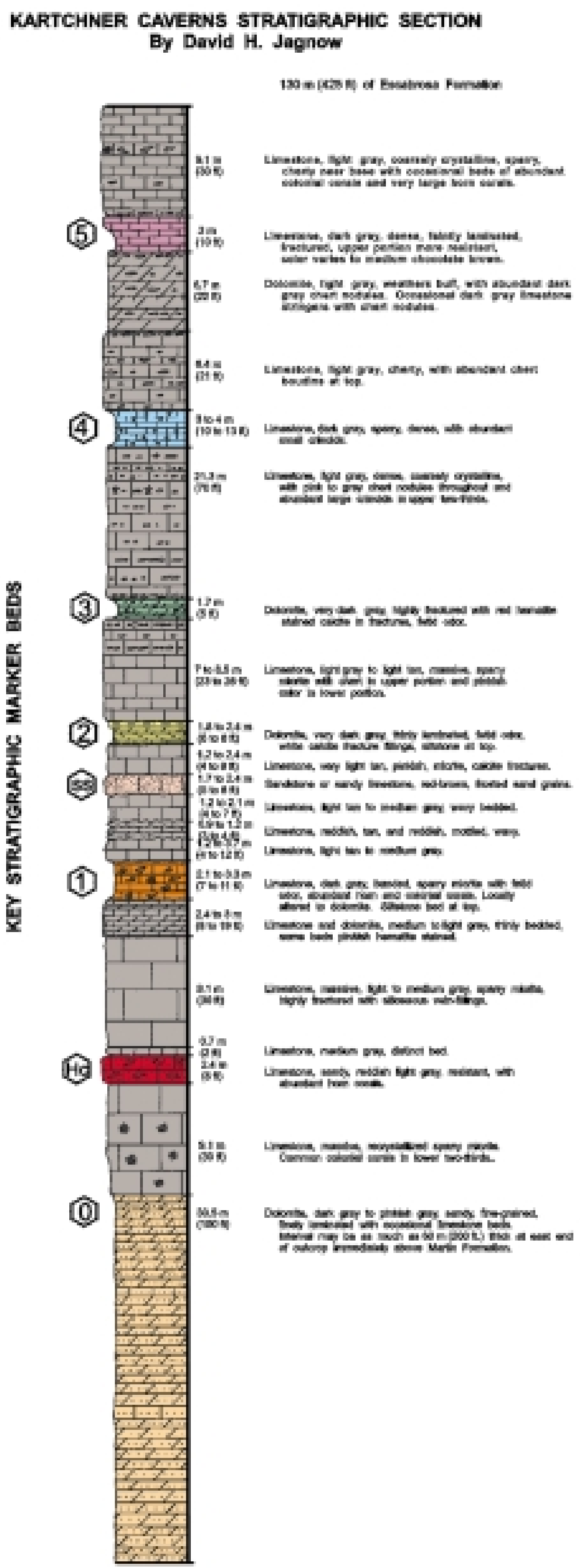

Figure 5. Kartchner Caverns stratigraphic section.

Figure 7. Photograph with stratigraphic interpretation of the northeast wall of the Big Room, showing key marker beds, fault interpretation, and location of cross-section A-A'. The unique stratigraphic signature of the interval below marker bed 2 is matched in the Throne Room.