Geologic Map of the Carlsbad Caverns 7.5' Quadrangle, Eddy County, New Mexico

By

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Open-file Digital Geologic Map OF-GM285

Scale 1:24:000

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INTRODUCTION

This Carlsbad Caverns 7.5' Quadrangle encompasses the area from Whites City on the east to Rattlesnake Canyon on the west, and from Mosley Springs on the north to ½ mile south of the Highway 62/180 crossing of the Black River. A portion of the Carlsbad Caverns National Park is located in an approximately 18-square-mile rectangular band across the center of the quadrangle. The remainder is a mixture of State and Private land. The entrance to the world famous Carlsbad Caverns lies near the center of the quadrangle on the eastern side of Section 36, Township 24 South, Range 24 East. Approximately two miles north of the Caverns and trends east-northeast across the quadrangle, Guadalupe Ridge forms a major watershed divide that extends more than 60 miles to the southwest into the Guadalupe Mountains National Park. A hiking trail follows most of this ridge. Elevations in the quadrangle range from 3,440 feet in the southeast corner to 4,810 feet on Guadalupe Ridge on the west-central side of the map.

The National Park Service has produced a large amount of information about the multitude of identifiable plant communities within the Park, which can be found at the National Park Service, Inventory and Monitoring webpage (https://www.nps.gov/im/vmi-cave.htm). In general, the vegetation is a mixture of low shrubs, spiny succulents, cacti, yucca, and grasses. Shade is almost non-existent except below north-facing cliffs. From the perspective of the off-trail geologist, many of the plants have sharp spines and grow closely together (particularly *Agave lechuguilla*) making travel in a straight line very difficult (Figure 1). Combined with the dissolved and pitted sharp-edged nature of the carbonate rocks exposed at the surface, in addition to the strong winds here throughout much of the year, walking any distance overland can be quite treacherous. Fieldwork for this study was carried out during the summer and autumn of 2019.

Figure 1. Tough and spiny *Agave lechuguilla* are abundant in the Carlsbad Caverns quadrangle.

METHODS

The most obvious contact within the Paleozoic rocks is between the Yates Formation and the overlying Tansill Formation. This contact was placed with confidence by observations on the ground from several of the ridge tops. However, because of the nearly flat-lying nature of the rock layers, it was much more efficient to map much of this contact, as well as the Quaternary/Tertiary deposits, using aerial photographs. Fortunately, the technology had improved dramatically (not surprisingly) in the decades since Hayes (1957) created the first geologic map of the quadrangle. An extension to the ArcGIS software known as Stereo Analyst, was used to three-dimensionally model the land surface using aerial photography. Stereo Analyst uses the 2009-vintage National Agriculture Imagery Program (NAIP) aerial photography in stereo pairs that are rectified to remove parallax and alternately turned on and off at a rate of 120 times per second. The refresh rate alternating between the image pair is imperceptible to the human eye. The user wears special glasses equipped with liquid crystal display lenses that are linked wirelessly to Stereo Analyst. The left and right lenses are alternately turned opaque and clear in sync with the computer. Looking through the glasses, this gives the illusion of 3D at the resolution of about 1 meter or better. Linked to ArcGIS (ArcMap), it is possible to trace contacts on the stereo image (on one computer monitor) while at the same time those contacts are drawn in the georeferenced space within ArcMap. This method is very efficient and accurate. However, because the accuracy even supersedes the accuracy of the available topographic map, some of the contacts may diverge from the map contours, making the map appear inaccurate. Fortunately, this effect is rare and mostly seen in steep areas with deep ravines and contours close together.

Subsurface formations and depths to contacts were estimated by examining well logs obtained through the online portal of the State of New Mexico Oil Conservation Division (http://ocdimage.emnrd.state.nm.us/imaging/). The relations of the units rely heavily on the stratigraphic model presented by Hayes (1957) in his cross-section (his Figure 2) as well as on a wealth of published stratigraphic information created since then.

PREVIOUS WORK

Hayes (1957) mapped what was then known as the Carlsbad Caverns East quadrangle, which was the 1:62,500-scale geologic map that includes the more recent Carlsbad Caverns 7.5' quadrangle. Hayes and Koogle (1958) mapped the Carlsbad Caverns West quadrangle (1:62,500 scale) that includes the region immediately to the west of the current map area.

SHELF/LAGOONAL ROCKS AND PERMIAN REEF

The quadrangle encompasses three distinct geologic depositional environments. In the south, the topographically low area is a portion of the Delaware basin in which the salt of the Castile Formation is exposed. The abrupt increase in elevation along the south-facing escarpment is the result of the debris of the ancient reef front (the Capitan Formation), and represents the change from deep water to the south, to shallow water in the north, in the ancient Guadalupian-age sea. North of the reef front, the shallow-water shelf/lagoonal deposits are represented by, from oldest to youngest, the Seven Rivers, Yates, and Tansill Formations. The formations in this area, and to the west, represent some of the best exposures for studying the sedimentology of an ancient reef and lagoon system. Many papers have been published that discuss the details of the various rock fabrics and depositional environments. This report will not reproduce their work here but, instead, will only discuss the formations in general terms in relation to new observations made during this study.

Shelf/Lagoonal Rocks

The Seven Rivers Formation is the oldest formation exposed in the quadrangle. It is exposed in the northwest corner of the map, along a cliff face formed by a large meander-bend in Lechuguilla Canyon (Figure 2) which, at this location on the map, is labelled as “Dark Canyon” (Section 4, T. 24 S., R. 24 E.). Excellent exposures on this cliff immediately west of the map reveal bedded dolomite that appears rather regularly bedded with individual beds typically between 1–3 meters thick. Most of the exposed section here does not contain interbedded sandstone, and is the major reason why this section was distinguished as a separate unit. One obvious sandstone bed less than 1 meter thick was observed near the top and two others occur near the bottom within a few meters of the modern creek bed. Hayes (1957) also mapped this unit as the Seven Rivers Formation.

In this same location, the Seven Rivers Formation is overlain by the Yates Formation (also Guadalupian in age) comprised of dolomite and less abundant interbedded fine-grained sandstone. The lowermost 100 feet or so, are composed of dolomite beds interbedded with thinner, but abundant, sandstone that form steep, ledgy outcrops (Figure 2). This basal portion is overlain by slope-forming deposits composed mostly of fine-grained sandstone and siltstone, interbedded with less abundant, thin, individual beds of dolomite. Throughout much of the quadrangle, the Yates Formation is composed mostly of medium to thick dolomite beds interbedded with less abundant fine-grained sandstone beds of variable thickness (Figures 3 and 4). From a distance, and in aerial photographs, the thicker sandstone beds typically form vegetated slopes that appear slightly darker than the carbonate beds. The dolomite beds in the Yates Formation are typically massive and structureless. Locally, faint laminae are visible. Some dolomite beds contain a weak horizontal fabric defined by thin, horizontal fenestrae up to several centimeters long, that may have been formed by microbial metabolism during deposition (gas produced by microbes).

Figure 2. One of the best exposures of the Paleozoic rocks is immediately west of the northwest corner of the map, along a meander bend in Lechuguilla Canyon. The steeper ledgy layers represent the Seven Rivers Formation. The uppermost slopes and thin, single layers represent the Yates Formation.

Figure 3. This is probably the best exposure of fine-grained quartz sandstone/siltstone layers, exposed in the road-cut in the northern half of Section 29, T. 24 S., R. 25 E. All layers exposed here are within the Yates Formation. The rusty yellow layers are sandstone, interbedded with lighter tan-colored more massive layers of dolomite.

Figure 4. This view is looking south-southeast down Rattlesnake Canyon from near the southeast corner of Section 32, T. 24 S., R. 24 E. The furthest ridge in the distance, just before the basin lowlands, is composed of the Capitan Formation, while most of the other layers are composed of the Yates Formation, capped on the far right and left by the flat plateaus of the Tansill Formation.

Figure 5. This is a typical outcrop view of the Yates Formation showing thick massive layers containing abundant pisoliths alternating with thinner beds of thinly bedded dolomite.

Figure 6. Close-up of a fallen block of Yates Formation showing partially graded pisoliths that exhibit beautiful concentric laminae. Reverse grading of pisoliths is common.

Closer to the reef front, the Yates Formation contains layers comprised almost exclusively of subspherical pisoliths (Figures 5 and 6). The upper and lower contacts of these beds are locally sharp and planar, while in other areas the contacts appear to cut down across older beds. Pisolith beds are rarely thicker than 1.5 meters. The Yates Formation also contains abundant teepee structures typically between 5 to 10 meters across, and several meters tall (Figures 7 and 8). These have been interpreted to have formed just behind the reef during periods of low sea level, when the sediments experienced periodic desiccation and/or partial replacement by expansive cements such as calcite spar.

In Walnut Canyon and in Rattlesnake Canyon, Neese and Schwartz (1977) measured several stratigraphic sections (see their Figure 2). Their sections show two, thick, fine-grained sandstone intervals, each up to seven meters thick, separated by a small cliff of dolomite within the upper portion of the Yates Formation. This "triplet," as Neese and Schwartz (1977) called it, makes an obvious and convenient marker horizon that can be traced across much of the quadrangle. Neese and Schwartz (1977) placed the contact at the top of the uppermost sandstone within the triplet. This study agrees with this placement. The dolomite beds between the two sandstone horizons exhibit the same tan-colored weathering as the underlying Yates dolomite beds, and locally contain pisoliths.

Overlying the Yates Formation, the Tansill Formation (also Guadalupian in age) is very similar in appearance to the Yates Formation, but weathers slightly lighter gray than the tan-weathering beds of Yates Formation (Figure 9). Similar to the Yates Formation, the Tansill Formation also contains thinner beds of fine-grained sandstone that form predominantly covered slopes. In most of the areas observed, the Tansill Formation appears to contain far fewer pisoliths than does the Yates Formation, and commonly forms a small cliff immediately above the contact with the Yates Formation. Besides these characteristics, however, there are few other useful means for distinguishing the two units. They both look nearly identical at the outcrop, in a fresh hand-sample, and with a hand lens. Both are composed of rather massive grainstone and packstone. The dolomite in both commonly appears microcrystalline, mostly massive and featureless, and neither contains useful fossils that are immediately distinguishable in the field.

Figure 7. This cliff face is one of the best exposures of the Yates Formation in the quadrangle, exposed on the north side of Walnut Canyon in the northern half of Section 30, T. 24 S., R. 25 E. Arrows point to some of the more obvious teepee structures. View is to the north-northeast. The thin tan-colored dolomite layer near the top is sandwiched between two slope-forming (and covered) siltstone/sandstone layers that, together, form the "triplet." This is overlain by the slightly lighter gray cliff-forming Tansill Formation.

Figure 8. Teepee structure exposed on the west side of the parking lot at the Carlsbad Caverns Visitor Center. This is probably the most accessible teepee structure in the Park.

Figure 9. This view is looking northwest up Rattlesnake Canyon from near the southeast corner of Section 32, T. 24 S., R. 24 E, immediately west of the map area within the Serpentine Bends 7.5' quadrangle. Most of the layers within the canyon are the Yates Formation. The Tansill Formation forms the lighter gray-colored cliff in the foreground and on the right side of the image, as well as the dark cliff that caps the layers in the upper left corner of the photo.

Figure 10. The view looking southwest along the reef front from near the southwest corner of the Carlsbad Caverns Visitor Center parking lot. Note how the well-defined layers of the Tansill Formation in the upper right become less and less distinct as they merge southward with the more massive slope of the Capitan Formation. Here, in the southwest corner of the photo, the lower slope of the Capitan Formation exhibits faint layering that dips approximately 30 degrees toward the basin. The Guadalupe Mountains National Park in Texas is visible on the horizon in the far distance.

The Capitan Formation is composed of limestone (not dolomite) and forms the southern boundary to the shelf/lagoonal rocks. From a distance, it locally exhibits a faint layering that is inclined basin-ward (south-southeast) between approximately 5 to 35 degrees. It is difficult to identify the boundaries of individual beds as they appear to merge with the neighboring carbonate, which appears to be massive, structureless dolomite. Upon closer examination, the limestone unit locally exhibits a faint fragmental texture defined by irregularly shaped masses of carbonate, surrounded by an indistinct matrix of fragmental and massive limestone of almost identical color. Small, sparse, rusty colored disseminated authigenic chert appears to replace some of the smaller fragments, some of which may be fragments of sponges, bryozoans, or echinoderms, but none were identified with much confidence. This formation has been interpreted as the foreslope debris shed off the paleo-reef that existed within 100 feet of the surface of the ancient ocean. This material moved down slope into deeper water as debris flows and avalanche deposits. The faint layering probably reflects that ancient subaqueous slope.

The lagoonal formations described above merge southward into the Capitan Formation. As they do, they lose their interbedded sandstone layers, making identification of individual formations more difficult. The well-bedded nature of the lagoonal deposits also gradually disappears into the massive deposits of the reef-front. Notice how the contact appears to dip moderately to the north-northwest suggesting that the Capitan Formation and reef grew seaward (southward) and upward as an overall progradational sequence during rising sea levels. Hayes (1957) and Hayes and Koogle (1958) subdivided the Capitan Formation into a lower reef-talus facies (their map unit Pct) and an upper massive fine-grained reef facies (their map unit Pcm). In practice, distinguishing the two in the field is not easy, and no attempt was made here to do so.

The Capitan Formation, much more so than the lagoonal formations, contains abundant and widespread secondary calcite spar, filling large (cm scale and larger) voids in the host rock. From their shape, the voids appear to represent both dissolution features and cracks that have subsequently been filled. These features were probably precipitated during one or more episodes of exposure and dissolution that affected these rocks more so than the lagoonal rocks (possibly because it is limestone and not dolomite). It is possible that this dissolution was caused by uplift of the rocks and/or lowering of the groundwater table and subsequent infiltration of meteoric waters. Conversely, deep acidic groundwater may have risen along fractures and pore spaces to dissolve the features from below. The paucity of calcite spar in the lagoonal rocks may be an artifact resulting from incomplete observations on the part of the author, or it could indicate that the lagoonal rocks did not experience the same dissolution events or were not as susceptible to the same style of dissolution. Because the Capitan Formation contains a fragmental texture, enclosed within faint southward-dipping bedding, meteoric waters may have been more effectively channeled than through the nearly flat-lying lagoonal formations.

CASTILE FORMATION

The Castile Formation within the quadrangle appears to be composed exclusively of anhydrite. It forms the bedrock in the lowlands south of the Capitan Formation escarpment. It is mostly covered by much younger Tertiary and Quaternary conglomerates, though some flat areas show expansive exposures. Some of the flat areas underlain by anhydrite are preferentially mantled by a thin veneer of eolian dunes (not mapped separately). The best outcrops of the unit are exposed in the walls of drainages where alternating light-colored and dark-colored laminae are visible. Scholle, Goldstein, and Ulmer-Scholle (2007) reported that 209,000 individual 'lamination cycles' have been observed in the 1,800 feet thickness of the Castile Formation, which are thought to represent seasonal (yearly) varves. The laminae are commonly folded and contorted at the centimeter scale which has been interpreted to be the result of the "structural effects of Tertiary block faulting, anhydrite-gypsum transformation during uplift, and flowage at the outcrop [scale] due to erosion of laterally adjacent deposits" (Scholle et al., 2007). At the scale of tens of meters or more, bedding is commonly contorted and is rarely consistent for more than 10 meters or so. This is particularly noticeable in road-cuts where U.S. Highways 62/180 crosses the margin of the Castile Formation further to the south, just north of the Texas-New Mexico border. It is possible that some of this deformation may be the result of dissolution and subsurface collapse.

GEOLOGIC CROSS SECTION

The geologic cross section A–A' is shown trending north to south across the quadrangle, approximately one mile east of the Carlsbad Caverns Visitor Center. This line was established to take advantage of the presence of deep oil wells near the northern and southern ends of the cross section. Driller's Logs for some of these wells include very general lithologic descriptions (e.g., "sandstone" or "Limestone") and, more useful with regard to this project, the depth to the top of named formations (e.g., "Delaware", "Atoka", and "Barnett"). Fourteen wells contained useful formation depths. This information was used in conjunction with published stratigraphic information (in particular, see Scholle et al., 2007, and Manti Resources, Inc., 2016) to make the cross section.

"WHITES CITY FAULT"

This structure is visible as an obvious linear feature that parallels the bottom of the slope of the Capitan Formation. It appears as a fault on the geologic map created by Hayes (1957) and on the State of New Mexico geologic map (NMBG, 2003). There is not a good exposure of the fault plane itself as it is concealed by thin slope deposits almost along its entirety. The lineation is visible by vegetation preferentially growing along this structure. East of Whites City (east of the map) the lineation cuts uphill across some the lower slopes of some of the hills, apparently cross-cutting both the Capitan Formation and the overlying Tansill Formation further to the northeast. In these areas, the vegetation lineation appears to separate hard layered bedrock of the Tansill Formation on the northwest from conglomerate on the southeast. West of Whites City (on this map) the exposures are not as good but appear to present the same relationship. Besides the lineation, no topographic scarp is visible, indicating that there has been no recent significant movement along this structure. As a result, most of the fault itself is shown as being obscured by younger Quaternary alluvial deposits (Qm, Ql, and Qy). Only in a few locations, where the lineation appears to trend uphill significantly, was the structure drawn as a fault contact separating the Capitan Formation (Pcp) from Tertiary/Quaternary conglomerates (QTc2).

The timing of movement on this fault is not clear from the visible relations. The presence of probably faulted conglomerate suggests that movement along the fault occurred as late as the Tertiary or even into the Quaternary. However, it is not known when the fault first formed and how much offset it represents. If it first initiated in the Permian, during the formation of the Delaware/Permian basin, then differences in the thickness of pre-Capitan-Formation beds on opposite sides of the fault would provide clues to its history. However, no deep wells exist north of the fault within the National Park. Hayes (1957) does not show this fault on his cross-section (his Figure 2), and shows no offset of the pre-Capitan-Formation beds across the northern boundary of the basin. The exact nature of this feature remains unclear.

FAULTS IN WALNUT CANYON

Within approximately ¾ mile northwest of White's City, just north of the mouth of Walnut Canyon, two high-angle faults form a small graben near the southern margin of the lagoonal deposits. The faults are best visible near the base of the steep canyon slopes, just above the valley floor. Here, the offset in the dolomite and thinner sandstone beds is obvious. Further upslope the faults are very difficult to see. On top of the adjacent plateaus the faults are practically invisible, even in aerial photos. With this in mind, it is possible that both of these faults continue both eastward and westward.

FOLDS

Because of the very shallow dips of the lagoonal carbonate formations within the quadrangle, most of the bedding attitudes were determined using aerial photos in conjunction with the Stereo Analyst extension described above in the Methods section. The attitudes obtained this way are shown on the map as a special symbol that is distinct from the strike-and-dip symbol used for bedding attitudes measured on the ground (see the map legend). The paucity of vegetation and lack of thick soil allowed many attitudes to be estimated, providing excellent resolution across the map.

Figure 11. The view looking west along Walnust Canyon showing the gently dipping layers that form a broad syncline.

The fold axes are shown as thin red lines on the map. They represent shallow synclines and anticlines whose parallel axes trend mostly east-northeast west-southwest, parallel to the band of exposure of the

Capitan Formation. Two of the best vantages from which to view the folded nature of the rocks are (1) along the paved road to the Caverns, where it begins to climb southward out of the canyon bottom, and (2) just west of the map, on the saddle north of the Rattlesnake Canyon Trailhead, overlooking Lechuguilla Canyon. From both of these vantages, it is obvious that Walnut Canyon follows the axis of the syncline (Figure 11). In fact, several other valleys are coincident with synclines, while anticlines tend to form ridges. This suggests that the present drainage pattern was controlled by the folds (Horberg, 1949). The fold axes are also roughly parallel to the folds and thrusts within the Marathon fold belt to the south, in southwestern Texas, suggesting that the two fold belts may have been created at the same time.

QUATERNARY/TERTIARY DEPOSITS

The surficial deposits throughout the quadrangle form several discrete levels or terraces. Some of these exhibit relatively flat constructional surfaces that appear to represent the original upper limit of aggradation. Others exhibit a somewhat irregular, hummocky appearance, which is more visible in stereo aerial photographs, but also on the surface. Some of this irregularity may be the result of subsequent erosion, but some may be the result of subsequent local dissolution of the underlying anhydrite and slow collapse of the overlying sediments. This irregularity made it very difficult to definitively distinguish separate terrace levels in many areas, particularly in the southeastern portion of the quadrangle on both sides of Black River. In most areas, the subdivisions delineated on the map are rather tentative and should be viewed with some caution. They are probably best viewed as relative indicators of depositional age rather than as firm ages.

Two things are apparent by the map pattern of these deposits. First, the Castile Formation evidently experienced one or more long periods of erosion that subsequently exposed the anhydrite at the land surface. Then the environment changed and large volumes of coarse debris were eroded from the highlands to the north, and deposited on the eroded surface of the Castile Formation, probably in separate and discrete pulses that may have coincided with climatic changes throughout the Late Tertiary and Quaternary. This dramatic change also suggests a change in the regional base level of the streams in the area, from relatively steep to relatively gentle. Much of this detritus has subsequently been reworked and/or stripped away, leaving the remnants visible today. The abundance of large rounded cobbles attests to the great energy of the streams that carried this material. The map pattern of these deposits, as well as the direction of the modern drainages in the region, indicate that these streams formerly flowed more or less eastward towards the Pecos River.

In the southern portion of the quadrangle, south of the escarpment, nearly all of the Quaternary and Tertiary deposits are comprised of carbonate-clast conglomerate. These deposits are typically poorly sorted, and contain subrounded to well-rounded clasts of carbonate probably derived from all of the carbonate formations exposed to the north (the Capitan Formation, the Yates Formation, the Tansill Formation, and possibly also the Seven Rivers Formation). The matrix of the deposits of all ages, where visible, is commonly strongly cemented by lighter gray carbonate. Where exposed, this cement is very strong and creates concrete-like outcrops where the erosional surface slices through clasts instead of the clasts weathering out in relief.

The relative ages of Quaternary deposits are commonly distinguished based on three primary criteria: (1) their elevation in the landscape, (2) their degree of soil formation, including calcium carbonate cementation, and (3) the depth of dissection. Other criteria, such as unique plant communities and the presence or absence of preserved constructional surfaces, can help. Since the deposits in the southern portion of the map are all strongly cemented with calcium carbonate, and all show very similar plant communities, their relative elevation in the landscape and depth of dissection are the most useful distinguishing characteristics. Based on these criteria, the oldest deposits are labeled as QTc1 and QTc2. Preserved constructional surfaces appear to have been extensively modified by dissolution (as described below) such that these surfaces are no longer flat, even though large areas contain only minor integrated drainage networks. Progressively younger deposits are less dissected by drainages and are lower in the landscape.

North of the escarpment, the surficial deposits occur within much more constrained narrow canyons. These deposits are much better preserved than their counterparts to the south. Several distinct terrace levels are preserved along most of the valley floors. Here, too, most of the deposits are composed of poorly sorted carbonate-clast conglomerates, but, where exposed in stream cuts, some contain finer grained pebbly and sandy deposits that are also typically strongly cemented (rudites and calcarenites). Many of the younger well preserved terraces are mantled with a thin layer of silt that may have originated as either low-energy over-bank deposits or as eolian dust, or both. The units on the map reflect the two major terrace levels (Qy and Qyc) that can be easily distinguished across the area of the map. Each of these, however, can be locally subdivided further, but at the scale of the map this was impractical. Similar to the surficial deposits to the south, these deposits represent alternating periods of erosion and deposition that are probably tied to much larger regional causes.

DISSOLUTION FEATURES

Sinkholes

Sinkholes are labeled as Qs. Almost all of them occur south of the escarpment in the southwest portion of the map. Each is typically characterized by a subcircular to oblong shape, several meters to several tens of meters across, that form a depression up to several meters lower than the surrounding map unit. Most depressions contain very flat floors that are mantled with silt and clay. Some depressions appear to have formed from two or more depressions that coalesced. Most of these features are found within units QTc1 QTc2—the oldest of the surficial deposits. Fewer sinkholes are found within unit Qm, and none were found in any of the younger surficial units. This pattern suggests that most of these features are relatively old—they formed after deposition of units QTc1, QTc2, and Qm, but before the younger deposits formed. Their presence in the south and absence in the north indicates that they formed via the dissolution and collapse of the underlying Castile Formation in the south.

The largest numbers of sinkholes are visible in the southwestern corner of the map (Figure 12). Here almost all of them are within conglomerate of unit QTc1. It is not common for a sinkhole to form in conglomerate, so it is interpreted that these sinkholes formed by subsequent collapse of caverns formed by fresh-water dissolution of the salt in the underlying Castile Formation. Unit QTc1 resides relatively high in the landscape, compared to the younger Quaternary units, and forms a protective mantle above the Castile Formation, which is also slightly higher in elevation here. The slightly thicker section of salt above the water table may have been the reason for the formation of the caverns in the first place, and suggests that they may reside at very shallow depths in the subsurface. Two prominent sinkholes are exposed in the southeast corner of the map where they also appear in cemented Quaternary conglomerates (Figure 13). A larger subcircular zone of radially converging dips is visible in the canyon 2.5 miles north-northeast of Carlsbad Caverns that may represent a collapse feature that has not yet breached the surface (Figure 14).

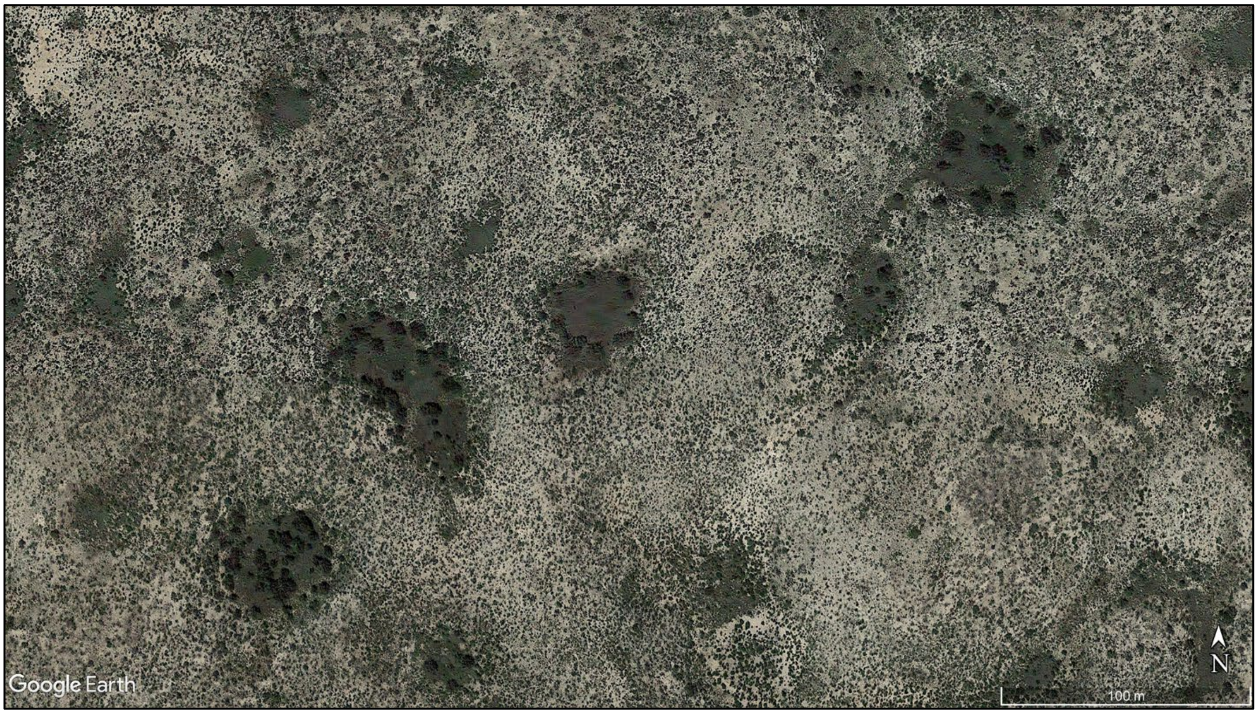

Figure 12. Circular depressions within conglomerate of unit QTc1 are filled with fine sediment and are interpreted as collapsed and filled sinkholes in the underlying salt of the Castile Formation. View is centered on 32.136094°, -104.490863°. Image courtesy of Google Earth.

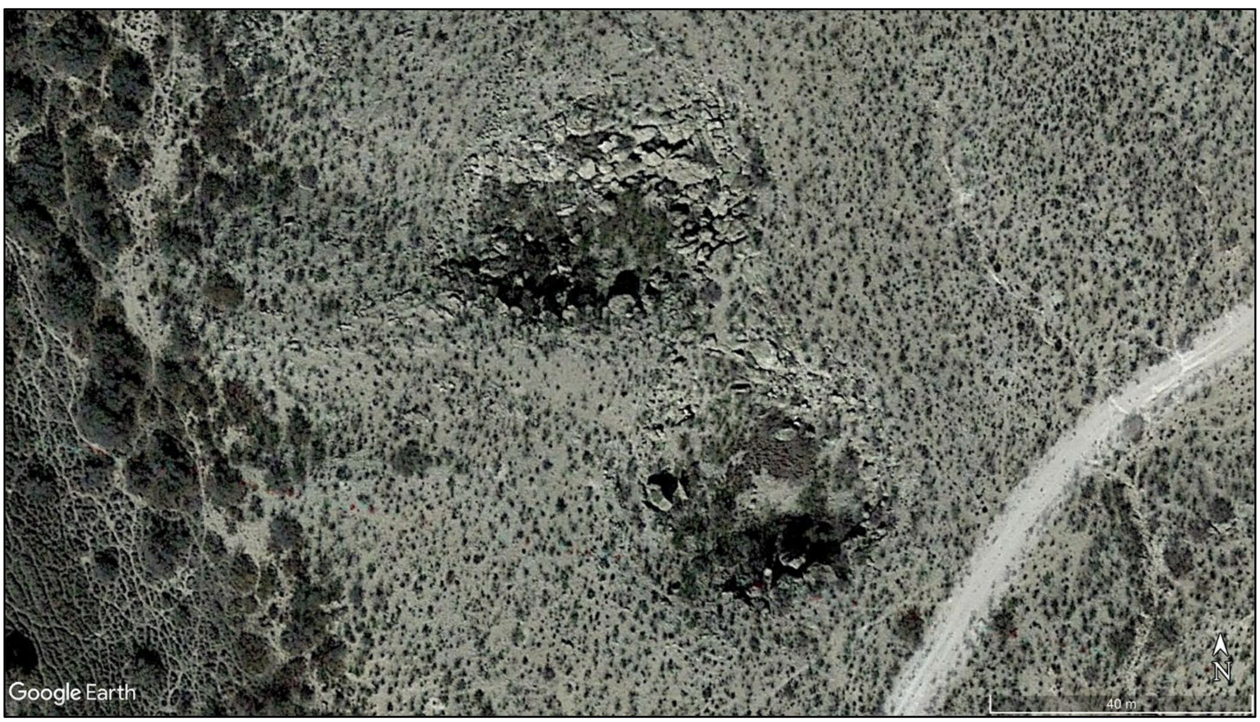

Figure 13. Two circular sinkholes exposed in the southeast corner of the map within unit QTc2. View is centered on 32.135362°, -104.395543°. Image courtesy of Google Earth.

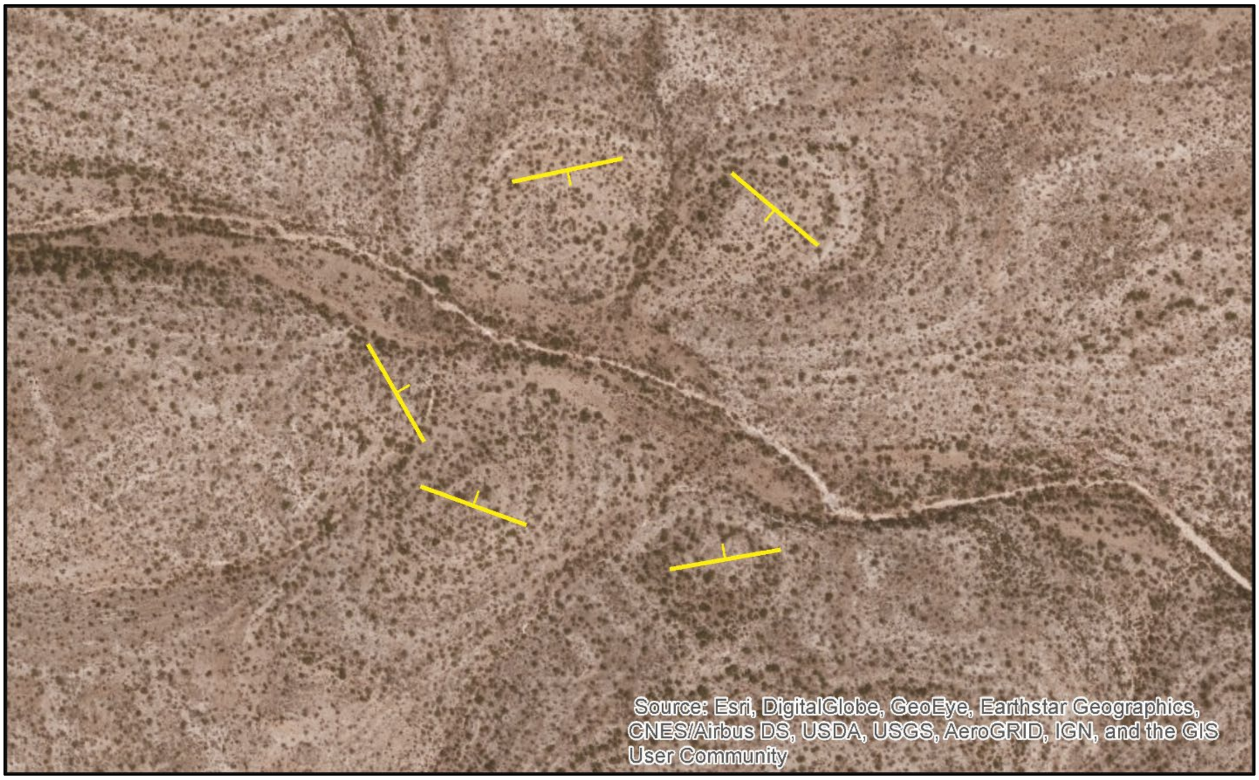

Figure 14. Located approximately 2.5 miles north-northeast of Carlsbad Caverns in the southeast corner of Section 18 and the northwest corner of Section 19, T. 24 S., R. 25 E.

Disappearing Streams

Unfortunately, these features were only identified in stereo aerial photographs after the field work had been completed and where not observed in the field. These features are characterized by streams that terminate in depressions within the salt of the Castile Formation. Figure 15 shows a Google Earth view of one such feature (32.147963°, -104.415397°). Two small streams with a very small catchment join and terminate in a small flat-floored depression within the salt. The disappearing streams suggests that a subsurface cavern probably formed within the salt, and was probably created by dissolution of the salt in fresh (meteoric) water. The floor of the depression is filled with fine-grained sediments suggesting that the former cavern in the salt is completely filled with sediment. Figure 16 shows a large shallow depression (darky vegetated) on the north side of a broad exposure of salt (32.150340°, -104.423967°). A small drainage on the south side of the basin appears to drain the basin into a fissure in the salt. A small bridge of salt separates the drainage from a dark opening that appears to be the collapsed roof of the fissure. No other expression of this feature is visible at the surface further south. Figure 17 shows several small streams forming a dendritic drainage pattern that merge and disappear into a shallow depression in the salt (32.140624°, -104.447473°). The catchment of these streams is very small at this location.

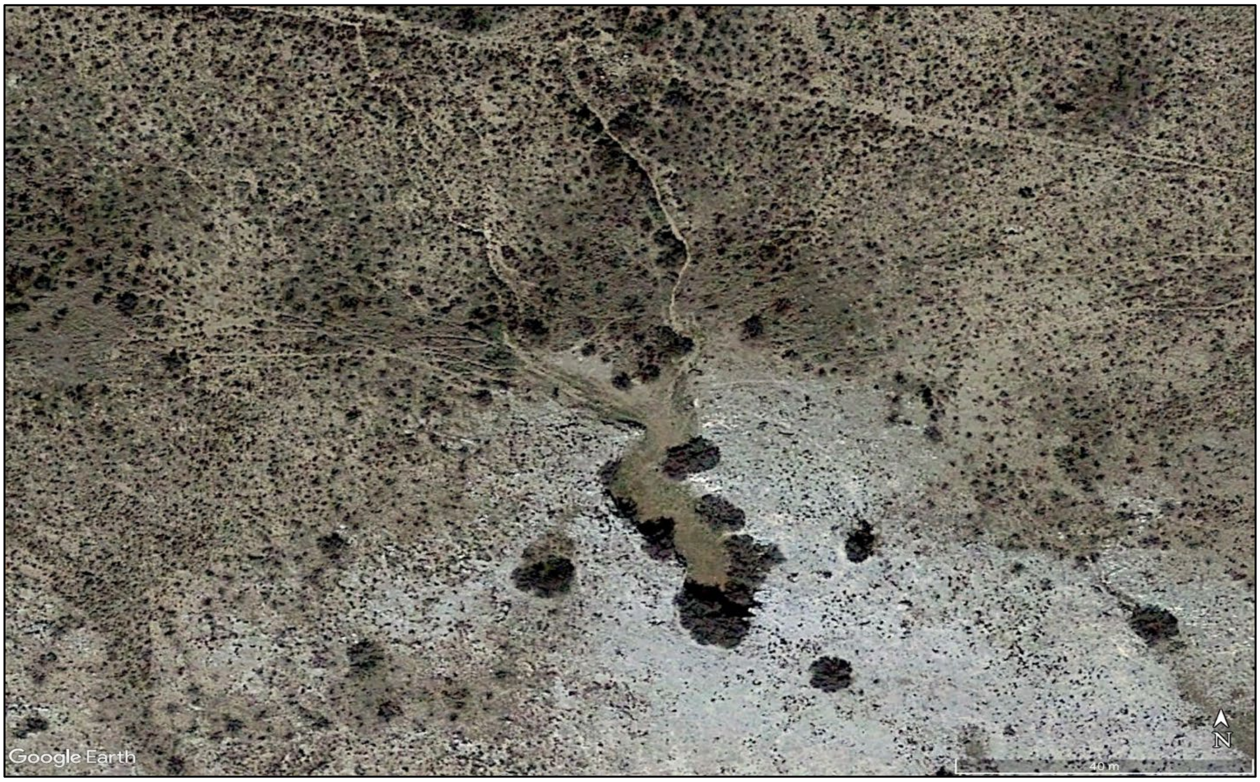

Figure 15. Two small disappearing streams terminate in a flat-floored depression within salt of the Castile Formation, located at 32.147963°, -104.415397°. Image courtesy of Google Earth.

Figure 16. A small darker colored shallow depression drains into a small ravine which appears to disappear southward into salt of the Castile Formation. Located at 32.150340°, -104.423967°. Image courtesy of Google Earth.

Figure 17. Several small streams merge together and disappear into salt of the Castile Formation. Located at 32.140624°, -104.447473°. Image courtesy of Google Earth.

Carlsbad Caverns

According to the Park Service and Wikipedia, the famous Carlsbad Caverns is just one of more than 119 identified caves within the Carlsbad Caverns National Park, and one of only three that are open to the public (the other two are Slaughter Canyon Cave and Spider Cave). The caverns formed as the Guadalupe Mountains were uplifted, and the carbonate rocks within were subjected to chemical dissolution by groundwater. The presence of gypsum ($CaSO_4$) minerals and the near absence of alluvial stream-derived sediments within the caves suggests that they were formed when hydrogen sulfide gas, derived from hydrocarbons in the underlying formations, rose and combined with oxygen in the groundwater to produce sulfuric acid. This acid dissolved away the chemically reactive carbonate rocks, leaving gypsum as a by-product. Most of the cavern below the visitor center was sculpted within the limestone of the Capitan Formation. The largest chamber within the cavern, called The Big Room, is almost 4,000 feet (1,220 m) long and encompasses 357,469 square feet (33,210 m^2). The Big Room is the largest such chamber in North America.

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UNIT DESCRIPTIONS, CARLSBAD CAVERNS 7.5’ QUADRANGLE

Quaternary

Holocene Sedimentary Deposits

Qyc **Active channel deposits.** Predominantly unconsolidated sand and gravel dominated by clasts of carbonate surrounded by a silty to sandy carbonaceous matrix. Mostly devoid of vegetation though some low terraces typically less than 1 m above the active channel contain weak soil horizons and thicker vegetation. Thickness unknown but probably less than several meters.

Qy **Older Holocene sedimentary deposits.** These deposits are composed of weakly to strongly indurated sand and gravel in a silty to sandy carbonaceous matrix. They form terraces typically between 1-3 meters above the active channel deposits. Most terraces have well developed silty soil that supports abundant vegetation, particularly grasses. Estimated thickness up to 5 meters.

Dissolution Features

Qs **Sinkholes.** Most of these features form shallow depressions filled with fine-grained silt and clay that supports the growth of grasses and other vegetation. Most of these features are sub-circular and range from several meters across to tens of meters across. The majority of these features occur in the older sedimentary deposits (QTc1 and QTc2) that overlie the anhydrite of the Castile Formation (Pc) where they probably represent the surface expression of collapsed dissolved caverns that have filled with sediment.

Qss **Disappearing streams.** These features are near-vertical caverns in the anhydrite of the Castile Formation (Pc) into which local streams drain and disappear without apparent external drainage locations.

Qsl **Externally drained collapse features.** These few features are larger than unit Qs. They are circular in shape and form depressions that have been breached by external drainage. These features are typically much deeper than the smaller sinkhole depressions of Qs and are found in the southeast corner of the map within unit QTc2 and in the northern portion of the map within dolomite.

Qsc **Cave.** Only one feature contains this map label—the opening to Carlsbad Caverns. It was given its own map label because of its size and significance.

Pleistocene Sedimentary Deposits

Ql **Late Pleistocene sedimentary deposits.** Contains poorly sorted, angular to subrounded material from boulders to sand and silt composed dominantly of dolomite locally derived from the nearby bedrock and strongly cemented by carbonate. This unit forms small terrace remnants between the younger Holocene deposits (Qy) and older alluvial deposits (Qm).

Qm **Middle Pleistocene sedimentary deposits.** Contains poorly sorted, angular to subrounded material from boulders to sand and silt composed dominantly of carbonate and is strongly cemented by carbonate. North of the reef front (unit Pcp) the unit is mapped as small remnants of alluvial that mantle steep slopes. South of the reef front the unit forms irregularly shaped mesas that are lower in elevation than QTc1 or QTc2, suggesting they are younger than the later two units.

Quaternary and/or Tertiary

QTc2 **Quaternary or Tertiary sedimentary deposits, younger unit.** Composed of poorly sorted, subrounded to rounded clasts of carbonate from silt and sand size to large cobbles. Exposures are poor except where exposed in stream cuts. Top surfaces are commonly mantled with fine-grained eolian deposits a few cm thick. Slopes are mantled with regolith. Stream-cut exposures are strongly cemented by carbonate. This younger unit is slightly lower in the landscape than QTc1 and tends to form mostly rather flat constructional surfaces and rounded ridges.

QTc1 **Quaternary or Tertiary sedimentary deposits, older unit.** Composed of poorly sorted, subrounded to rounded clasts of carbonate from silt and sand size to large cobbles. Exposures are poor except where exposed in stream cuts. Top surfaces are commonly mantled with fine-grained eolian deposits a few cm thick. Slopes are mantled with regolith. Stream-cut exposures are strongly cemented by carbonate. This older unit is slightly higher in the landscape than QTc2 and forms rounded ridges and locally rather flat constructional surfaces.

Permian

Pc **Castile Formation (Ochoan).** Anhydrite. Composed of alternating regular laminae and thin beds of dark-colored and light-colored anhydrite. Layering is mostly contorted and is rarely consistent for more than a few meters. Both stream-cut exposures and upper surface exposures show abundant brittle deformation cracks, many of which on the surface are filled with fine sediment. As mapped, many areas underlain by anhydrite are extensively mantled by a thin layer of alluvial and eolian deposits a few cm thick. Low widely spaced dunes are visible on some of these surfaces.

Pt **Tansill Formation (Guadalupian).** Mostly light gray dolomite and minor thin dark tan siltstone beds. Dolomite beds are mostly thick-bedded and massive though locally faint layering within beds is defined by sub-horizontal fenestrae. No fossils are obvious. The lower portion of this unit forms a prominent cliff that overlies the uppermost slope-forming thick siltstone layer of the underlying Yates Formation. Close to the reef front (unit Pcp) the unit contains some teepee structures, but fewer than in the immediately underlying Yates Formation. Some beds contain abundant pisoids (or pisoliths), but overall, pisoids are less abundant in the Tansill Formation in the quadrangle than within the Yates Formation.

Py **Yates Formation (Guadalupian).** Interbedded dolomite and siltstone/fine-grained sandstone. Characteristically contains many more interbeds of dark yellow-weathering siltstone and fine-grained sandstone than does the overlying Tansill Formation. Dolomite is typically massive and fenestrate, and commonly weathers a dark tan color compared to the lighter gray weathering of the Tansill Formation. In Walnut Canyon the unit contains abundant beds of pisoids (or pisoliths) interbedded with dolomite. Teepee structures are locally abundant, particularly within a few hundred meters of the Capitan Formation.

Psr **Seven Rivers Formation (Guadalupian).** Exposed only in the far northwest corner of the map. Thick-bedded gray dolomite occurs in rather massive beds between 1-3 meters thick separated by thin partings. From a distance, the formation appears regularly bedded and conspicuously contains very few siltstone/fine-grained sandstone beds up to a few tens of centimeters thick, mostly in the lower portion of the exposed outcrops. Forms cliffs and steep ledgy slopes.

Pcp **Capitan Formation (Guadalupian).** From a distance this unit exhibits a weekly developed inclined layering that dips southeastward between ~15 and 30 degrees. This layering is more pronounced closer to the Delaware basin. In outcrop, most exposures appear massive and structureless. A faint brecciated texture is visible locally where angular clasts of dolomite of all sizes are strongly cemented by different generations of carbonate. Coarse-grained light yellow palisade calcite spar commonly fills dissolution fissures and cracks. Fossils of sponge and brachiopod fragments are locally visible. Forms steep slopes and imposing cliffs. This unit represents the fragmented debris shed from the ancient reef down into the Delaware basin.

<u>Cross Section Only Units</u>

Pbcs **Bell Canyon Formation (Guadalupian).** Fine-grained sandstone/siltstone member of the Bell Canyon Formation—Thin-bedded to laminated planar beds of siltstone and fine-grained sandstone. Typically erodes into smooth slopes. Fresh surfaces are commonly light-mustard yellow in color. This unit is present in the cross section only.

Ppg **Queen and Grayburg Formations, undivided (Guadalupian).** Queen and Grayburg Formations, undivided—Queen and Grayburg Formations, undivided. This unit is present in the cross section only.

Pgs **Goat Seep Formation (Guadalupian).** Upper unit; mostly limestone, in part dolomitic, in part sandy, mostly thick bedded, massive, light gray to brownish yellow; sandstone interbeds more abundant downward; poorly preserved marine fossils; thickness is from 200+ to 1,200 ft. Lower unit; mostly sandstone, very fine to fine grained, soft, brownish yellow to pink; some units of limestone, cherty, sandy, thin bedded, brown, limestone more abundant in Guadalupe Mtns; forms moderate slope; silicified marine fossils; thickness is from 150 to 300 ft. This unit is present in the cross section only.

Pcc **Cherry Canyon Formation (Guadalupian).** Sandstone, siltstone, and limestone. Mostly very fine-grained quartz sandstone and siltstone, mostly noncalcareous, in part shaly, mostly thin bedded, some varvelike bedding and ripple marks, irregularly bedded channel fillings common in lower two-thirds. Locally persistent thin quartzite beds in lower part. Sandy limestone in thin beds, lenses, and nodules in a few places. Limestone, thin to thick bedded, some sandstone interbeds. Western Apache Mountains; interbedded dolomite, limestone, and fine to very fine-grained dolomitic sandstone; basal 50 ft. exposed. Thickness 1,000 ft. This unit is present in the cross section only.

Pbs **Bone Spring Formation (Leonardian).** Bone Spring Formation, this unit is present in the cross section only.