Geologic Map of the El Paso Gap 15-Minute Quadrangle, Eddy and Otero Counties, New Mexico and Culberson and Hudspeth Counties, Texas

By

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New Mexico Bureau of Geology and Mineral Resources
Open-File Geologic Map OF-GM 315

Scale 1:62,500

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INTRODUCTION

The El Paso Gap 15′ quadrangle encompass the northeastern portion of the Guadalupe Mountains and most of the Brokeoff Mountains to the west. The southern boundary of the map is the Texas-New Mexico border, and occupies a region immediately north of the Guadalupe Mountains National Park. The El Paso 15′ quadrangle includes the La Paloma Canyon, Pickett Hills, Panther Canyon, and El Paso Gap 7.5′ quadrangles.

The study area can be conveniently subdivided into two types of landforms. The eastern third of the map forms a high plateau underlain by unfaulted, relatively flat-lying Permian sedimentary rocks that dip less than 5° to the east. It is here that the formations of the Artesia Group (the Queen, Seven Rivers, and Yates formations) are visible. The rest of the map is composed of north- and northwest-trending ridges, separated and down-dropped from the higher plateau to the east by abundant parallel normal faults. The name "Brokeoff Mountains" is very appropriate because the whole region really appears to have broken off and foundered from the main mass of the Guadalupe Mountains. Most of the Brokeoff Mountains and isolated ridges to the east are underlain by the Grayburg Formation. The highest elevation in the map is 7,487 ft, on the east side of Upper Dog Canyon just north of the state line. The lowest elevation is a little lower than 3,600 ft in the southwest corner of the map.

METHODS

At the beginning of this project, the El Paso Gap 7.5′ quadrangle was mapped in detail and a separate map and report were produced (available on the NMBG webpage). Because of this, the current report for the El Paso gap 15′ quadrangle does not go into detail about the geology within the El Paso Gap 7.5′ quadrangle. The El Paso Gap 7.5′ map and report contain two additional cross sections and abundant photos. Geologic mapping of the El Paso Gap 7.5′ quadrangle was performed between December 2022 and February 2023. Mapping in the El Paso Gap 15′ was performed during mid-November 2023 and mid-January 2024.

Geologic mapping was carried out with the goal of producing a final layout at a scale of 1:62,500. Some areas that exhibited complex geology and/or closely spaced contacts had to be simplified in order to be understandable at this scale. The reader should keep in mind that enlarging the map significantly closer than ≈1:30,000 will probably not increase the amount of detail seen on the map.

A DJI MAVIC™ Pro drone was used to augment the mapping. This 1.6-pound, foldable aircraft was carried in a backpack during fieldwork (**FIGURE 1**). Its ability to fly up to approximately 2 mi, one way, and approach within 4 ft of distant rock outcrops was a very valuable aid, particularly in inaccessible canyons and along precipitous cliff-faces. Some of the images shown in this report were taken by the drone's 4k, 12Mp camera. The panoramas were spliced together from multiple images using either Google Photos™ or Lightroom®.

PREVIOUS GEOLOGIC MAPPING

Boyd (1958) mapped the geology within the El Paso Gap 15′ quadrangle, and described the facies relationships, the paleontology, and the structural geology of the region. Hayes (1964) compiled a 1:62,500-scale geologic map of the Guadalupe Mountains that includes the El Paso Gap 7.5′ quadrangle and the geology along the Algerita Escarpment. Kelly (1971) produced an approximately 1:250,000-scale geologic map of the Guadalupe Mountains. Immediately to the east, Hayes and Koogle (1958) mapped the Carlsbad Caverns West 15′ quadrangle (1:62,500 scale). Also to the east, Skotnicki and Allen (2023) mapped the Gunsight Canyon 7.5′ quadrangle. To the west, O'Neill (1988) made a geologic map of the Cienega School 7.5′ quadrangle located immediately west of the Panther Canyon quadrangle. Moore and others (1989) created a 1:24,000-scale geologic map of the Brokeoff Mountains Wilderness Study Area. Skotnicki (2024) mapped the El Paso Gap 7.5′ quadrangle that occupies the southeast quarter of the El Paso Gap 15′ quadrangle, and Skotnicki and Knight (2021), mapped the Guadalupe Mountains National Park immediately to the south.

FIGURE 1—A photograph of the DJI MAVIC™ Pro drone that was used to view inaccessible areas. The view is SW towards the Salt Basin.

SOUTHWESTERN ESCARPMENT

The southwestern escarpment exhibits up to 2,000 ft of relief, more relief than anywhere else in the study area. By far the best access to this area is via the well-maintained dirt road that closely parallels the Texas-New Mexico state line (Road 008). In the valley, this road crosses ancient lake beds and contorted ridges composed of granular gypsum and silt and terminates near the base of the alluvial fans where it intersects with the north-northwest-trending Road G008. O'Neill (1998) mapped these deposits in detail immediately to the west. From here it is a hike of only one mile to the nearest bedrock hills and less than another mile to the base of the escarpment. Fortunately, most of the alluvial fans in this area are Holocene in age, where dissection along the major streams rarely exceeds 2 m and the land surface is mantled by silt and smaller rocks. This is in contrast to the older alluvial fans to the south that exhibit deeper dissection and very rocky surfaces, creating significant impediments to hiking (Skotnicki and Knight, 2021). The vegetation on most of the distal fans is dominated by creosote, with cat claw more abundant along the washes and sparse yucca on the rockier slopes (**FIGURE 2**).

FIGURE 2—A photograph of the southwestern escarpment, looking east. The distal alluvial fan in the foreground is mostly covered with silt and low creosote bushes.

Kerans and others (1993) describe the history of geologic mapping in the area and explain why there was a long-lived disconnect between the Leonardian strata along the southwestern escarpment north and south of the state line (figure 8 of Kerans et al., 1993). In addition to separate studies performed at different times, the southwestern escarpment just north of the state line also contains an important transition zone between the shelf (to the north) and the basin (to the south) (see, in particular, Boyd, figure 3, 1958 and Hayes, 1964). Kerans and others (1993) give the reader a good idea of the long-lived complexity associated with this transition from the shelf to the basin (figure 10 of Kerans et al., 1993)(See also figure 4 of Fitchen, 1993). Unfortunately, the area of this transition is remote and difficult to access, has been extensively faulted, and is obscured with debris at steep slopes. These characteristics did not allow a thorough and detailed study of the transition zone with the limited time available. The reader should be aware that this area is grossly simplified and needs a better-detailed study at a scale of about 1:10,000 to better understand this important transition.

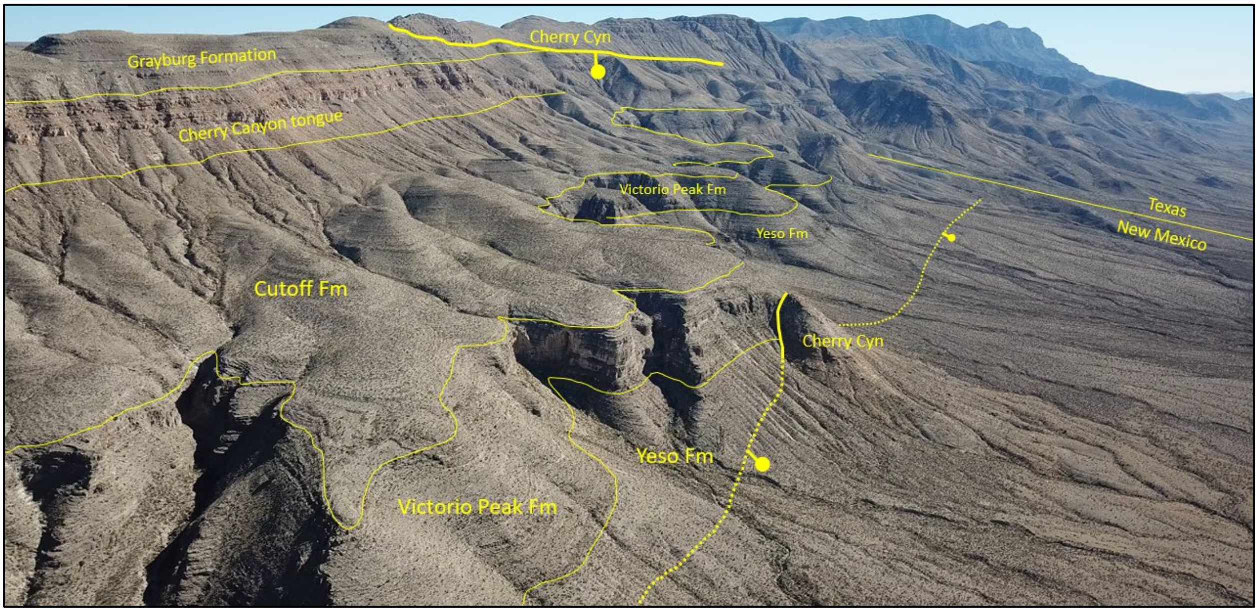

FIGURE 3—A view of the southwestern escarpment featuring distinct contact lines and formation labels, looking southeast toward the Texas and New Mexico border. The photograph was captured with a drone.

The Grayburg Formation

Some of the best exposures of the Grayburg are exposed on Cutoff Ridge (**FIGURE 3**), and along the deeply dissected canyon near and within Cork Draw. Here, the lower portion of the Grayburg Formation, as mapped, contains mostly thin- to thick-bedded dolomite, interbedded with recessive-weathering, light-orange, quartz sandstone and siltstone. This lower portion typically forms a steep slope that appears rather smooth from a distance, punctuated by numerous thin ledges of dolomite. The upper portion of the unit here contains exclusively gray dolomite that forms a series of small cliffs. The lower portion of the formation appears to represent a transition from mostly sandstone below (in the Cherry Canyon Tongue) to dolomite above. The contact was drawn at the base of this transition because it overlies a widespread, thick cliff of sandstone and is easier to distinguish and map than any other horizon (**FIGURE 4**). Based on his descriptions of the Cherry Canyon Formation, Boyd (1958) may have placed the contact slightly higher.

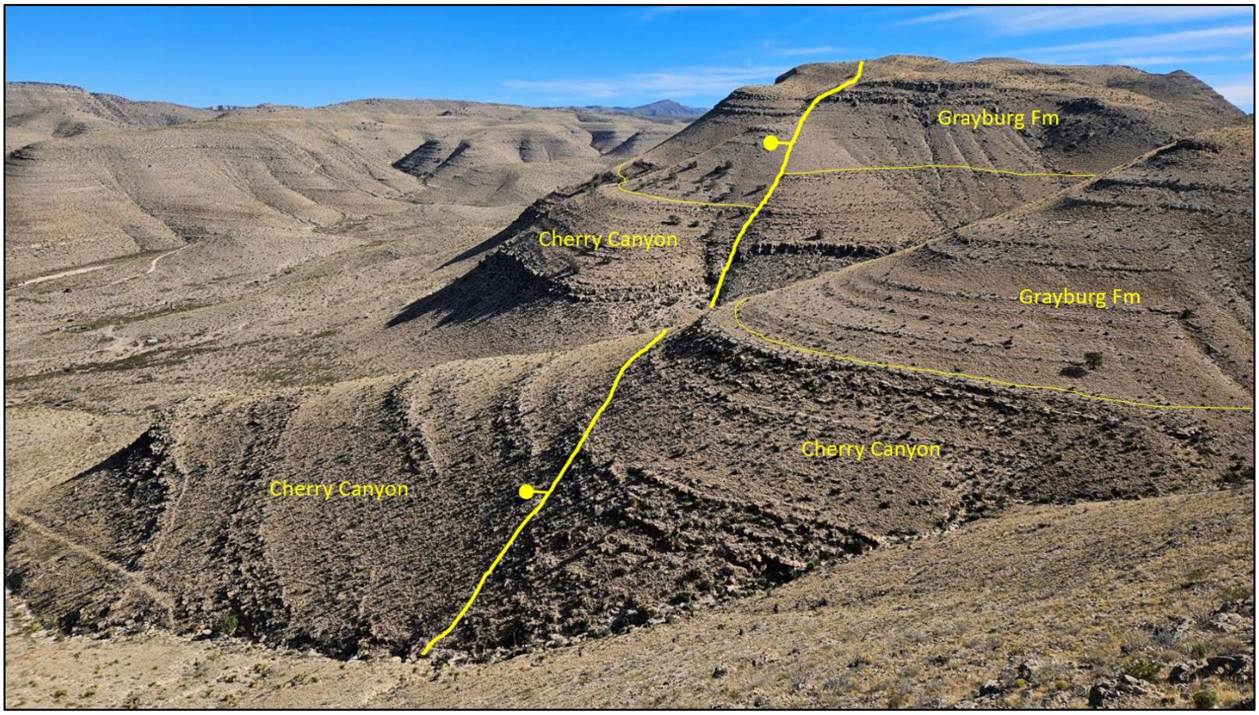

FIGURE 4—An photograph facing south-southeast along Cutoff Ridge and the western side of West Dog Canyon, shows where the contact was placed between the Grayburg Formation and the underlying Cherry Canyon tongue. The lower portion of the Grayburg Formation that forms a smooth slope contains interbedded dolomite and sandstone, but the prominent ledge of sandstone is easier to identify consistently across the region.

The Cherry Canyon Tongue

The Cherry Canyon Tongue is well exposed along the southwestern escarpment, where it forms light-rusty-orange cliffs of thick-bedded sandstone. The unit appears thickest in the south and thins gradually northward where it gradually becomes more dolomitic. The exact nature of this change is unclear due to the remoteness and incompleteness of the exposures. From a distance, it looks like some of the sandstone beds thin and interfinger with dolomite; whereas on aerial imagery, it appears that the sandstone, as a whole, abruptly changes to dolomite along strike. More detailed work needs to be done in this area to adequately understand this change. Along the southwestern escarpment, the Cherry Canyon Tongue abruptly overlies carbonate beds of the Cutoff Formation.

In the center of the map, exposed within the anticlinal ridge separating Middle Dog Canyon and Upper Dog Canyon, a sandstone unit was mapped. Here, the sandstone appears to be entirely between dolomite beds assigned to the Grayburg Formation, and pinches out southward into dolomite. It is not at all clear that this sandstone unit is part of the Cherry Canyon tongue, but its position in the stratigraphy suggests it is not the Queen Formation (the only other formation containing a thick interval of sandstone).

The Cutoff Formation

The Cutoff Formation is composed of interbedded light- to medium-gray limestone (**FIGURE 5**). The layers are commonly thin- to medium-bedded and the rocks typically break into thin platy fragments. These fragments litter the surface, however, and, as a result, good exposures are rare. From a distance, layering is obvious but close up it is more obscure. Freshly broken rocks exhibit a fetid odor and the color of fresh surfaces are very dark-gray; the upper 30 m or so is a lighter-gray dolomite (also recognized by Boyd, 1958, p. 14). As a whole, the formation forms rounded hills and slopes. The Formation can be followed along the far northwest prong of Cutoff Ridge until somewhere south of West Dog Canyon it appears very similar to the surrounding dolomite, and faulting has made it difficult to understand the geology of this area. Wilde (1986) studied these rocks in more detail.

FIGURE 5—A photograph taken looking southeast along the southwestern escarpment. The gently tilted beds in the center of the photo belong to the Cutoff Formation, sandwiched between the tan sandstone cliff of the Cherry Canyon tongue (above) and the darker cliffs of the Victorio Peak Limestone (below).

The Victorio Peak Limestone

The Victorio Peak Limestone is exposed only along the southwest escarpment where it forms a prominent cliff along the lower third of the escarpment (**FIGURES 6** and **7**). From a distance, the unit does not look that much different from the underlying and overlying sediments. Up close, however, it comprises a thick-bedded fossiliferous limestone that effervesces strongly in 10N hydrochloric acid. Most beds are abundantly fossiliferous and contain crinoid-stem fragments, shell fragments, and less abundant intact spirifer and productid brachiopods. Many layers do not contain any chert, but some contain abundant light-gray, irregularly shaped chert nodules that weather a rusty-orange color. Faulting has down-dropped a ridge of the unit further from the escarpment which now forms a series of elongated hills mostly buried by alluvial deposits.

Based on fossils, Boyd (1958) suggested that the Victorio Peak Limestone appears similar to the lower portion of the San Andres Formation and the two may correlate. Subsequent studies appear to confirm this correlation (see Kerans and others for a discussion and references therein). Based solely on lithostratigraphic criteria, however, during the current study the fossiliferous limestone beds of the Victorio Peak Limestone are distinct from the fossil-poor dolomite of the San Andres Formation. This may be the reason why Boyd (1958) also mapped the San Andres Formation and Victorio Peak Limestone as different and distinct units.

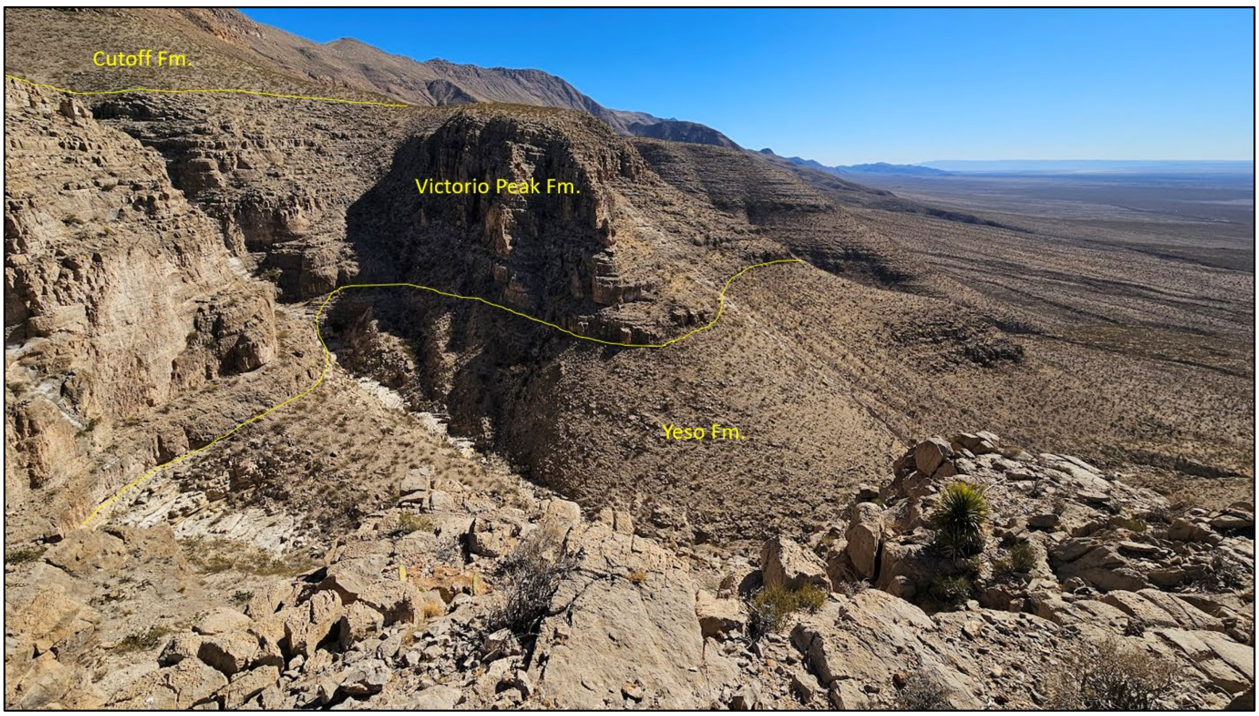

FIGURE 6— A photo of the Victorio Peak Limestone with distinct contact lines between overlying and underlying formations, looking southeast along the southwestern escarpment.

FIGURE 7—A photograph of thick beds of fossiliferous limestone of the Victorio Peak Limestone, looking west.

The Yeso Formation

The Yeso Formation is poorly exposed along the southwestern escarpment. Only the upper portion is exposed where it forms a slope below the cliff-forming Victorio Peak Limestone. The Yeso is entirely dolomitic. From a distance, it forms light- and dark-gray layers. Close up, these layers are less distinct and form mostly thick-bedded massive layers. With a hand lens, the dolomite exhibits a sucrosic, microcrystalline texture with no visible fossils, suggesting that the rock was recrystallized during dolomitization.

THE NORTHEAST QUARTER

The northeastern quarter of the map is dominated by a high plateau incised by numerous small drainages. Elevations range between about 5,800 and 6,200 ft above mean sea level. The vegetation is dominated by open piñon-juniper woodland. Most of this plateau is formed by the Grayburg Formation, which dips very gently (typically between 2 and 4°) to the northeast, and the overall slope of the plateau to the northeast mimics this underlying dip. Along the western edge of the plateau, along the Algerita Escarpment, several shallow stream valleys appear to be beheaded, suggesting that the drainage pattern pre-dates the formation of the escarpment. Most of the shallow stream valleys on the plateau are filled with silt and some clay. Possible sources for this fine sediment are (1) the insoluble residue released from dissolution of the nearby carbonate rocks, (2) erosion of the interbedded siltstone beds, and (3) wind-blown dust. It is possible that all three sources contributed.

Last Chance Canyon

Near the northeastern corner of the map, Last Chance Canyon slices deeply though the Grayburg Formation into the underlying San Andres Formation (**FIGURES 8** and **9**). As elsewhere, the San Andres is typically cliff-forming, compared to the predominantly slope-forming Grayburg, and forms a barrier to easy entry into the canyon. The base of the Grayburg Formation, here, contains a conspicuous (though thin) sandstone layer less than 1 m thick that is traceable throughout most of the canyon. The canyon itself forms a series of large meanders that probably began forming when a meandering river originally occupied softer overlying sediment. The meandering pattern was locked in place as the stream cut downward. Several large caves are visible along the base of the cliffs within the San Andres Formation. One cave, visible from the road, contains a metal wheelbarrow. It is not immediately clear how the wheelbarrow was transported up the steep rocky slope or for what purpose it was used. Quite a few geologists have studied and described the San Andres Formation within Last Chance Canyon (in particular, see Hayes, 1959).

FIGURE 8—An aerial photo of Last Chance Canyon, looking south towards the village of Queen. The cliffs lower in the canyon are the San Andres Formation, overlain by slopes of the Grayburg Formation.

FIGURE 9—A photo of Last Chance Canyon with contacts drawn and formations labeled, looking west. Note the large caves in the shade near the base of the cliffs.

Sinkholes

Also in the northeastern corner of the map, abundant small circular playas are visible near the village of Queen (**FIGURE 10**). The floors of the playas are very flat and are composed mostly of silt and clay. These features are interpreted to be the surface expression of collapse pits, or sinkholes that likely formed as a result of the dissolution of subsurface carbonate rocks. The silt and clay may have originated as insoluble residue from the dissolution of carbonate rocks at the surface and as wind-blown dust, both of which were probably slowly transported into these depressions.

FIGURE 10—An aerial photo of two circular playas north of the village of Queen, interpreted to be the surface expression of sinkholes that have been filled with sediment.

The Algerita Escarpment

The Algerita Escarpment, exposed in the north-central portion of the map, provides some of the most continuous exposures of Leonardian and early Guadalupian strata in the region. The 1,000 ft of relief on the escarpment was created by normal faulting that down-dropped the western block (now Upper Dog Canyon), leaving the eastern block as a high plateau.

The oldest rock unit exposed along the base of the escarpment is the Yeso Formation. From a distance, the Yeso Formation forms relatively smooth, light-colored slopes that deceptively resemble sandstone. Close-up, however, the Yeso is comprised entirely of light- to medium-gray, thin- to thick-bedded dolomite. The author took advantage of the continuous exposures and examined the Yeso Formation at two locations outside of the study area; the first location was with a drone, located at Section 18, T. 23 S., R. 19 E.; the second location was approximately one mile to the southeast of the first location within Section 20, T. 23 S., R. 20 E. where faulting down-dropped a section of the Yeso Formation further (and more accessible) from the escarpment. Both of these locations are approximately two miles southwest of Algerita Flat (not on this map).

Overlying the Yeso Formation along the escarpment is the San Andres Formation. North of the map area, the unit forms a prominent cliff that is slightly darker in color than the other rock units, making its base and top relatively easy to identify. However, south of the northern edge of the map, the prominent cliff grades abruptly into a series of slopes and ledges, making identification and delineation of the boundaries of the unit much more difficult. The possible presence of faults (as shown on the map) adds to the complexity. It is also possible the change in the cliff-forming nature of the San Andres represents facies changes delimited by sequence boundaries, as described by Fitchen (1993) for the San Andres further southwest. In any case, in this area, both the upper and lower contacts should be viewed as approximate, though at the scale of the map they are likely fairly accurate.

The youngest rock unit exposed along the escarpment is the Grayburg Formation, here composed of interbedded light-gray dolomite and light-yellowish-orange sandstone. As with elsewhere in the Brokeoff Mountains, the Brokeoff Formation here is commonly slightly lighter gray than the underlying San Andres Formation. Southward, however, bedding in both the Grayburg and San Andres Formations dip steeper to the west and in this area the two units are very difficult to distinguish from one another. Interbedded sandstone exposed near the base of the cliffs on the eastern side of Section 12, T. 22 S., R. 20 E. suggests that the lower slopes of this hill may be the southern limit of the San Andres Formation along the escarpment.

THE NORTHWESTERN BROKEOFF MOUNTAINS

In the northwest Brokeoff Mountains, deep canyons cut through the Grayburg Formation and down into the San Andres Formation. In this area the Grayburg is characterized by light-gray dolomite and smooth, rounded hills and slopes. By contrast, The San Andres is characterized by darker brownish-gray dolomite and steeper slopes and cliffs (**FIGURES 11** and **12**). Bedding in both units is conformable, so it is not immediately obvious where the contact should be drawn. In aerial imagery, the color difference is much easier to see than it is on the ground, but the exact position of the contact within the layers is still difficult to place. The reader should keep in mind that the contact between the two units is an approximation. On the western side of the Brokeoff Mountains, bedding in both formations dips gently to the west, forming a large westward-dipping homocline, or ramp.

FIGURE 11—A photo of a canyon incised into the northwestern Brokeoff Mountains. The canyon reveals the slightly dark-colored, cliff-forming layers of the San Andres Formation overlain by lighter-colored slopes of the Grayburg Formation.

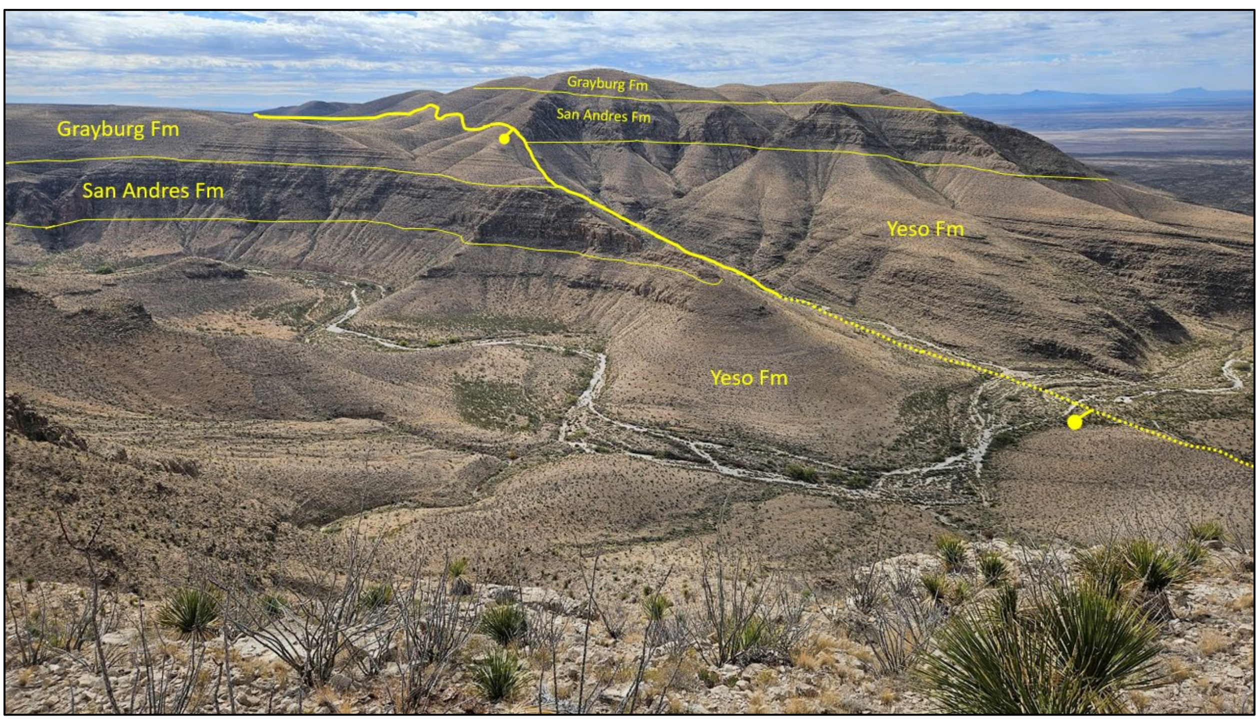

FIGURE 12—Looking southwest across Chosie Canyon. See also Plate 3 of Boyd (1958).

Another defining characteristic of the San Andres Formation in the northwestern Brokeoff Mountains is its large-scale porosity. At the outcrop scale, the rock commonly contains abundant small pores and cavities up to a few centimeters across, partially filled with calcite spar. Looking across a canyon, the unit contains abundant small, shallow caves, particularly in areas that form cliffs (**FIGURE 13**). In these same areas, the overlying Grayburg Formation conspicuously does not exhibit obvious caves.

FIGURE 13—A photo of an outcrop of the San Andres Formation in the northwestern Brokeoff Mountains shows the characteristic large-scale porosity.

One of the best areas to see the complete thickness of the San Andres Formation is in Chosie Canyon (**FIGURE 12**). Here, an imposing ridge forms the footwall of a major north-south trending normal fault. Within the footwall is exposed a thick section of the Grayburg, San Andres, and even the underlying Yeso Formation. All units here are composed of dolomite and the darker, cliff-forming San Andres helps to delineate all three as separate units. Small caves are abundant within the cliff faces of the San Andres.

BEDROCK WEST OF THE SALT BASIN

On the State geologic map, and in the geologic map created by O'Neill (1998), the expansive low plateau of bedrock of the southern Otero Plateau, west of the Brokeoff Mountains (west of the Salt Basin), is shown as the San Andres Formation. During the current study, the eastern edge of this bedrock plateau was examined to see how closely this rock matched the San Andres Formation within the Brokeoff Mountains and to confirm that both were actually indeed the same formation. The rocks along the eastern edge of the plateau are entirely light- to medium-gray dolomite and contain no interbedded sandstone. Many layers do not contain chert, but those that do contain light-gray, irregularly shaped chert nodules that weather a rusty-orange color. These characteristics most closely match those of the San Andres Formation as mapped within the Brokeoff Mountains, as opposed to the overlying Grayburg Formation or the underlying Yeso Formation.

Also on the west side of the Salt Basin, the small hill immediately east of Cienega Cemetery (not on this map) appears to be a different kind of rock than the San Andres. The hill is composed mostly of medium to dark gray thin- to medium-bedded dolomite, locally containing medium to dark gray irregularly shaped chert nodules. Although O'Neill mapped this outcrop as part of the San Andres Formation, it may instead belong to the underlying Yeso Formation.

QUATERNARY SEDIMENTARY DEPOSITS

On the map, all of the Quaternary deposits are lumped into two different deposits: alluvial deposits (**Qa**) and playa deposits (**Qp**).

As described in more detail above, most of the playa deposits are exposed in the northeast quarter of the map within small circular depressions interpreted to be the surface expression of sinkholes. The only other mapped playa deposit is in the north-central portion of the map. Here, the deposits form a conspicuous oval outline composed of silt and clay at the surface, which is mostly devoid of vegetation. This is the only visible closed depression outside of the smaller sinkholes to the east and the Salt Basin itself to the west. The drainage area that feeds this depression is relatively small—only a few square miles. Almost all of the upstream drainage of Upper Dog Canyon bypasses this depression and instead flows through a stream that is deeply incised through the northern end of the Brokeoff Mountains.

In the far southwestern corner of the study area, the Pleistocene lake basin deposits of the Salt Basin are exposed. At the scale of the map, however, these deposits form only a small area and were not mapped separately. Immediately to the west, within the Cienega School quadrangle, O'Neill (1998) mapped these deposits in great detail, where he distinguished gypsum-bearing lake deposits, stabilized dunes, and younger eolian silt and sand. He identified the highstand of the former lake at an elevation of approximately 3,685 ft above mean sea level and described how the adjacent alluvial fans became more and more dissected as the lake level dropped.

Within the El Paso Gap 15′ quadrangle, it was not practical to distinguish all of the ages and types of alluvial deposits (**Qa**) at the scale of the map. As mapped, they include colluvium on the steeper slopes, alluvial fans within the basins, and axial stream deposits (**FIGURES 14** and **15**). The older alluvial fan deposits are commonly moderately cemented with calcium carbonate, which makes them appear lighter gray in color and more resistant than younger, less-cemented deposits. The older fan-deposits are typically more deeply dissected than the younger fan-deposits and reside slightly higher in the landscape. In his Master's thesis, Given (2004) described the geomorphology and morphometric characteristics of many alluvial fans along the Brokeoff Mountains and Algerita Escarpment.

FIGURE 14—A photo of a stream-cut exposure in the northeastern Brokeoff Mountains. These exposed Quaternary alluvial deposits show typical interbedded coarse and fine clastic material.

FIGURE 15—A photograph of a typical view of Quaternary deposits within the active channel in West Dog Canyon.

Not far from the southwestern escarpment, near the center of the Panther Canyon 7.5′ quadrangle, Lambert (2005) identified and described a beautiful example of imminent stream capture. In this area, approximately 0.5 mi upstream from Cork Draw, a bend in the south-flowing drainage within South Tank Canyon is within two meters of overtopping the very low divide separating it from a shorter path to West Dog Canyon. As Lambert explained, once this stream capture occurs, the gradient of the captured stream will increase from 27.6 m/km to 124 m/km, leading to headward erosion and relatively rapid down-cutting of South Tank Canyon upstream from the capture. **FIGURE 16** shows this low-drainage divide as it looked on December 13, 2023.

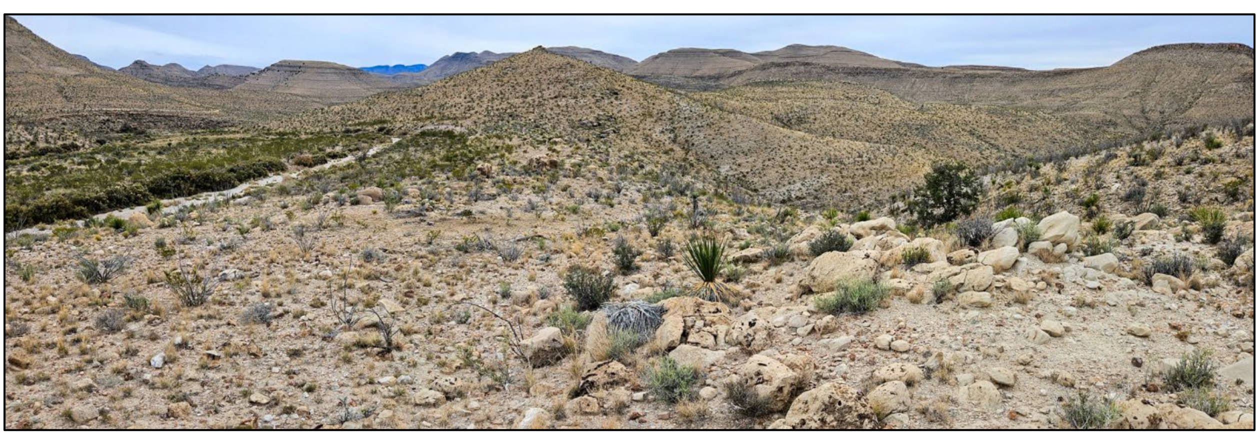

FIGURE 16—A photo of the low drainage divide between South Tank Canyon and West Dog Canyon, looking SE.

STRUCTURE

Folds

In the southeastern corner of the map, several closely spaced synclines and anticlines trend northeast. The dips of bedding in the limbs of the folds are mostly less than 5° and these folds are neither obvious on the ground nor in aerial imagery. This group of folds continues into the adjacent Gunsight Canyon 7.5′ quadrangle to the east (Skotnicki and Allen, 2023) where they deform rocks as young as the Tansill Formation. In the center of the study area, another series of parallel, closely spaced folds trends north-northwest. Although in most areas, the dip of bedding in the limbs of the folds is typically less than 8°, dips are locally as much as 25°. This group of folds mostly deforms the Grayburg Formation, although within the Shattuck Valley, rocks as young as the Seven Rivers Formation are folded.

The age and origin of these folds are not certain. The folds in the southeast are parallel to the mountainfront and to the Capitan Reef along the margin of the Delaware basin, suggesting a shared origin. The folds in the center of the map are, interestingly, also closely located parallel to the many faults in the area. The syncline in Shattuck Valley, in particular, may have been created by fault-drag folding along the Shattuck Valley fault. However, it is not clear if other synclines were formed the same way. For example, west of Shattuck Valley in Upper Dog Canyon (**FIGURE 17**), bedding on both sides of the valley dip towards the center of the valley, while the trace of the basin-bounding fault seems to also project down the center of the valley. It is possible that the orientation of folds was controlled by some underlying weak structure in the crust, and that weakness was later reactivated during extension to form faults with the same trend. If so, then the disparity between the orientation of folds in the southeast and center suggests that the Shattuck Valley fault and the basin-bounding fault(s) along the Algerita Escarpment may reflect a long-lived boundary between different crustal domains.

FIGURE 17—Photo of Upper Dog Canyon, looking south near the southern end of the Algerita Escarpment. Bedding within the Grayburg Formation dips up to 22° eastward on the western limb of a syncline that forms the valley.

Faults

To the southeast, the Shattuck Valley fault is visible along portions of the steep scarp in this area. Northeast of El Paso Gap itself, the fault is visible as a north-south lineation along the lower central portions of the cliff. Examination in the field reveals this lineation as a buttress unconformity between Permian carbonate rocks on the east and Holocene sedimentary deposits on the west. There is no visible offset of the Holocene deposits and the deposits show very little dissection. So although the Holocene deposits are not faulted, the contact probably closely follows the trace of the fault. On the map, the fault is shown in this area as concealed. Further south along the same escarpment, the fault is very difficult to identify with confidence. However, several knobs and outliers on the lower slope of the escarpment show bedding in carbonate rocks dipping as much as 25° to the west. These are interpreted to represent fault-drag folding within the hanging wall of the fault.

To the west of Shattuck Valley, the very linear western side of the ridge through which El Paso Gap cuts suggests it is formed by a west-side-down normal fault. Unfortunately, this inferred fault is almost nowhere exposed. Not far north of El Paso Gap, tilted bedding adjacent to the inferred trace of the faults suggests fault-drag folding. If the fault continues north of here it is not obviously visible within the walls of the deep canyon west of Effendale tank. North of here, the long, curving cliffs of the Algerita Escarpment suggest the presence of one or more large, basin-bounding, down-to-the-west, normal faults. Near the north-central edge of the map, a few similarly oriented faults appear to be entirely within the Yeso Formation, but these don't provide a good estimate of the amount of offset. Because the fault (or faults) is nowhere exposed, its trace was drawn simply as one concealed normal fault on both the map and within the cross section. The reader should be aware that faulting may be more complex. Not far to the north, north of the study area and along the Algerita Escarpment, better exposures show the faulting much clearer (**FIGURE 18**). Here, a southwest-side-down normal fault has down-dropped the San Andres and Grayburg Formations by more than 600 ft. And, at least in this particular area, the main fault that formed the escarpment is located further out in the valley and is not at the base of the escarpment.

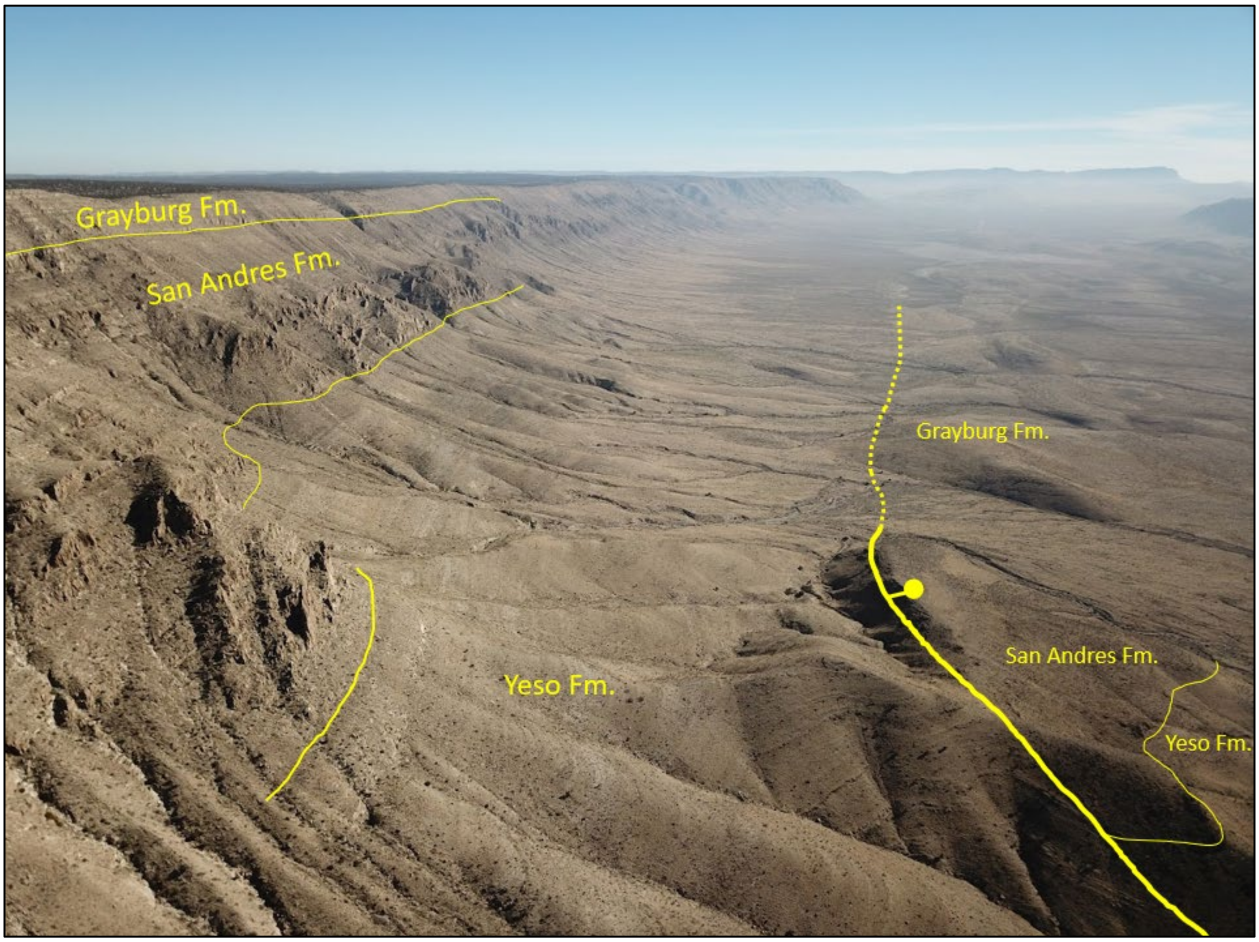

FIGURE 18—Photo looking southeast along the Algerita Escarpment (aerial view via drone), taken north of the El Paso Gap 15′ quadrangle, showing down-to-the-west displacement along a major fault. The ball and bar of the fault are on the downthrown block.

On the west side of Upper Dog Canyon, the eastern side of the Brokeoff Mountains forms a sharp, linear boundary defined in a few places by a down-to-the-east normal fault. Together with the inferred fault on the east side of the valley, along the base of the Algerita Escarpment, these two faults form a large north-northwest trending graben that extends north of the map area. To the south, the graben splits into two graben, forming Middle Dog Canyon and Upper Dog Canyon, separated by Martine Ridge.

In the southern Brokeoff Mountains, a normal fault along the east side of Cutoff Ridge and another on the west side of Big Ridge/Plowman Ridge, together form a large northwest-trending graben approximately 2.5 mi wide (**FIGURES 19** and **20**), here named the West Dog Canyon graben for the trunk stream that drains most of the structure. The southern portion of this graben extends southward into the Guadalupe Mountains National Park and can be seen particularly well from the top of Lost Peak (see figure 24 of Skotnicki and Knight, 2021).

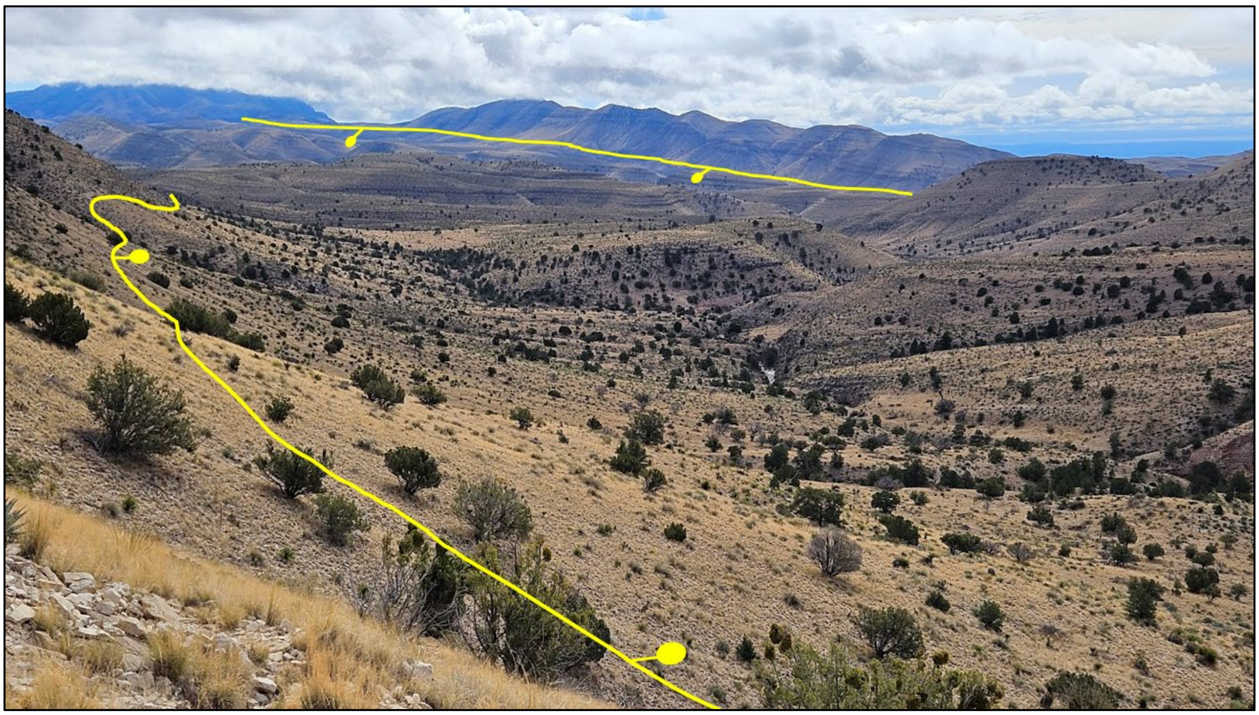

FIGURE 19— Photo taken, facing south, from Section 29, T. 24 S., R. 20 E. Two parallel inward-facing (ball and bar are on the downthrown block) normal faults are illustrated along Big Ridge/Plowman Ridge (left) and Cutoff Ridge (right) form the West Dog Canyon graben.

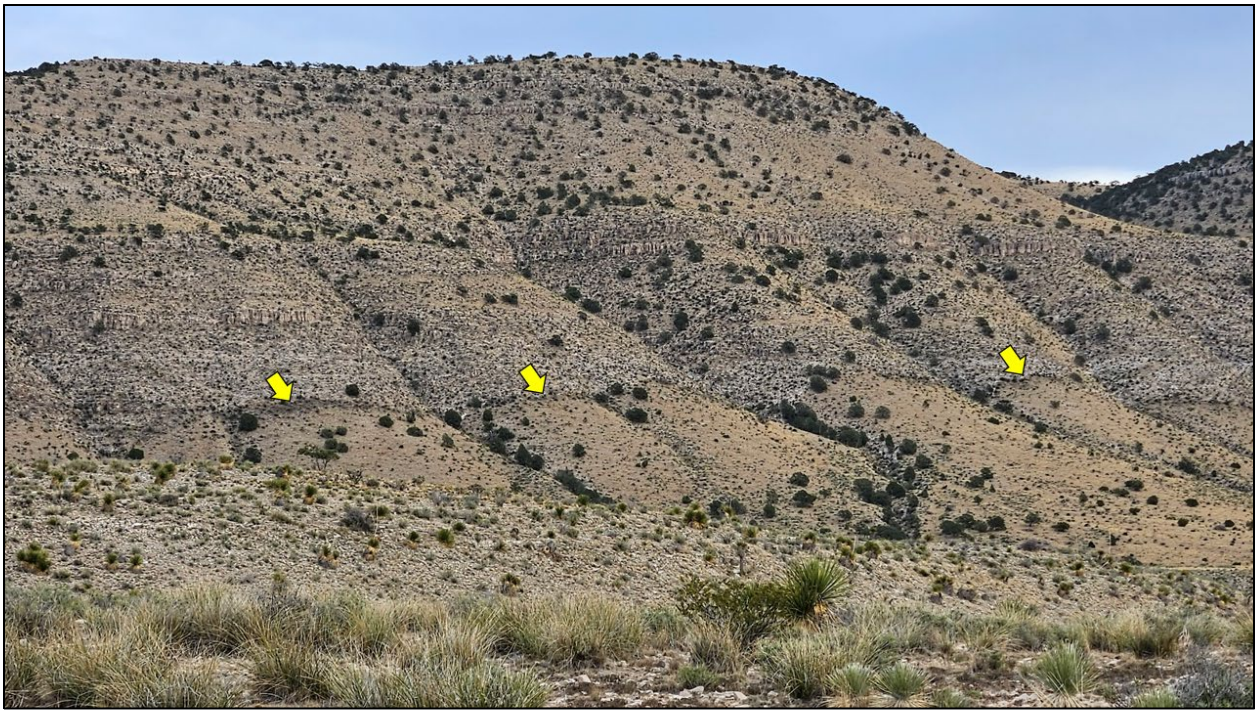

FIGURE 20—Photograph of Big Ridge/Plowman Ridge. The trace of the fault on the west side is highlighted with yellow arrows.

To the north, many of the northwest-trending linear ridges within the Brokeoff Mountains appear to have been formed by similarly oriented normal faults. Since most of these inferred faults displace carbonate rocks against carbonate rocks, the faults themselves are mostly very difficult to identify. Locally, offset of carbonate layers well exposed in the walls of canyons reveal the trace of faults but, in general, the faults are more easily identified using aerial imagery where they typically reveal themselves as faint, linear, color differences or breaks in slope. But even with aerial imagery faults can be very difficult to identify. The DataSourceID field within the ContactsAndFaults attribute table distinguishes which faults were identified in the field from those identified with aerial imagery. Where no fault could be confidently identified, even with the presence of a linear ridge, none was drawn. In addition, the scale of the map made it necessary to not show the smaller faults on the map. Therefore, the reader should keep in mind that there are more faults in the Brokeoff Mountains than are actually shown on this map.

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Unit Descriptions

CENOZOIC ERATHEM

Quaternary System

Qp Playa deposits (Holocene and Pleistocene)—Silt, fine-grained sand, and some clay. Forms flat, featureless deposits that fill sinkholes in the northwestern portion of the map, and one larger playa in the low valley near the north-central portion of the map. Mostly devoid of vegetation though the borders of the deposits filling the sinkholes are bordered by piñon and juniper. The thickness of these deposits is unknown.

Qa Alluvial deposits (Holocene and Pleistocene)—As mapped, these deposits are composed of weakly to strongly indurated sand and gravel in a silty to sandy carbonaceous matrix. The older deposits form terraces typically between 1–3 m above the active channel deposits and are lighter gray in color than younger deposits because erosion has exposed more of the carbonate pedogenic cements. The younger deposits typically exhibit well-developed silty soil that supports abundant vegetation, particularly grasses and creosote. Estimated thickness of deposits are up to 5 m.

PALEOZOIC ERATHEM

Permian System

Guadalupian Series

Artesia Group

Py Yates Formation (Permian, Guadalupian)—Interbedded dolomite and siltstone/fine-grained sandstone. Characteristically contains many interbeds of dark-yellow-weathering siltstone and fine-grained sandstone that tend to form vegetated slopes. Dolomite is typically light-gray, massive and fenestrated, and commonly weathers a darker tan. In the southeast portion of the map, particularly closer to the Capitan Formation, the dolomite beds locally contain abundant beds of pisoids (or pisoliths) interbedded with wavy-laminated dolomite. No teepee structures were obvious within the map area. The Yates Formation was recognized only in the far southeast portion of the map. The top has been eroded. Exposed thickness is ≈30 m.

Psr Seven Rivers Formation (Permian, Guadalupian)—Thick-bedded, gray dolomite occurs in rather massive beds between 1–3 m thick, separated by thin partings. From a distance, the formation contains very few siltstone/fine-grained sandstone beds up to tens of centimeters thick, mostly in the lower portion of the exposed outcrops. Forms cliffs and steep ledgy slopes. The best exposures are along the steep cliffs in the southeastern potion of the map. Elsewhere, the unit is mostly covered with vegetation and forms slopes covered with soil and debris. The contact with the underlying Queen Formation is drawn above a thick interval of sandstone within the Queen Formation. Thickness of the formation is up to 180 m.

Pq Queen Formation (Permian, Guadalupian)—Quartz siltstone and fine-grained quartz sandstone. Grains are subangular to subrounded. Typically contains very planar, thin to thick beds that commonly erode recessively and form slopes. Locally contains very minor thin beds of light-gray dolomite approximately 10–30 cm thick, that typically form small resistant ledges. The uppermost 20 m or so contain several thin to thick interbedded light–gray dolomite layers up to several meters thick. The unit commonly forms deep-rusty-orange soils. As mapped west of Upper Dog Canyon, the unit appears to contain siltier dolomite near the south side of the map. Formation thickness is up to 105 m.

Pg Grayburg Formation (Permian, Guadalupian)—Light-gray to very pale-yellowish-gray, laminated, fine-grained dolomite, interbedded with pale-orange siltstone and very fine-grained sandstone. Most beds are massive to weakly laminated and locally fenestrate. As mapped, this unit forms a thick sequence of layers that comprises most of the Paleozoic outcrops in the map. The unit is typically slightly light-gray and forms smoother, more gently sloping hills than does the underlying San Andres Formation. Commonly distinguished from the overlying Queen Formation by its lighter-gray color and steeper slopes and cliffs. Formation thickness is between 100 and 150 m.

Capitan Formation

Pcp Capitan Formation (Permian, Guadalupian)—Massive limestone, dolomite, and limestone/dolomite breccia. From a distance, the top of this unit exhibits a weakly developed inclined layering that dips southeastward between ≈15 and 30°. This layering is more pronounced up-section where it merges with the bedding in the lower part of the Seven Rivers Formation. Because of this, the contact as drawn, is dashed and is somewhat arbitrary. In outcrop, most exposures appear massive and without structure. A faint brecciated texture is visible locally where angular clasts of all sizes are strongly cemented by different generations of carbonate. Coarse-grained, light-yellow sparite 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 Capitan Reef itself and the fragmented debris shed from the ancient reef into the Delaware Basin. Typically forms very steep slopes and cliffs. Thickness is up to 400 m.

Delaware Mountain Group

Pcc Cherry Canyon Tongue (Permian, Guadalupian)—Mostly thin- to medium-bedded, light-orange, quartz siltstone and fine-grained sandstone, interbedded with less abundant layers of typically medium- to thick-bedded, gray dolomite. From a distance, the sandstone and dolomite layers commonly appear very similar in color, but can be distinguished fairly easily up close. The unit typically forms slopes that are mostly covered with debris and are poorly exposed. In the southwest corner of the map, along the western escarpment, the unit forms an imposing cliff and steep slope up to 200 m thick. In the center of the map, approximately 60 m of the unit is sandwiched between thicker layers of dolomite of the Grayburg Formation.

Loenardian Series

Psa San Andres Formation (Permian, Leonardian)—Planar-bedded dolomite mostly in beds between 10–30 cm thick with minor, thicker beds up to 1–2 m thick. All beds are massive and show no internal layering and rare laminae. The medium-gray color is similar on both fresh and weathered surfaces. Rocks emit a fetid odor when broken. With a hand lens, the rock is very fine-grained micrite. Where exposed, lower portions of the unit contain light-gray chert that weathers rusty-orange. No visible fossils in the rocks. Locally contains abundant cavernous pores 1–10 cm in diameter, lined by rims of botryoidal calcite that give outcrops a very porous appearance. Shallow caves are also abundant on some cliff exposures. Thickness varies from approximately 140 m in the southwest to 170 m in the north-central map area.

Pco Cutoff Formation (Permian, Leonardian)—Medium-gray, thin- to medium-bedded limestone. Featureless and massive micrite. Fresh surfaces are very dark-gray and exhibit a fetid odor; weathered surfaces are typically much lighter gray in color. The lower third contains abundant black chert. The uppermost 30 m is light gray dolomite. This unit mostly forms slopes along the western escarpment in the southwestern corner of the map. Bedding is best seen from a distance. Erodes into platy fragments up to ≈20 cm across. Formation thickness is up to 90 m.

Pvp Victorio Peak Limestone (Permian, Leonardian)—Thick-bedded limestone (effervesces strongly with hydrochloric acid). Contains abundant fossil debris, particularly crinoid-stem plates and shell fragments. Brachiopod moulds (both productid and spirifer) are locally as large as 6 cm across. Beds are massive and show almost no internal layering. Many beds do not contain chert. In those beds that do, it is abundant, light-gray, and forms small irregularly shaped nodules that weather rusty-orange. This unit forms a steep resistant cliff along the western escarpment in the southwest corner of the map. Formation thickness is approximately 85 m.

Pyo Yeso Formation (Permian, Leonardian)—Light-gray to dark-gray, medium-bedded dolomite exhibiting a sucrosic, microcrystalline texture. No visible fossils and rare chert. Everywhere, the unit forms slopes and is poorly exposed. Layering can be discerned easily from a distance but becomes more cryptic and indistinct up close. The best exposures are in the north, at the base of the Algerita Escarpment. Although Kerans and others (1993) described the Yeso Formation and the Victorio Peak Limestone as partly coeval, within the map area the Yeso is below the Victorio Peak. Only a portion of the unit is exposed. In the southwest the visible thickness is 105 m. Along the Algerita Escarpment, the formation thickness is up to 170 m.

U Unmapped Deeper regions in the subsurface where no confidence exists for placing contacts or unit names. Shown only in cross section.