# Geologic Map of the Rattlesnake Springs 7.5-Minute Quadrangle, Eddy County, New Mexico

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Scale 1:24,000

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**New Mexico Bureau of Geology and Mineral Resources**
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# Geologic Map of Rattlesnake Springs 7.5' Quadrangle

B.D. Allen and S. Attia, May 2021

# Setting

The Rattlesnake Springs 7.5-minute quadrangle lies on the northwestern side of the Delaware Basin, 40 km south-southwest of Carlsbad, NM along U.S. Highway 62-180 and approximately 35 km west of the Pecos River. Located in the Chihuahuan Desert, the climate is semiarid and vegetation is sparse. The southeast-facing escarpment of Guadalupe Ridge (eastern side of the Guadalupe Mountains), which exposes Permian marine shelf-margin carbonate rocks, rises abruptly a short distance west of the map area. Black River, a tributary of the Pecos River, drains northward through the western part of the map area, then turns eastward along the northern edge of the quad.

A short reach of the Black River drainage within the map area, referred to in reports as the upper perennial reach of Black River, contains riparian areas where groundwater originating in the Guadalupe Mountains is discharged at the surface in springs and in wetlands along the valley floor. Water supply for the Carlsbad Caverns visitor center is obtained from Rattlesnake Springs, located a short distance west of the main Black River channel. These riparian areas were somewhat modified by early Anglo settlers, and agricultural fields continue to be worked on private landholdings along the Black River drainage. Portions of the wetlands are administered by the Bureau of Land Management and the National Park Service, along with the privately administered Washington Ranch facility located a short distance to the northeast of Rattlesnake Springs. On the northern edge of the map area, near the Washington Ranch headquarters and the confluence of Black River with Rattlesnake Canyon Draw, the Black River becomes ephemeral and remains so for several kilometers downstream.

The map area is underlain by latest Permian evaporite rocks of the Castile and overlying Salado formations, which consist largely of calcium sulfate (anhydrite or gypsum) and lesser amounts of halite. Gypsum is present at or near the surface to the east of Black River in an eroded bedrock “upland” that is part of a larger area extending southward into Culberson County, Texas known as the Gypsum Plain. Dissolution of Permian evaporites has resulted in extensive karst development on the Gypsum Plain, and the entire map area is pockmarked by features associated with solution-subsidence. These features include the large solution troughs in the southern part of the map area, and outliers of younger Permian and Cretaceous strata that have foundered and subsided due to dissolution of underlying evaporites.

The Gypsum Plain ends in the western part of the map area where it adjoins the Black River, which is entrenched a few tens of meters below the level of the plain. West of this escarpment the landscape rises toward Guadalupe Ridge, and surface deposits consist largely of distal fan-piedmont alluvium derived from the Guadalupe Mountains.

The nearest major canyons that cut through the Guadalupe escarpment and provide sediment to the piedmont slope in the map area are Rattlesnake and Slaughter canyons. Drainages originating farther to the south, including the Black River drainage and McKittrick Canyon Draw, drain southeastward from the Guadalupes then northeastward, entering the map area on the southwest side. To the north, the next major breach in the Guadalupe escarpment is Walnut Canyon (which leads to Carlsbad Caverns). The dissected piedmont between Walnut Canyon and Rattlesnake Canyon contains interfluvial summits that are held up by cemented gravels lying on beveled Permian gypsum bedrock. These piedmont deposits extend into the northern part of the map area, and are graded to levels 20+ meters above the active

Black River drainage. A few scattered remnants of older piedmont deposits are present at higher levels to the east of Highway 62/180 on the Gypsum Plain.

The structural disposition and thicknesses of Permian and Pennsylvanian sedimentary rock units underlying the Castile Formation are depicted on the geologic cross section. These rock units consist of marine and marginal-marine carbonate and siliciclastic deposits that accumulated in a subsiding basin (Delaware Basin) at equatorial latitudes along the western margin of Pangea. Subsurface data obtained from geophysical well logs reveal a significant flexure in Carboniferous strata, involving ~1300 meters of structural relief, that was filled in for the most part by the Lower Permian Wolfcamp and Bone Spring formations. This structure lies on strike with a northwesterly trending structure, historically identified in the Guadalupe Mountains to the northwest of the map area, known as the Huapache flexure or monocline. The cross section is oriented perpendicular to the strike of this flexure, as indicated by structure contours on the Pennsylvanian Strawn Formation.

Late Cretaceous-Paleogene (Laramide) crustal contraction resulted in substantial regional uplift across western North America, including the greater Delaware Basin area, but evidence for Laramide deformation of sedimentary rocks underlying the western Delaware Basin is subdued. Regional Laramide uplift was accentuated by flexural uplift of the Delaware Mountains during Neogene Basin and Range crustal extension. Uplift involved substantial down-to-the-west faulting along the western side of the mountain range, relative down-dropping of the Salt Basin graben farther to the west, and tilting on the eastern side of the range and western Delaware Basin. Structure contours on top of the Permian Bell Canyon Formation indicate overall tilt in the map area of one or two degrees toward the east, with local dips up to about 4 degrees.

The distribution of surface features and deposits depicted on the geologic map are part of a larger landscape, the lower Pecos River valley, that developed in conjunction with Neogene uplift of the Guadalupe Mountains and a variety of regional factors and events spanning the last several million years. Many details of this relatively recent geologic history, which included significant fluctuations in climate and the widespread dissolution of thick sequences of Permian evaporites, continue to be worked out.

# Description of Map Units

## Anthropogenic

d Disturbed areas (highway, excavation, agriculture).

## Hydrologic

w Standing water in vicinity of Black River, from 20 May, 2016 aerial photographs. Includes Rattlesnake Springs and upper perennial reach of Black River, Bottomless Lakes sinkhole pond, and artificial storage ponds at Washington Ranch.

# Cenozoic Erathem

## Quaternary System

### Eolian, alluvial, and colluvial surface deposits

Qae Windblown silt, fine sand and slope-wash mud blanketing relatively flat areas to the east of Black River (Holocene). Grades downward into gypsite and Permian gypsum bedrock over most of the map area. Coarser-grained, locally derived reworked clastic materials may be present in varying amounts, especially in the north-central part of the map area where piedmont gravels are present at the surface. On the Gypsum Plain, patches of relatively intact bedrock gypsum are commonly exposed at the surface where the unit is thin. Small exposures of Permian bedrock also surround numerous karst openings or swallets (drains for surface runoff), many of which are present in the map area, but these outcrops of bedrock are generally too small to differentiate at the scale of the map. Overall, the unit ranges from pale tan to brown in color at the surface, with increasing proportions of white gypsite at depth. Deposits may rarely be 3 m thick or more, but in most areas, consist of a thin, decimeter-scale mantle over gypsite and underlying Permian bedrock gypsum.

Short Description: Windblown silt, fine sand and slope wash mantling relatively flat areas to the east of Black River.

Qaed Accumulations of eolian and alluvial silt, sand, clay and gravel in closed or nearly closed depressions (Holocene). On the Gypsum Plain, this map unit generally consists of eolian and alluvial silt to fine sand with scattered coarser materials, and varying amounts of gypsite. Depression-fill deposits west of Black River and in the north-central part of the map area contain variable amounts of gravel (Permian carbonate clasts) sourced from the Guadalupe escarpment to the west. Fines are generally pale tan to brown in color. Many, if not most of the depressions are surface expressions of pervasive karst development in the area; surface openings in depressions range in size from decimeter-scale crevices to cave-size openings. Fills in individual depressions in the large solution-subsidence troughs present in the southern part of the map area (Olive, 1957) may be only a few decimeters thick or less, whereas depressions on the fan piedmont west of and along Black River may contain several meters of relatively young fill. For example, the modern drainage from Black Canyon, to the southwest of the map area (headwaters of Black River), ends in solution subsidence depressions just to the west of the southwestern margin of the map area, and the thickness of relatively young depression fill may be substantial in that area.

Short Description: Silt, sand, clay and gravel in closed or nearly closed depressions.

Qac Accumulations of alluvium and colluvium along steep slopes and associated down-slope alluvial aprons (Holocene). On the Gypsum Plain these deposits are delineated along erosional scarps in Permian bedrock, which are present along the eastern side of the Black River drainage and along the solution-subsidence troughs present in the southern part of the map area. Deposits consist of white and gray gypsite and clasts of eroded Permian gypsum, together with pale tan to brown siliciclastic silt, sand and rarely coarser-grained materials (gravel) derived locally from higher levels on the landscape. Thickness of the deposits may be thin (< 1 m) to a few meters in thickness. Along the northern edge of the map area, Qac colluvium on slopes below dissected older piedmont deposits are commonly gravelly, and form a thin cover over Permian bedrock or undifferentiated alluvial fill deposits.

Short Description: Accumulations of alluvium and colluvium along steep slopes and associated down-slope alluvial aprons.

Qay Alluvium along active drainages (Upper Pleistocene? to Holocene). Alluvial sand, mud, and gravel along active drainages, including deposits underlying low terraces within and adjacent to modern channel systems. Alluvium in tributary drainages west of Black River contain abundant, poorly-sorted pebbles, cobbles and boulders of Permian carbonate rocks, although in some reaches surface deposits are comparatively fine grained. Thickness of channel deposits on the piedmont slope, including low fill terraces, is probably on the order of a few meters in most areas. Low terrace deposits above the Black River channel include gray, comparatively fine-grained gypsiferous mud containing mollusks, organic debris and precipitated calcium carbonate (tufa), and have been locally modified for control and storage of water. Upstream from the confluence with Slaughter Canyon Draw these terraces merge with map unit Qvae, and the incised, headward-eroding Black River channel ends. Discharge of groundwater with comparatively high concentrations of sulfate occurs in this perennial upstream reach of Black River (channel segments containing standing water are indicated on the map). Carbonate-cemented gravel (conglomerate) exposed along Black River channel may represent comparatively young deposits undergoing cementation, or may be exhumed remnants of older alluvial fills. The drainage containing Rattlesnake Springs is relatively short, broad and steep sided, appearing to have formed by groundwater sapping, and surface deposits are comparatively fine grained. Cemented gravels (conglomerate) exposed at the surface along the floor of the drainage are thought to be the main source of groundwater feeding the spring (Hale, 1955). Sediment in drainages on the Gypsum Plain is generally pale tan to brown silt and sand containing various amounts of white gypsite, and deposits are probably less than 2 m thick in most places. Drainages in the northeastern part of the map area (Chosa Draw) are comparatively narrow and deeply scoured into weathered Permian gypsum.

Short Description: Alluvial sand, mud, and gravel along active drainages.

Qvae Valley-floor sand, mud, gravel and gypsite underlying floodplains in larger drainages bordered by gypsum bedrock (Upper Pleistocene to Holocene). In general, sediments are relatively fine grained and likely contain significant amounts of wind-blown dust trapped by grasses and shrubs, together with gypsiferous material washed in from embankments eroded in Permian bedrock. Fills on the order of a few meters in thickness in the larger west-to-east-flowing drainages in the southern part of the map area range from brown to gray in color, and grade downward into white gypsite overlying gypsum bedrock. Changes in vegetation apparent on aerial photographs suggest that the depth to saturated sediment varies along different reaches of these drainages, with shallow groundwater, ephemeral seeps and areas subject to flooding present in some reaches. Deposits adjacent to the gypsum-bedrock escarpment along the eastern margin of the Black River are similar in texture, composition and color, and contain contributions of sand and gravel from piedmont drainages and alluvial aprons to the west. Available water-well logs in this part of the map area suggest that approximately 20 m of clayey sediment is present beneath the surface in some areas; other areas are underlain at shallow depth by "white gypsum" (gypsite?). Shallow groundwater emerges at the surface along the perennial upper reach of the Black River, and in the Bottomless Lakes sinkhole pond in the west-central part of the map area.

Short Description: Valley-floor sand, mud, gravel and gypsite underlying floodplains in larger drainages bordered by gypsum bedrock.

Qvg Valley-floor gypsite along Black River (Upper Pleistocene-Holocene). Relatively light (porous), earthy aggregate of silt- and sand-sized gypsum grains in a very fine-grained gypsum matrix, derived from weathering and local transport of Permian bedrock gypsum along the western margin of Black River valley. Unit is white to light-gray, is generally thinly mantled by brown eolian dust, and may exhibit a durable decimeter to meter-scale surficial gypsum crust. Crude stratification is suggested in some gully-cut exposures, and in places intercalated clastic sediment derived from the fan piedmont to the west and tufa are present. The unit underlies flat to gently sloping, sparsely vegetated areas adjacent to and up to several meters above the Black River floodplain, and forms isolated positive-relief areas along Black River just downstream from the BLM Cottonwood Day Use Area. Grades laterally into generally less gypsiferous valley-floor sediment of map unit Qvae. Differentiation of the map unit as a Quaternary "deposit" (implying transport and deposition of clastic sediment) is somewhat arbitrary; in places the distinction between this unit and weathered Permian gypsum bedrock is subtle, and there are areas on the Gypsum Plain to the east, mapped here as Permian bedrock, that may be genetically analogous.

Short Description: Valley-floor gypsite along Black River.

Qpy Younger piedmont-slope sand, gravel and mud (Upper Pleistocene to Holocene). These deposits are graded to levels a few meters above present drainages, and form an alluvial apron that extends eastward toward valley-floor deposits along the Black River. Unit includes deposits graded to more than one closely-spaced level (see Love and Land, 2006). Sediment contains gravel clasts derived largely from Permian carbonate bedrock in the Guadalupe Mountains, and from reworking of previously deposited, piedmont-slope alluvium. Gravelly deposits are present in lenticular channels and in more continuous, decimeter- to meter-scale beds, and are typically indurated with calcium carbonate cement. Cementation of comparatively young gravel deposits in the area, including gravelly beds along modern drainages, is commonly observed, and apparently does not indicate substantial antiquity. Finer-grained sandy deposits appear to comprise much (> 50 %) of the unit, are pale tan to reddish-brown in color, and exhibit filaments and small isolated nodules of pedogenic carbonate. Cutbank exposures a few meters in thickness are present along Rattlesnake Canyon Draw in the northwestern part of the map area.

Short description: Younger piedmont-slope sand, gravel and mud.

Qpi Intermediate piedmont-slope sand, gravel and mud (Middle? to Upper Pleistocene). Remnant distal fan-piedmont deposits consisting of discontinuously stratified sand, gravel and finer-grained alluvium derived in large part from Permian carbonate rocks in the Guadalupe Mountains to the west. Summit areas are graded to a somewhat higher level than inset deposits of map units Qay and Qpy. Qpi deposits in the northwestern corner of the map area exhibit typical alluvial fan morphology and converge up slope toward the mouth of Slaughter Canyon, about 6 km from the western edge of the map area. Drainage from Slaughter Canyon presently wraps around the northern end of the fan and joins Rattlesnake Canyon Draw to the west of the map area, but historically skirted the southern end of the fan in Slaughter Canyon Draw. Although mapped as a single unit, Qpi fan remnants are stripped by erosion in some areas, especially along eroded sideslopes, and summit areas are mantled by younger deposits in other areas. Gravelly strata are cemented by carbonate, and surface soils developed in finer-grained deposits exhibit well-developed (stage III) pedogenic carbonate horizons. Water-well driller's logs that were examined indicate beds of gravel (conglomerate) and "red clay" to a depth of at least 55 m beneath the surficial deposits in the fan-piedmont portion of the map area. Hale (1955) reported an estimated maximum thickness of about 60 m of accumulated clastic sediment, with gravel beds comprising a comparatively small proportion of the total alluvial fill. The maximum age of

piedmont/valley-fill deposits west of Black River that lie above Permian bedrock and beneath the surficial deposits delineated on the map is open to speculation

Short Description: Intermediate piedmont-slope sand, gravel and mud.

Qpo Older piedmont-slope sand, gravel and mud (Lower? to Middle Pleistocene). Pebbly sand to poorly sorted gravel containing subangular to rounded pebbles and cobbles of Permian carbonate, typically well cemented by calcium carbonate. Finer-grained strata including reddish-brown muds are rarely exposed. Map unit is present in the northern part of the map area southeast of and approximately 20 m above the Black River channel, and as mapped includes what may be lower inset fills near the valley floor. North of Rattlesnake Canyon Draw, higher-level remnant gravels lie on Permian gypsum bedrock (which is generally thinly covered in the map area by hillslope alluvium and colluvium). Slumping and tilting of the deposits due to solution subsidence is common. Deposits are up to about 15 m thick on higher-level remnants north of Rattlesnake Canyon Draw. In the area to the southeast of Black River, the thickness of clastic deposits beneath the surface deposits mapped here is unclear. Hayes (1964) depicted Permian bedrock near the surface on both sides of Black River in this area, suggesting a discontinuous and relatively thin cover of gravel. This stands in contrast with the 50+ m of alluvial fill present in the subsurface west of the Black River. Insufficient shallow borehole data from the vicinity of Black River and the northern edge of the map area were available to resolve this question. The age range of deposits comprising the older piedmont map unit also remains conjectural. The area north of Rattlesnake Canyon Draw (off the map) is on the southern side of a dissected piedmont slope with both rounded and flat-topped interfluvial summits capped by older piedmont alluvium overlying Permian evaporite bedrock. These higher-level summit areas were correlated with the Blackdom Plain geomorphic surface of the Roswell basin to the north by Horberg (1949, Fig. 3), and summit areas within the northwestern part of the map area to the Orchard Park Plain. Hawley (1993) noted that such correlations should be considered provisional, and suggested that Blackdom and Orchard Park alluvium in the Roswell basin was deposited during the two or three glacial-interglacial cycles preceding the Wisconsin glacial stage. The older piedmont alluvium map unit, discounting possible inset fills, is provisionally assigned a Middle Pleistocene age here.

Short description: Older piedmont-slope sand, gravel and mud.

## Spring deposits

Qt Calcium carbonate (tufa) deposits along Black River (Upper Pleistocene to Holocene). Accumulations of tufa are present within and along embankments of the Black River, extending downstream from its confluence with the drainage from Rattlesnake Springs. The tufa consists of gray porous calcium carbonate precipitated from spring water, contains casts of vegetation, and lines the embankment in places and forms tufa dams across the drainage in others. The unit is mapped at three localities in order to show the general location of the deposits, which are more extensive than shown on the map. As noted by Land and Love (2006) the spring deposits are intercalated with distal piedmont slope and floodplain deposits, suggesting intermittent episodes of tufa precipitation and clastic deposition along the drainage.

Short Description: Calcium carbonate (tufa) deposits along the Black River drainage.

# Neogene-Quaternary Systems

QTg Piedmont conglomerate remnants at high levels on the Gypsum Plain (Pliocene to Early Pleistocene?). Gravels are dominantly Permian carbonate clasts, apparently transported from the Guadalupe escarpment ~10 km to the northwest. Finer-grained sediments are poorly exposed. Gravel clasts range in size from pebbles to cobbles, are poorly sorted and are generally rounded. Exposures that were observed generally appear to consist of loose accumulations of gravel, but examination reveals that the surface gravels are weathered residue derived from carbonate-cemented conglomerate. Exposed deposits are up to a few meters thick, form small, rounded hilltops or ridges, and typically overlie dense micritic carbonate assigned here to the Permian Rustler Formation. Both units appear to have been let down to their present position by solution subsidence of surrounding Permian evaporites. Remnant outcrops encountered in the field are small and not readily apparent on aerial photographs; similar unmapped outcrops are likely present in the area. The age of the deposits is open to speculation. They are apparently derived in large part from the Guadalupe Range to west, which is thought to have undergone substantial relative uplift during the last 12 Myr (Polyak et al., 1998).

Short description: Piedmont conglomerate at high levels on the Gypsum Plain

# Paleogene System

## Oligocene Series

Ti Mafic dike (Oligocene). Greenish-gray intrusive igneous rock, generally weathered and poorly exposed, although reasonably intact outcrops over a meter in width are present in gully cuts. The dikes intrude Permian gypsum bedrock that has been stained a yellowish-brown color, making the dikes readily apparent on aerial photographs. Broken samples commonly reveal abundant vesicles with white crystalline fillings. In some exposures, the margins of the dikes contain fragments of surrounding gypsum bedrock. The dikes shown on the map are referred to as the Yeso Hills dikes, and were first described petrographically in Pratt (1954); the following petrographic description is summarized from Calzia and Hiss (1978): Basaltic Andesite. Feldspar lathes 3 to 6 mm long in a groundmass containing plagioclase, rare orthoclase, biotite, minor apatite, resorbed ferromagnesian minerals (pyroxene?) altered to chlorite, and magnetite. Abundant vesicles are coated or filled with chalcedony, anhydrite, calcite or chlorite. As noted in the literature, vesicular igneous rocks are also scattered over a small area about 4.5 km northeast of the northernmost Yeso Hills dike, and igneous intrusions are noted in the subsurface in lithologic logs from a few boreholes drilled within the map area. No radiometric ages have been reported for the Yeso Hills dikes (a sample for dating was collected); a K-Ar age of 32.2 to 33.9 Ma was reported from a dike of similar composition, located about 80 km to the northeast (Calzia and Hiss, 1978).

Short description: Mafic dike.

# Mesozoic Erathem

## Cretaceous System

### Lower

K Cretaceous, undivided (Albian). Sandstone, conglomerate and carbonate beds (Albian) present as broken blocks and eroded remnants within exhumed solution-subsidence depressions on the gypsum plain. Limestone beds are gray wackestone to packstone, some of which are fossiliferous, containing bivalve and echinoid macro-invertebrate fossils (Lang, 1947). Yellowish-brown quartzose sandstone beds range in texture from coarse-grained channel fills with little internal stratification, to thin beds of planar- to cross-laminated quartz sand, some of which also contain casts of marine bivalves. Conglomerate is present in decimeter- to meter-scale, clast-supported beds and channel fills; white to dark-gray clasts are dominantly rounded, siliceous (quartz, chert, quartzite) pebbles up to a few centimeters in diameter in a sandy to granular matrix cemented by calcium carbonate. Tilted blocks probably representing several meters of Cretaceous strata are present in the map area. Examination of fossils from Lang's (1947) outcrop led Kues and Lucas (1993) to conclude that the strata are probably correlative to the middle part of the Washita Group of Texas, indicating a Lower Cretaceous (Albian) age for the deposits. Cretaceous deposits apparently once covered the Delaware Basin and adjoining Guadalupe Range. As the regional landscape was denuded during the late Cenozoic, siliceous gravel and coarse-grained sand were reworked into fissure fills in the Guadalupes, and incorporated in late Cenozoic alluvial fills along the Black River. For the most part, Cretaceous strata have been stripped from the area, leaving scattered remnants of siliceous gravel on the land surface and the broken masses of rock associated with karst features shown on the map.

Short description: Sandstone, conglomerate and carbonate. Limestone and sandstone beds contain Lower Cretaceous (Albian) marine invertebrate fossils; clasts in fluvial conglomerate beds are dominantly siliceous (quartz, chert, quartzite).

# Paleozoic Erathem

## Permian System

### Lopingian Series

### Ochoa Group

Pr Rustler Formation (Lopingian). Carbonate, siltstone to fine-grained sandstone, gypsum and redbed mudstone. Carbonate beds, probably belonging to the Culebra Dolomite Member (present in the lower part of the Rustler Formation), are pale yellowish-gray, ledge-forming carbonate mudstone in thin tabular beds, commonly exhibiting abundant, mm-scale voids or vugs. Exposures of dense, gray, finely crystalline, vaguely bedded to structureless carbonate are also assigned to the Rustler Formation. Carbonate beds in the Rustler are comparatively resistant to erosion, and form low hills and ridges on the Gypsum Plain. Siliciclastic intervals are generally colluviated and poorly exposed. Covered hillslopes below some of the carbonate-capped Rustler outcrops are faintly yellowish to red in color, suggesting

the presence of siltstone and mudstone intervals. In some areas red-weathering cobble-sized nodules of gypsum associated with red mudstone are observed. Some of the poorly exposed siliciclastic and gypsum intervals may belong to the Virginia Draw Member at the base of the Rustler Formation. Up to about 15 meters of Rustler Formation strata underlie hills on the Gypsum Plain. The contact between Rustler Formation outcrops and surrounding gypsum of the Castile or Salado formations appears to be subvertical in places, and many, if not most of the Rustler outliers in the map area are probably karstic, having been let down to their present position by solution subsidence.

Short description: Rustler Formation. Carbonate, siltstone to fine-grained sandstone, gypsum and redbed mudstone.

Pcs Castile and Salado formations, undivided (Lopingian). Finely crystalline calcium sulfate (hydrated to gypsum near the land surface), interlaminated with calcite (typical Castile Formation lithology), or vaguely laminated to structureless. The Castile Formation consists mainly of laminae of white to pale-gray gypsum (anhydrite) and thinner, dark-gray laminae of calcite, which alternate repetitively through hundreds of meters of section. The formation also contains a thin, basal laminated limestone, and discrete halite intervals that provide a basis for dividing the formation into members (Anderson et al., 1972), together with intervals of nodular anhydrite and breccia resulting from dissolution of halite. The Salado Formation overlies the Castile Formation in the subsurface east of the Pecos River, where it consists of a thick sequence of halite and other soluble salts, some named anhydrite beds, and minor amounts of admixed and intercalated siliciclastic mud. It is unclear if or how much of the Salado Formation is present in the western Delaware basin; soluble salts in the Salado that may have been present presumably have been removed by solution. Many exposures observed in the southern part of the map area are typical of the Castile Formation, consisting of interlaminated gypsum and calcite. Exposures on the gypsum plain in the northern two thirds of the map area include outcrops of vaguely laminated to thinly bedded, finely crystalline gypsum without the sharply defined calcite laminae. Pervasive karst features developed on the Gypsum Plain range in size from small, individual swallets, to the large solution-subsidence troughs in the southern part of the map area. Other features encountered on the surface are masses of selenite, intraformational collapse breccias, and circular areas, tabular discordant masses, and resistant, bedding-parallel exposures of Castile/Salado sulfate that have been replaced by calcite (a succinct explanation for genesis of these replacement features, through microbial sulfate reduction in the presence of hydrocarbons, is provided by Kirkland and Evans, 1974). Only a few of these unusual features are indicated on the geologic map. The Castile Formation overlies the Bell Canyon Formation in the subsurface. The combined Castile/Salado unit in the northeastern part of the map area is about 450 m thick, and the lower two intervals of salt in the Castile (Halite I and II) are apparent on sonic logs. Based on the well logs that were examined, these salt beds appear to have been removed by disssolution to the south and west, perhaps contributing to formation of the large solution-subsidence troughs and widespread subsidence apparent in the upper Black River valley area.

Short description: Finely crystalline calcium sulfate, with interlaminated calcite (typical Castile Formation lithology), or vaguely laminated to structureless.

## Guadalupian Series

## Delaware Mountain Group

Pbc Bell Canyon Formation (Guadalupian). Cross section. Predominately buff to brown, fine-grained sandstone to siltstone, with 5 named carbonate intervals (from oldest to youngest the Hegler, Pinery,

Rader, McCombs and Lamar members), which thin and pinch out to the east of the Guadalupe escarpment. Siliciclastics are similar to those in the underlying Cherry Canyon Formation, consisting mainly of fine-grained quartz and lesser feldspar (arkose to subarkose), coarse siltstone (many intervals enriched in organic matter), and minor, thin shaley beds. Siltstone and fine sands are commonly finely laminated. Siliciclastic sediment is commonly present as channel fills, reflecting submarine density-flow processes. Carbonate intervals are dark- to light-gray, fossiliferous, thin- to medium-bedded limestone, which thicken and grade into the Capitan Formation along the margin of the Delaware Basin. The uppermost named limestone, the Lamar, extends farther basinward than the underlying carbonate intervals, and is readily apparent on gamma-ray logs. The top of the Bell Canyon Formation beneath the Castile in the basin is picked at the top of a siliciclastic interval (Reef Trail Member) that overlies the Lamar limestone beds. The Bell Canyon is approximately 260 m thick in the map area.

Short description: Fine-grained sandstone to siltstone, with 5 named carbonate intervals that thin and pinch out eastward of the Guadalupe escarpment.

Pcc Cherry Canyon Formation (Guadalupian). Cross section. Predominantly buff to brown, fine-grained sandstone to siltstone, with three named carbonate intervals (the Getaway and overlying South Wells and Manzanita members) that thin and pinch out eastward of the Guadalupe escarpment. Siliciclastic beds are thinly to thickly bedded, frequently occupying discontinuous, submarine channels, are predominantly composed of quartz and lesser feldspar grains (generally altered), and are typically finely laminated. Carbonates are tan to dark gray, fossiliferous and dolomitic. The contact between the Cherry Canyon and Brushy Canyon formations was historically chosen in outcrop, to the southwest of the map area, at a lithologic change from comparatively coarse-grained channel sands of the Brushy Canyon to finer-grained sands in the Cherry Canyon beneath the Getaway limestone interval. Neutron density-porosity logs from the map area show a distinct, laterally traceable log response that is compatible with such a change. The top of the Cherry Canyon Formation is placed at the base of the lowest carbonate interval (Hegler) in the Bell Canyon Formation. Based on the log picks, the Cherry Canyon Formation is approximately 400 m thick beneath the northeastern part of the map area.

Short description: Fine-grained sandstone to siltstone, with three named carbonate intervals (the Getaway and overlying South Wells and Manzanita members) that thin and pinch out eastward of the Guadalupe escarpment.

Pbrc Brushy Canyon Formation (Guadalupian). Cross section. Very fine- to coarse-grained, tan and brown siliciclastic sandstone and siltstone, with shale in the lower part; unit may contain rare, thin beds of gray-brown carbonate and conglomerate near the base of the unit. The unit is thinly to thickly bedded; coarser-grained sandstones are commonly present in lenticular channels. Sandstone and siltstone is commonly finely laminated. The contact between siliciclastic deposits at the base of the Brushy Canyon Formation and uppermost Bone Spring carbonate sediment is readily identified on gamma-ray logs. Unlike the overlying formations of the Delaware Mountain group, the Brushy Canyon does not grade shelfward (westward) into transitional carbonate shelf-margin or bank deposits; instead, it thins westward and overlaps the Bone Spring/Victorio Peak formations, with a relatively thin, intervening interval of deposits (Cutoff Formation) that are discontinuously present in outcrops to the southwest of the map area. The Brushy Canyon Formation is approximately 420 m thick along the trace of cross-section A-A'.

Short description: Fine- to coarse-grained sandstone and siltstone, with shaley intervals in the lower part.

## Cisuralian Series

Pbs Bone Spring Formation (Cisuralian). Cross section. Dark gray to brown, thinly bedded carbonate mudstone, with varying amounts of intercalated dark gray calcareous shale. Contains three regionally recognized sandy intervals (first, second and third Bone Spring sands) consisting of light gray to tan, fine-grained sand with micaceous, shaley or calcareous intervals (the stratigraphic position of the lower and upper sandy intervals are indicated on the cross section). The Bone Spring Formation is approximately 910 m thick in the northeastern part of the map are, thinning to about 635 m over the crest of the Huapache flexure to the southwest.

Short description: Carbonate mudstone and subordinate shale, with three regionally recognized sandstone intervals.

Pw Wolfcamp Shale/Formation (Cisuralian; unit likely contains Upper Pennsylvanian strata in its lower part). Cross section. Greenish gray, brown and black calcareous and carbonaceous shale, with some carbonate and siliciclastic sand. The top of the Wolfcamp Formation, as depicted on the cross section, lies beneath the third Bone Spring sand; the base of the unit was chosen on wireline-logs at the top of a sequence of alternating shale and carbonate beds assigned to the Upper Pennsylvanian Canyon-Cisco interval. Approximately 510 m thick in the northwestern part of the map area, thinning to a few tens of meter over the Huapache flexure, and thickening to about 140 m at the southwestern end of cross-section A-A'.

Short description: Calcareous and carbonaceous shale with carbonate and sandstone intercalations and interbeds.

# Pennsylvanian Subsystem

## Upper

IPcc Cisco and Canyon formations (Upper Pennsylvanian). Cross section. Interbedded carbonate and shale, with lesser amounts of coarser siliciclastic sediment likely present. Gamma-ray logs suggest carbonate and shale beds alternate on a scale of meters to several meters in the upper part of the unit, and that thicker carbonate intervals are present in the lower part. The base of the unit is placed at the top of a prominent carbonate interval assigned here to the top of the Strawn Formation. The Cisco-Canyon interval is approximately 140 m thick in the northwestern part of the map area, and thins to about 35 m over the crest of the Huapache flexure.

Short description: Interbedded carbonate and shale, with lesser amounts of coarser siliciclastic sediment likely present.

## Middle

IPsa Strawn and Atoka formations (Middle Pennsylvanian; may include Lower and Upper Pennsylvanian strata). Cross section. Interbedded carbonate, sandstone and shale. Strawn carbonates are tan to brown and fossiliferous; phylloid algal mounds are reportedly present in the Strawn interval on the Northwest Shelf to the southeast of Carlsbad, NM, where the unit has been targeted for oil and gas production. Sandstones are tan to brown and generally medium grained, with some pink feldspar grains reported from cuttings. Black shale is also reported. The underlying Atoka Formation in the Delaware basin

contains gray to brown carbonate and shaley limestone, some of which is cherty. The base of the Strawn-Atoka interval is chosen at the top of the upper-Morrow carbonate interval, as indicated by gamma-ray and resistivity logs. Approximately 170 m thick.

Short description: Interbedded carbonate, sandstone and shale.

### Lower

lPm Morrow Formation (Lower Pennsylvanian). Cross section. The upper third of the Morrow Formation consists of brown to gray fossiliferous limestone and shaley limestone, some of which is oolitic or cherty, together with brown to gray, fine- to medium-grained sandstone, and shale. The underlying middle and lower Morrow intervals are dominantly fine- to coarse-grained quartz sandstone, with lesser shale. Approximately 265 m thick beneath the map area.

Short description: Carbonate and intercalated shale in the upper part of the formation, overlying fine- to coarse-grained sandstone and lesser shale in the lower two thirds of the formation.

## Mississippian Subsystem

### Upper

Mb Barnett Shale/Formation (Upper Mississippian). Cross section. Brown shale to silty shale with lesser fine-grained sandstone and siltstone. The Barnett Formation is approximately 75 m thick in the northwestern part of the map area, and overlies Mississippian limestone.

Short description: Shale to silty shale with lesser fine-grained sandstone and siltstone.

# Suggested Reading

Hill, C.A., 1996, Geology of the Delaware Basin, Guadalupe, Apache, and Glass Mountains, New Mexico and West Texas: Permian Basin Section SEPM, Publication No. 96-39, 480 p.

*[This book provides a comprehensive summary of the geology of the region, and an extensive listing of pertinent scientific literature through 1996]*

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