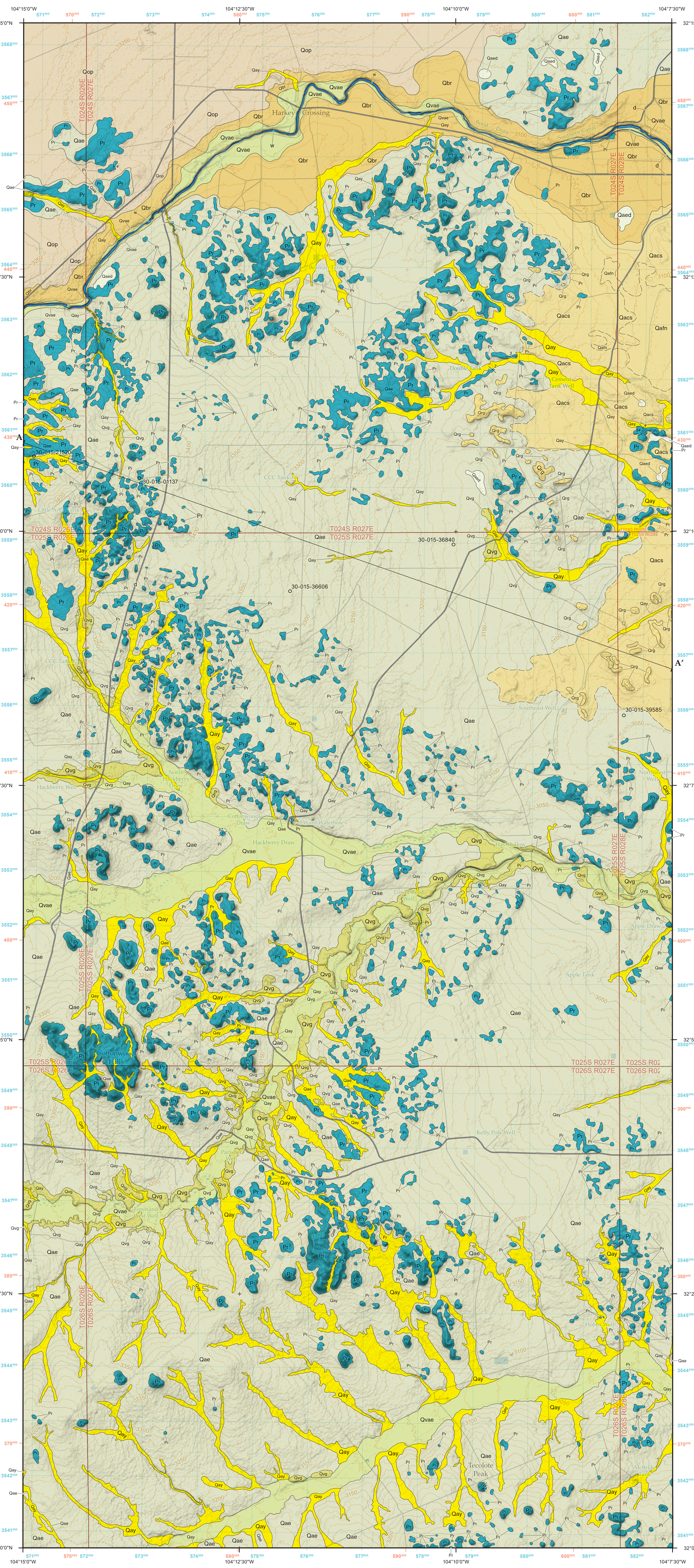
NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES A RESEARCH DIVISION OF NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY

NMBGMR Open-File Geologic Map 297

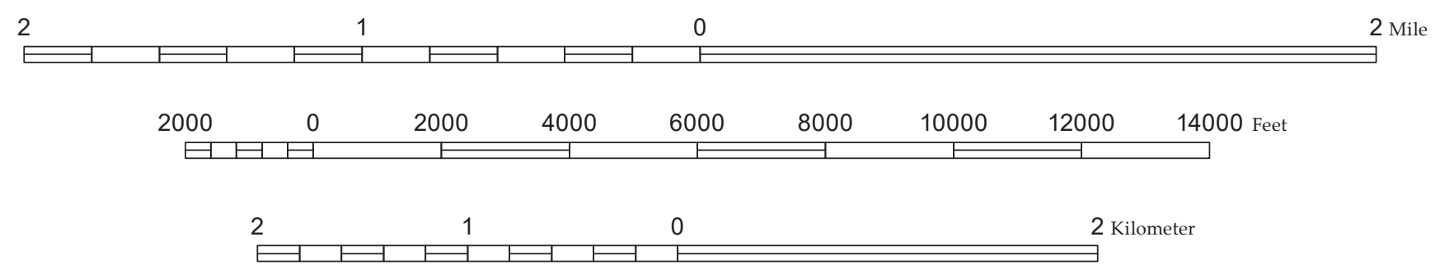
Last Modified June 2022

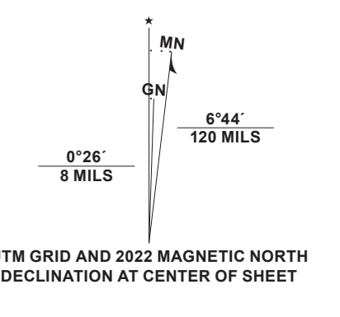


Base map from U.S. Geological Survey 2021.
North American Datum of 1983 (NAD83)
Projection and 1,000-meter grid: Universal Transverse Mercator, Zone 13S, shown in blue.
10,000-foot ticks: New Mexico Coordinate System of 1983 (East zone), shown in red.

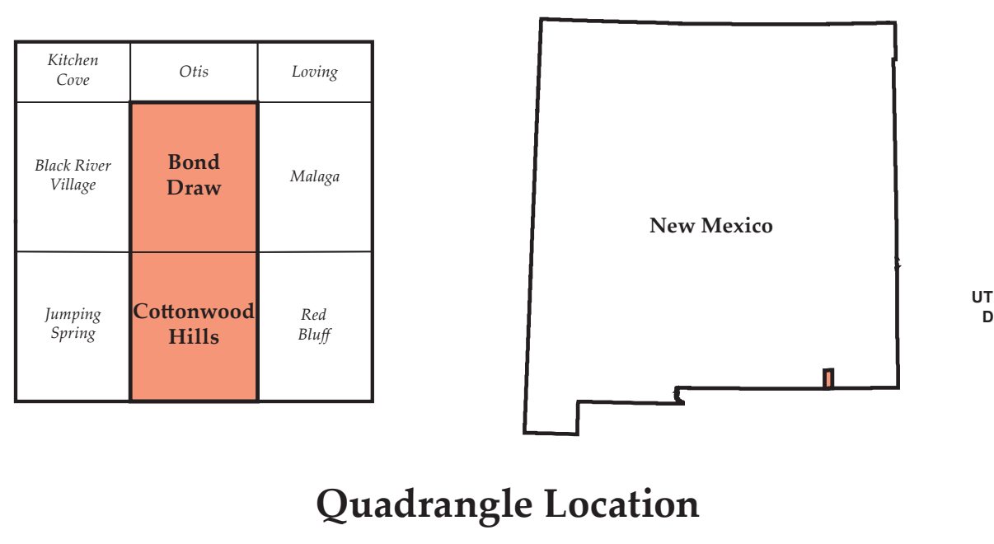
Roads	U.S. Census Bureau, 2015–2016
Names	GNIS, 2016
Hydrography	National Hydrography Dataset, 2014
Contours	IFSAR 4.5 m Digital Terrain Model, 2008
Wetlands	FWS National Wetlands Inventory 1977–2014

1:36,000





UTM GRID AND 2022 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET



Quadrangle Location

New Mexico Bureau of Geology and Mineral Resources
New Mexico Tech
801 Leroy Place
Socorro, New Mexico
87801-4796

[575] 835-5490

This and other STATEMAP quadrangles are available
for free download in both PDF and ArcGIS formats at:

http://geoinfo.nmt.edu

Digital layout and cartography by the NMBGMR Map Production Group:
Phil L. Miller, Amy L. Dunn, Ann D. Knight, and A. R. Baca

New Mexico Bureau of Geology and Mineral Resources
Open-File Geologic Map 297

Mapping of this quadrangle was funded by a matching-funds grant from the STATEMAP program of the National Cooperative Geologic Mapping Act (Fund Number: G21AC10770), administered by the U. S. Geological Survey, and by the New Mexico Bureau of Geology and Mineral Resources (Dr. J. Michael Timmons, *Interim Director and State Geologist*; Dr. Matthew Zimmerer, *Interim Program Manager for Mapping Programs*).

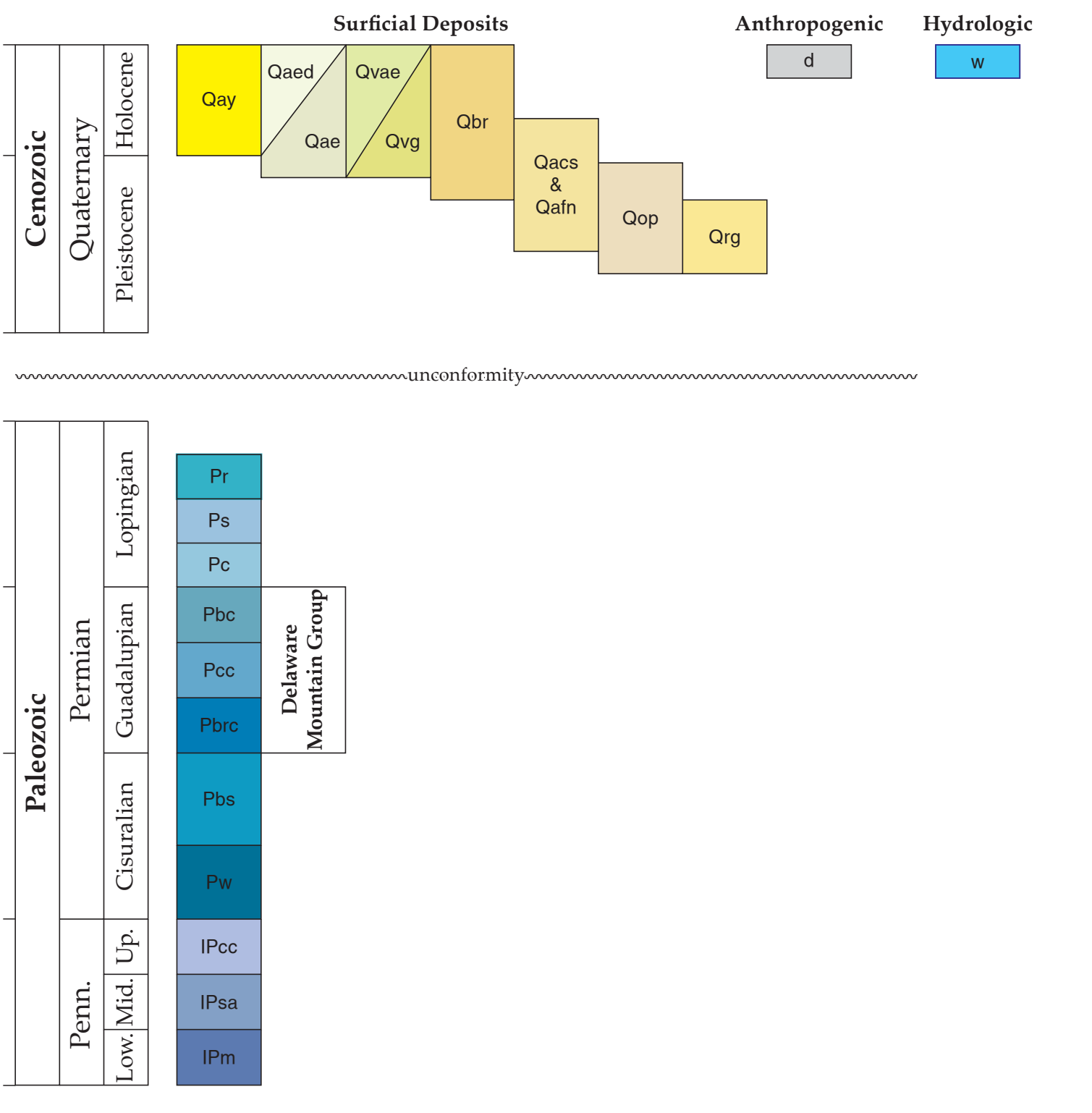
Geologic Map of the Bond Draw and Cottonwood Hills 7.5-Minute Quadrangles, Eddy County, New Mexico

September 2022

by
Bruce D. Allen and Snir Attia

New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, New Mexico, 87801.

Correlation of Map Units



Explanation of Map Symbols

Contact—Identity and existence are certain. Location is accurate where solid and approximate where dashed.

Unconformity

Shoreline

79 Inclined bedding—Showing strike and dip.

30-015-39585 Drill hole for hydrocarbon exploration or exploitation

A A′ Cross section line and label

30-015-21520 Well in cross section showing the well identification information.

Comments to Map Users

A geologic map displays information on the distribution, nature, orientation, and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map may be based on any of the following: reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes may not be shown due to recent development.

Cross sections are constructed based upon the interpretations of the author made from geologic mapping and available geophysical and subsurface (drillhole) data. Cross sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.

The New Mexico Bureau of Geology and Mineral Resources created the Open-file Geologic Map Series to expedite dissemination of these geologic maps and map data to the public as rapidly as possible while allowing for map revision as geologists continued to work in map areas. Each map sheet carries the original date of publication below the map as well as the latest revision date in the upper right corner. In most cases, the original date of publication coincides with the date of the map product delivered to the National Cooperative Geologic Mapping Program (NCGMP) as part of New Mexico's STATEMAP agreement. While maps are produced, maintained, and updated in an ArcGIS geodatabase, at the time of the STATEMAP deliverable, each map goes through cartographic production and internal review prior to uploading to the Internet. Even if additional updates are carried out on the ArcGIS map data files, citations to these maps should reflect this original publication date and the original authors listed. The views and conclusions contained in these map documents are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico, or the U.S. Government.

Description of Map Units

CENOZOIC ERATHEM

Quaternary System

Anthropogenic Units

d **Disturbed areas (Historic to Modern)**—paved roads and irrigation canals.

Hydrologic Features

w **Water in Black River Channel (Modern)**—Water in Black River Channel.

Eolian, Alluvial, and Colluvial Surfacial Deposits

Qay **Alluvium in active drainages (Holocene)**—Alluvial sand, mud, and gravel associated with active drainages, including deposits underlying low terraces adjacent to incised channels. Sediment is generally pale-tan, brown, or reddish-brown silt and sand containing various amounts of gravel. Generally less than 2 meters thick.

Qaed **Accumulations of eolian and alluvial silt, sand, clay and gravel in closed or nearly closed depressions (Holocene)**—Map unit generally consists of pale-tan to brown silt and sand with minor amounts of locally derived coarser alluvium. The depressions likely represent areas that have undergone relatively recent subsidence caused by the dissolution of underlying Permian evaporites. Qaed deposits are probably on the order of several meters thick or less.

Qae **Windblown silt and fine sand, fine- to coarse-grained slope-wash alluvium, rocky colluvium and regolith, generally forming a thin mantle over weathered Rustler Formation bedrock (Upper Pleistocene to Holocene)**—Siliciclastic deposits range in texture from silty, sandy mud to gravelly sand, and are generally tan, brown, or pale-red in color. This lithologically heterogeneous unit includes areas surfaced by pale-gray gypsite, which may represent accumulations of gypsum dust and/or weathering of near-surface Permian gypsum bedrock. Rocky colluvial deposits surrounding hills of Permian bedrock are locally cemented by calcium carbonate; some of these apparently older colluvial deposits may be Pleistocene in age. Although a significant proportion of the surficial cover is likely composed of eolian dust, extensive deposits of eolian sand (dunes) are not present in the map area. Deposits generally range from less than one meter to a few meters in thickness but might be 10 meters thick or more in some areas (e.g., along drainages low in the landscape or in thick colluvial wedges).

Qvae **Valley-floor sand, mud, gravel, and gypsite underlying floodplains and low terraces of larger drainages (Upper Pleistocene to Holocene)**—In general, deposits are relatively fine-grained and likely contain significant amounts of windblown dust trapped by grasses and shrubs, together with gypsiferous sediment and reddish mud derived from erosion of Permian bedrock. Fills on the order of a few meters in thickness in the larger west-to-east-flowing ephemeral drainages in the map area are brown, pale-red, and gray in color. Small unmapped exposures of weathered and commonly brecciated Rustler Formation strata are locally exposed along cutbanks and channel floors in gullied and scoured reaches. Ephemeral seeps and areas subject to flooding are apparent in local reaches of the larger drainages; cutbanks in some areas consist of reddish mud infused or surfaced by a dusting of efflorescent salts. Discontinuous, relatively narrow incised channels are common in the major drainages. Qvae deposits along the Black River are generally gray in color, consisting of comparatively fine-grained, locally gypsiferous mud underlying terrace levels a few meters or more above the present channel. Coarser-grained deposits carried in during floods are also present. Perennial stream flow is sustained in the Black River's lower reach by groundwater discharge at Blue Spring and Castle Spring, located a short distance west of the map area.

Qvg **Valley-floor gypsite along major drainages (Upper Pleistocene to Holocene)**—A relatively porous aggregate of gypsum silt, sand, and gravel in a fine-grained gypsiferous matrix, derived from weathering and transport of Permian bedrock gypsum. Unit is white to light-gray, is generally thinly mantled by brown eolian dust, and may exhibit a durable decimeter-scale surficial crust. Cutbank exposures commonly reveal a basal one or two meters containing abundant rounded pebbles of white gypsum. Commonly cross-stratified and intercalated with pale-brown siliciclastic sediment, overlain by a meter or more of massive, fine-grained gypsite that may represent eolian deposition. Qvg deposits are common along Hay Hollow but are present in other major drainages and tributaries in the map area. Surface accumulations of gypsite that occupy higher positions on the landscape are included in map unit Qae.

Qbr **Composite map unit consisting mainly of surficial valley-border alluvium and colluvium along Black River (Upper Pleistocene to Holocene)**—For the most part, surface deposits consist of tan and brown mud, sand, and gravel carried in by the Black River or locally derived from hill slopes and drainages on both sides of the river. Coarse deposits contain sub-angular to rounded pebbles and cobbles of Permian carbonate and sandstone likely derived from the Guadalupe Mountains to the west, and from nearby bedrock exposures to the south and north of the river. Beds of coarse-grained, well-sorted, thinly bedded to laminated sandstone, likely representing fluvial deposition, are exposed at a few localities. Exposures of cemented gravel, sparse in the map area but increasingly common along incised reaches of the Black River downstream, contain minor amounts of rounded siliceous pebbles (quartz, chert, quartzite), likely recycled from Cretaceous conglomeratic strata that once covered the region. Some geologists (e.g., Bachman, 1980; Cikoski, 2019) assign these deposits of cemented coarse sand and gravel to the Pleistocene Gatuña Formation, which was originally named for pale-red sandy and gravelly alluvium lying beneath a pedogenic carbonate caprock (Mescalero caliche) to the east of the Pecos River. Qbr deposits underlie a gently sloping surface slightly entrenched below the extensive Orchard Park alluvial plain to the north, and locally merge with thin deposits (Qae, Qay) overlying bedrock on both sides of the river. Depth to bedrock in the vicinity of the river, based on available driller's logs, is variable, and, locally, may be up to 50 meters, according to a few reports. The thickness of Quaternary deposits generally appears to be; about 18 m along the western reach of Black River in the map area, 30 m in the central reach where the river valley widens, and 15 m or less along the eastern reach downstream from the low Rustler Hills that are present on both sides of the river. In the vicinity of the Black River crossing of the Southern Canal, Rustler Formation carbonate bedrock is locally exposed in the river bed.

Qacs & Qafn **Alluvial aprons extending eastward from the bedrock uplands in the northeastern part of the map area (Upper Pleistocene to Holocene)**—These accumulations of clay, silt, sand, and gravel extend eastward toward the Pecos River and merge indistinctly westward with map unit Qae. Still, overall the unit is thicker than Qae deposits and contains gravel clasts likely carried in by a prehistoric (Pleistocene) Pecos River. Eroded remnants of rounded gravel containing exotic clasts are present in proximity to the Qacs-Qafn deposits, and are mapped separately (unit Qrg). Qacs-Qafn deposits are tan to brown in color, with reddish hues present in some areas; gravel clasts are dominantly rounded, pale-tan-gray carbonate, and reddish-gray to dark-gray chert, presumably derived from local (Rustler Formation) sources or reworked from prehistoric Pecos River deposits. Gravel is commonly cemented by calcium carbonate, and gully cuts and excavations expose accumulations of pedogenic carbonate that fill entirely, or nearly completely fill, void spaces (Stage II-III pedogenic carbonate morphology). A generalized distinction between coarser-grained, gravelly deposits (Qacs) and finer-grained, silt–sand–clay deposits (Qafn) is depicted on the map, with finer-grained deposits occupying a lower position on the local landscape. Few well-driller's logs were obtained for areas mapped as Qacs and Qafn; the available logs suggest that the alluvial aprons may be up to 30 meters thick in places, thinning in proximity to surface exposures of Permian bedrock.

Qop **Clastic deposits underlying the Orchard Park alluvial plain north of Black River (Middle to Upper Pleistocene)**—Silt, sand, clay, and gravel (commonly conglomeratic) underlying the large, triangular-shaped area extending east-west between the Pecos River and the Guadalupe Mountains and south-north between the Black River and Carlsbad. The unit is largely covered by a thin mantle of Holocene eolian and alluvial deposits similar in age to unit Qae, which is mapped extensively over the bedrock upland that extends southward of Black River. In the map area, Qop deposits are expressed at the land surface as small gravelly knolls and locally along the incised Black River drainage in artificial exposures (trenches, gravel pits, excavations along the Southern Canal), where they are included in the map unit Qbr. Shallow-borehole logs indicate that the unit consists mainly of relatively fine-grained red and yellow sandy, silty, and pebbly alluvium. Discontinuous beds and lenses of gravel up to several meters thick, typically well cemented by calcium carbonate, make up a smaller proportion of the deposits. Carbonate-cemented gravelly intervals are variously reported as "gravel," "conglomerate," and "limestone" in driller's logs. Hills of Permian bedrock rise above Qop deposits in the map area and elsewhere on the alluvial plain. To the west and north of the map area, Quaternary gravelly deposits with a well-developed pedogenic carbonate horizon rise above the plain in small hills and ridges that likely represent older fan-piedmont deposits derived from the Guadalupe Mountains to the west. Accumulations of pedogenic carbonate (caliche) are commonly noted in well-driller's logs extending to a depth of a few meters below the Orchard Park surface. Fractures in Qop conglomerate locally provide groundwater to water wells in the area and to Blue Spring and Castle Spring, which sustain a perennial flow in the lower reach of Black River above its confluence with the Pecos. The alluvial plain underlain by Qop deposits has long been considered equivalent (e.g., Hale, 1945; Horberg, 1949) to the Orchard Park plain or terrace initially identified in the Roswell reach of the Pecos Valley to the north. As with most Quaternary (and perhaps older) deposits in the lower Pecos region of New Mexico, chronology is lacking, and age assignments are relative and speculative; the middle to late Pleistocene age reported here is provisional, and older alluvial deposits may be present at depth. As discussed by Hale (1945), the thickness of the "valley fill" underlying the Orchard Park plain is variable, likely due partly to the dissolution of Permian evaporites and associated land subsidence. Hale (1945) reported maximum thicknesses for the valley fill to the north of the map area ranging from 60 to 80 meters.

Qrg **Deposits of rounded gravel on interfluvial summits and low ridges underlain by Permian bedrock, containing cobble-sized clasts of quartzite and porphyritic igneous rock (Middle to Upper Pleistocene)**—These deposits are present in the northeastern part of the map area. They are generally obscured by Holocene eolian deposits and colluvium, however, well-rounded clasts over 10 cm in diameter, suggesting fluvial transport, are scattered across the surface where the unit is mapped. The deposits are probably cemented by calcium carbonate below the surface in most areas. Clasts consist largely of carbonate, presumably Permian in age, but minor amounts of purple and gray quartzite and igneous porphyry are present. Rounding, inferred provenance, and large clast size suggests fluvial transport by an ancestral Pecos River that transported cobble-sized clasts from source areas to the north in central New Mexico. Siliceous clasts scattered across the land surface and incorporated in Quaternary deposits are commonly observed throughout the northwestern Delaware basin. However, the size of those clasts is typically smaller (up to a few centimeters). The interpretation favored here is that they are reworked from beds of Cretaceous conglomerate that once blanketed the region. As mapped, Qrg deposits appear to define an arcuate swath truncated on the north by the incised Black River valley; additional field transects are needed to delineate their full lateral extent. In the vicinity of the northern mapped exposures, the rounded gravel deposits form a thin veneer of scattered clasts over Rustler Formation carbonate strata. Continuing southward, the deposits form ridges with rounded summits that rise nearly 10 meters above the surrounding terrain. Where the deposits cross the map area to the east, they are surrounded by and contribute gravel to relatively thick accumulations of coarse alluvium mapped as Qacs. The deposits appear to be 5-to-10-meters thick or less based on topography, but may be thicker in some areas and nearly stripped from the landscape in others.

PALEOZOIC ERATHEM.

Permian System

Lopingian Series

Pr **Rustler Formation (Lopingian)**—Lithologically heterogeneous strata consisting of siltstone, fine-grained sandstone, mudstone/shale, gypsum, and carbonate. Carbonate strata of the Culebra Dolomite Member, the next-to-lowest member of the Rustler Formation, are pale-gray carbonate mudstone forming thin tabular beds, commonly exhibiting abundant, millimeter-scale voids or vesicles. Macro-invertebrate fossils are not apparent. Beds of gray, yellowish-weathering, vaguely bedded to structureless carbonate mudstone are commonly present several meters below the Culebra Member. Carbonate strata in the Rustler Formation are relatively resistant to erosion and form most of the low hills and ridges in the map area. The Virginia Draw Member at the base of the Rustler Formation is largely comprised of intervals of fine-grained siliciclastic sediment and beds of gypsum. Virginia Draw strata are underlain by the Salado Formation and are generally poorly exposed in the map area. In some gully-cut outcrops, Virginia Draw redbeds and gypsum are steeply tilted or brecciated, likely the result of solution subsidence, and masses of secondary selenite are abundant. Disturbed Virginia Draw strata in the map area and elsewhere east and west of the Pecos River are considered by some geologists (e.g., Hayes, 1964; Gard, 1968) to represent Salado Formation "residues" left behind following dissolution and removal of salt in the formation. Hence, previous geologic maps (e.g., Kelley, 1971; Bachman, 1980) have variably assigned such deposits in the map area to the Salado Formation. Nonetheless, it seems clear that the deposits in question are present a few tens of meters or less below Culebra carbonate strata, and are assigned here to the Rustler Formation. Rustler deposits above the Culebra Member have been removed over much of the map area, although younger Rustler strata are apparently present beneath some of the covered areas. Exposed remnants of Culebra carbonate in the map area are a few meters thick. Based on cuttings logs obtained from boreholes drilled using cable tools, the underlying Virginia Draw Member (including intervals logged as "redbeds" and "shale") is on the order of 50 to 70 meters thick in the map area. Borehole logs from some areas suggest that nearly 100 meters of Rustler strata in total may be present in parts of the map area.

Ps **Salado Formation (Lopingian)**—Cross section only. Based on cable-tool cuttings logs, the Salado Formation underlying the map area consists primarily of gypsum (or anhydrite), with lesser amounts of shale and sandstone. Salt and potash are reported in minor amounts in some boreholes, especially in the eastern part of the map area. To the east of the Pecos River, in contrast, the Salado formation consists dominantly of salt (halite) with economically important potash zones, a number of named anhydrite beds, and minor amounts of siliciclastic mudstone and fine sandstone. This lateral change from chloride (east) to sulfate (west) evaporite mineralogy may reflect post-depositional dissolution and removal of salt toward the west, and/or a westward facies change from halite to anhydrite precipitation in the basin as the Salado was being deposited. Redbeds overlie the Salado Formation in the lower part of the Rustler Formation, and this lithologic change is generally indicated on gamma-ray logs. The Salado is underlain by the Castile Formation, which also consists largely of anhydrite in its upper part. Siliciclastic sediment near the base of the Salado in the map area generally produces a response on gamma-ray logs, providing a reasonably consistent basis for identifying the contact between the two formations. To the west of the map area, it is more difficult to differentiate the Salado and Castile based on typically available geophysical logs. The thickness of the Salado Formation in the vicinity of the cross section, based on gamma-ray log picks and borehole cuttings logs, ranges from approximately 120 to 220 meters.

Pc **Castile Formation (Lopingian)**—Cross section only. Finely crystalline calcium sulfate interlaminated with calcite, with two relatively thick salt intervals in the lower part. The Castile Formation consists mainly of laminae of white to pale-gray gypsum (anhydrite) and thinner, dark-brownish-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). Halite intervals in the Castile have been variably removed by dissolution across the Delaware basin; in the map area, the lower two intervals (Halite I and II) are largely intact and are each on the order of 60 meters or more in thickness. The Castile is overlain by the Salado Formation and rests on the Guadalupian Bell Canyon Formation. The total thickness is approximately 460 meters.

Guadalupian Series

Formations of the Delaware Mountain Group

Pbc **Bell Canyon Formation (Guadalupian)**—Cross section only. Predominately buff to brown, fine-grained sandstone to siltstone, with five named carbonate intervals (from oldest to youngest; Hegler, Pinery, Rader, McCombs, and Lamar members), which thin eastward from the escarpment forming the east side of the Guadalupe Mountains. Siliciclastic sediment consists mainly of fine-grained quartz and lesser feldspar (arkose to subarkose), coarse siltstone (many intervals enriched in organic matter), and shaley intervals. Siltstone and fine sand are commonly finely laminated. Carbonate intervals are dark- to light-gray, fossiliferous, thin- to medium-bedded limestone, which thickens and grades 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 Formation, is picked at the top of a siliciclastic interval (Reef Trail Member) that overlies the Lamar limestone beds. The Bell Canyon is approximately 275 meters thick in the map area.

Pcc **Cherry Canyon Formation (Guadalupian)**—Cross section only. Predominantly buff to brown, fine-grained sandstone to siltstone, with three named carbonate intervals (from oldest to youngest; Getaway, overlying South Wells, and Manzanita Members), that thin eastward of the Guadalupe escarpment. Siliciclastic deposits are predominantly composed of quartz and lesser feldspar grains (generally altered) and are typically finely laminated. Some siliciclastic beds reportedly occupy discontinuous submarine channels. Carbonates are tan to dark-gray, fossiliferous, and dolomitic. The contact between the Cherry Canyon and underlying Brushy Canyon formations was historically chosen in outcrop, to the southwest of the map area, at a lithologic change from comparatively coarse-grained sand of the Brushy Canyon to finer-grained sand in the Cherry Canyon Formation. Neutron density-porosity logs 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. The Cherry Canyon is approximately 330 m thick in the map area.

Pbrc **Brushy Canyon Formation (Guadalupian)**—Cross section only. Fine- to coarse-grained, tan and brown siliciclastic sandstone and siltstone, with shaley intervals in the lower part. Near the unit's base, it may contain thin beds of gray-brown carbonate and conglomerate. The unit is thinly to thickly bedded; coarser-grained sandstones are reportedly present in lenticular channels. Sandstone and siltstone is commonly finely laminated. The contact between siliciclastic sediment at the base of the Brushy Canyon Formation and uppermost Bone Spring carbonate is readily apparent on gamma-ray and resistivity 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 in the Guadalupe Mountains to the southwest of the map area. The Brushy Canyon is approximately 480 m thick in the map area.

Cisuralian Series

Pbs **Bone Springs Formation (Cisuralian)**—Cross section only. Dark-gray to brown, thinly bedded carbonate mudstone, with varying amounts of 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 945 meters thick in the map area.

Pw **Wolfcampian Series (Cisuralian)**—Cross section only. Greenish-gray, brown, and black calcareous and carbonaceous shale, with carbonate and siliciclastic sand beds. The top of the Wolfcamp Formation lies directly beneath the third Bone Spring sand; the unit's base is identified on wireline logs at the top of a sequence of alternating shale and carbonate beds assigned to the Upper Pennsylvanian Canyon-Cisco interval. The Wolfcamp interval ranges in thickness from approximately 430 meters along the western part of the cross section to 595 meters on the eastern end. The unit may contain Upper Pennsylvanian strata in its lower part.

Pennsylvanian Subsystem

Upper Pennsylvanian Series

IPcc **Cisco-Canyon Formations, undivided (Upper Pennsylvanian)**—Cross section only. Interbedded carbonate and shale, with lesser amounts of coarser siliciclastic sediment likely present. Gamma-ray logs suggest that carbonate and siliciclastic 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 unit's base 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 130 meters thick in the map area.

Middle Pennsylvanian Series

IPsa **Strawn-Atoka Formations, undivided (Middle Pennsylvanian)**—Cross section only. Interbedded carbonate, sandstone, and shale. Strawn carbonates are reportedly tan to brown and fossiliferous; sandstones are generally medium-grained, with pink feldspar grains reported from cuttings. Black shale is also reported. The underlying Atoka Formation contains gray to brown carbonate and shaley carbonate in its upper part, some of which is cherty, and the unit becomes sandy in its lower part. 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 190 m thick, and may include Lower and Upper Pennsylvanian strata in part.

Late Pennsylvanian Series

IPm **Morrow Formation (Lower Pennsylvanian)**—Cross section only. The upper part of the Morrow Formation consists of brown and gray fossiliferous carbonate, some of which is oolitic or cherty, together with beds of brown and gray, fine- to medium-grained sandstone and shale. Strata underlying this upper "Morrow lime" interval contain an abundance of fine- to coarse-grained quartz sandstone, with shale and carbonate interbeds. Dark-brown/black shale underlying the "Morrow clastics" interval is assigned by petroleum geologists to either the (Mississippian) Barnett Shale or the "lower Morrow shale." The thickness of Morrow strata, from the top of the Morrow lime to the base of the Morrow clastic interval, appears to increase eastward in the map area from approximately 260 to 315 meters along the cross-section line.

Geologic Cross Section A—A′